

# Tropical Field Course Tanzania

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10<sup>th</sup> – 31<sup>st</sup> July 2018





## Foreword

This booklet serves as an accompaniment to the 3-week Tropical Field Class in Tanzania, part of the Biology curriculum of Universiteit Antwerpen, in collaboration with the Department of Wildlife Management, Sokoine University of Agriculture. It contains some background information on Tanzania, as well as more specific information on each ecosystem that will be visited during the study trip.

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Day	Date	Activities	Overnight
Tuesday	10/7/18	Departure from Brussels Airport at 20:10 (flight ET 725 to Addis Ababa, be at airport 17:30h)	Airplane
Wednesday	11/7/18	arrival Addis Ababa 8:50, departure to Dar es Salaam 10:30h (flight ET 805). Arrival Dar es Salaam 13:20h. Bus transfer to Morogoro (4h bus ride). Install camp & explore surroundings	Camp Morogoro
Thursday	12/7/18	Microprojects	Camp Morogoro
Friday	13/7/18	Microprojects (visit SUA, Apopo, market as preferred....)	Camp Morogoro
Saturday	14/7/18	Microprojects (visit SUA, Apopo, market as preferred....)	Camp Morogoro
Sunday	15/7/18	Microprojects visit Masai boma (Kambala village)	Camp Morogoro
Monday	16/7/18	Microprojects (visit SUA, Apopo, market as preferred....)	Camp Morogoro
Tuesday	17/7/18	Final day microprojects, bbq & local performing group	Camp Morogoro
Wednesday	18/7/18	Packing & transfer to Ruaha, departure 8h00 (10h bus ride). Install camp.	Camp Ruaha
Thursday	19/7/18	Morning and evening game drives (talk by 11am by Park Warden)	Camp Ruaha
Friday	20/7/18	Morning and evening game drives (possibility to entire day game drive: miombo woodland);	Camp Ruaha
Saturday	21/7/18	Morning observations by foot safari. Evening game drive	Camp Ruaha
Sunday	22/7/18	Transfer Ruaha - Udzungwa, departure 8h00 (9h bus ride). Install camp at dusk.	Camp Udzungwa
Monday	23/7/18	Visit forest: waterfalls & mangabey; talk by Park Ecologist?	Camp Udzungwa
Tuesday	24/7/18	Visit forest: waterfalls & mangabey; talk by Mammal Research Center?	Camp Udzungwa
Wednesday	25/7/18	Transfer Udzungwa - Saadani, departure 8h00 (8h bus ride). Install camp at dusk	Camp Saadani
Thursday	26/7/18	Organised activities in small groups (mangroves and salt pan, snorkling, coastal forest, game drives)	Camp Saadani
Friday	27/7/18	Organised activities in small groups (mangroves and salt pan, snorkling, coastal forest, game drives)	Camp Saadani
Saturday	28/7/18	Organised activities in small groups (mangroves and salt pan, snorkling, coastal forest, game drives)	Camp Saadani
Sunday	29/7/18	Organised activities in small groups (mangroves and salt pan, snorkling, coastal forest, game drives)	Camp Saadani
Monday	30/7/18	Packing, departure 8:30h, road to Dar (6h bus ride). Departure from Dar Es Salaam at 17:40 with ET804; arrival Addis Ababa 20:20h. Departure to Brussels 23:45h (ET724).	Airplane
Tuesday	31/7/18	arrival Brussels 8:30h	

## **Chapter1: Tanzania and Morogoro**

*“Ik probeer me te gedragen. Maar als wie eigenlijk?  
Ik moet me aanpassen aan een nieuw, onmetelijk continent.”*

-Ramsey Nasr, *Homo sapiens*



### **1.1 Tanzania**

#### **1.1.1 Brief history of Tanzania**

This rich region of Eastern Africa is one of the oldest known areas that have been inhabited continuously by humans and pre-*Homo* hominids (starting > 2 million years ago). It has been, and still is in some regions, inhabited by Cushitic and Khoisan speaking hunter-gatherer communities. Migrations from other parts of Africa have been common, especially since 2000 years ago, but the immigrations from outside Africa begun only after about 1000 years ago when Persian and Indian traders and merchants started visiting. Islam was established around the 9<sup>th</sup> century. In 1840, Zanzibar became a stronghold of the sultan of Oman, and also the hub of Arab slave trade, enslaving between 65% to 90% of the Zanzibar population.

In the late 1900s the area that is now known as mainland Tanzania (=Tanganyika), Rwanda and Burundi was colonized by the German Empire. After the First World War, Tanganyika was politically designated as a British Mandate. Around 1954, the Tanganyika African National Union (TANU) was founded by Julius Nyerere, which had the independence of the area as its main objective. By 1960, Nyerere managed to become Minister of the Tanganyika region (still under British rule), and became Prime Minister when it became independent in 1961. At that time Zanzibar (which became independent in 1963) was still under Arab rule. The Zanzibar Revolution of 1964 overthrew this power, causing Zanzibar to merge with Tanganyika to form Tanzania on 26 April 1964.

#### **1.1.2 Geomorphology and climate of Tanzania**

The most prominent geological feature of eastern Africa is undoubtedly the Great Rift Valley that runs about 5000km long, from northern Syria in Southwest Asia to the center of Mozambique in East Africa. It has arisen as a consequence of rifting, caused by the divergence of the African, Somalian and Arabian tectonic plates. This process, which started 35 million years ago, is still ongoing and is separating East Africa



**Figure 1-1:** Geology of the Great Rift Valley

from the rest of Africa along the East African rift. The divergence is maintained because of the phenomenon of “African superswell”, which is the lifting of the continent by mantle plumes. This in turn has already caused the continental crust to become thinner, as it is now only 20km thick instead of its average thickness of about 100km. Eventually, in a few million years, the crust will rupture completely and cause East Africa to completely separate from the rest of Africa, resulting in the birth of a new ocean.

Temperatures in equatorial areas do not in general show large annual fluctuations although a hot summer (December-March) and a somewhat colder winter (June-October) can be distinguished. Rainfall on the other hand changes dramatically over the year and can differ strongly between regions. Whereas the southern, western and central regions have only one distinct rainfall period between December and April, the northern and eastern regions (including Morogoro) have a bimodal rainfall pattern. The *vuli* (Swahili: short rains) last from October to December, and the *masika* (Swahili: long rains) start in March and end in May.

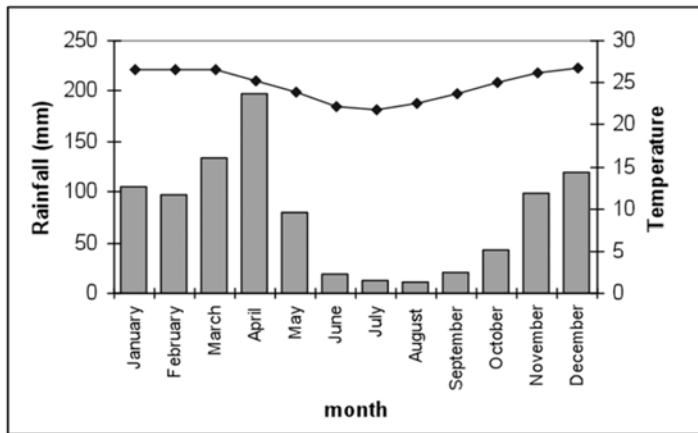


Figure 1-2: Rainfall and temperature around Morogoro, Tanzania

### 1.1.3 General facts

Tanzania occupies an area of almost 950000km<sup>2</sup> (30 x Belgium), and an average population density of 46/km<sup>2</sup> (13% of Belgium), ranging from 1 person per km<sup>2</sup> in arid regions to 51/km<sup>2</sup> in humid regions. There are over 120 ethnic groups, and most Tanzanians have Bantu origins (e.g. Sukuma, Nyamwezi, Hehe). The nomadic Maasai and the Luo have a Nilotic origin, and there are also Khoisan speaking groups that have roots in the Kalahari region of southern Africa. Although many local languages are still in use, the language that unites the Tanzanian people is Swahili, closely followed by English.

Religious groups in Tanzania can be largely subdivided into three categories that are represented in roughly equal numbers: Muslims, Christians and indigenous religions.

The currency is the Tanzanian shilling (€1 = TZS 2405 on 27/6/2016).

The main natural resources are obtained by mining: tin, phosphates, iron ore, coal, diamonds, gemstones, gold, natural gas, nickel.

#### 1.1.4 Environment

Tanzania exhibits a great variety of ecosystems, due to a complex interplay of several historical factors giving rise to specific faunal and floral compositions: parent material (geology), climate, topography, soil and human influence. Several of these ecosystems will be visited during the trip, all of which are discussed in more detail in the rest of this booklet.

There are many severe environmental issues, some of which will be discussed in the chapters on ecosystems. They include soil degradation, deforestation, desertification, destruction of coral reefs, droughts, wildlife threatened by illegal hunting and trade - especially for ivory.

Some of the large and better-known national parks include Selous Game Reserve, Ngorongoro Crater, Serengeti National Park, Ruaha and Gombe National Park (see map p3).

### 1.2 Morogoro

Having arrived in Tanzania, Morogoro will be the first stop, and the starting point for the journey. This city, with its population of over 250,000, is amongst the larger Tanzanian cities and the capital of the Morogoro region. It lies at the bottom and on the slopes of the Uluguru mountains that are part of the Eastern Arc Mountain Range that runs from the south of Kenya to the south of Tanzania (described in more detail in the chapter on Eastern Arc Mountains). Morogoro mainly serves as an agricultural center, as seen in the plethora of surrounding



**Figure 1-3:** Rodent-trapping in Sisal field

fields and the presence of the *Sokoine University of Agriculture (SUA)*. Fruits and vegetables typical for East Africa are sold everywhere, and the central market thrives on food products. One of the most recognizable plants that are being grown however is not a consumable: Sisal, an Agave plant originating in Central-America that has a very recognizable cactus-like appearance and produces strong fibers that can be used to create rope, twine and paper, amongst other things.

Water is supplied by the Mindu dam, created in 1978, and the Ngerengere river. Although it is currently hard to imagine Morogoro without the Mindu dam, it has been and still is the

subject of controversy; The large body of water has been the cause of a significant rise in Schistosomiasis infections, and mercury pollution from neighbouring gold mining industry has contaminated the water supply. Deforestation in the surrounding areas is also causing silting of the water due to excessive run-off.

### **1.2.1 Biotopes around Morogoro**

The Morogoro area is densely populated and hence very few natural biotopes remain. The city is spread out over a fairly large area, with densely packed multistory residential and commercial buildings in the center and more spread out residential areas surrounding it. Most residential houses have a ground floor only and the richer parts of the town are often situated on compounds with a garden and surrounded by a wall. In the residential areas, patches of open space are used for urban agriculture, small fields with maize, bananas, and vegetables.

The agricultural areas are situated around the city. The red soils are mainly well-drained loamy sand and sandy clay on young alluvial plains, offering good agricultural opportunities. For more information on soils, see Hathout (1983). The major crop in the area is maize, which is usually planted around February-March and then harvested in August. Rarely, after abundant rains, an early maize crop is planted already late in the year. Near the rivers, or in irrigated areas, farmers do plant rice, but the area is limited. Other crops, but usually on a much smaller scale, include cassava, fruits and vegetables. The mountain slopes are rich agricultural land used for fruit and vegetable crops.

The university farm is mainly used for maize growing, but there are some considerable parts that are left fallow.

### **1.2.2 Sokoine University of Agriculture**

The history of Sokoine University of Agriculture dates back to 1965 when it started as an Agricultural College offering diploma training in the discipline of agriculture. With the dissolution of the University of East Africa and the consequent establishment of the University of Dar es Salaam (UDSM) in July 1970, the College was transformed into a Faculty of Agriculture of UDSM and thereby started offering Bachelor of Science in Agriculture. In 1974, the Division of Forestry was established and hence the faculty was named Faculty of Agriculture and Forestry. After the introduction of Bachelor of Veterinary Science in 1976 and the establishment of the Division of Veterinary Science, the Faculty was re-named “Faculty of Agriculture, Forestry and Veterinary Sciences”. The Faculty was on the 1st of July 1984 transformed, through Parliamentary Act No. 6 of 1984, into a full-fledged University and became known as Sokoine University of Agriculture (SUA) with the Faculty of Agriculture, Faculty of Forestry and Faculty of Veterinary Medicine.

Currently SUA has four faculties namely; the Faculty of Agriculture (FoA), Faculty of Forestry and Nature Conservation (FoF & NC), Faculty of Veterinary Medicine (FVM) and the Faculty of Science (FoS), the latter which was established in 2001. Other academic units include the



Directorate of Research and Postgraduate Studies (DRPGS), Institute of Continuing Education (ICE), Development Studies Institute (DSI), Computer Centre (CC), Pest Management Centre (PMC), SUA Centre for Sustainable Rural Development (SCSRD) and the Sokoine National Agriculture Library (SNAL). SUA also hosts the African Seed Health Centre and Virtual Centre known as “Southern African Centre for Infectious Disease Surveillance”.

The university, which is located in Morogoro Municipality, has 3,350 ha of land for training, research and production in Morogoro municipality; 840 ha of forest land in Arusha; 320 ha of virgin forest for research in Usambara Mountains in Tanga and 500 ha of miombo woodlands in Kitulanhalo in Morogoro region. The university has for campuses namely, the Main Campus within Morogoro municipality; Solomon Mahlangu Campus (SMC) in Morogoro municipality; SUA Training Forest (SUATF) Olmotonyi in Arusha region and Mazumbai Forestry Reserve in Tanga region.



**Figure 1-4:** SUA campus, with Uluguru Mountains backdrop

SUA’s academic business is guided by the University’s vision and missions as well as the Corporate Strategic plan (2005-2010), the latter that spells out plans in keeping with university’s core missions and functions as well as the need to remain competitive. The Vision of the university is “To become a center of excellence and a valued member of the global academic community in agriculture and other related fields with emphasis on implementing practical skills, entrepreneurship, research and integration of basic and applied knowledge in an environmentally friendly manner”. The vision is guided through the mission, which is “To promote development through training, research, extension, provision of services to the public and private sector in an environmentally friendly manner”.

SUA is currently offering 24 undergraduate and 39 postgraduate programmes in agriculture, forestry and veterinary medicine, environmental sciences and allied disciplines. To date, SUA is the only university, amongst 34 universities and university colleges in Tanzania that offers degree programs in the broad field of agriculture. In addition, SUA offers degree programs in Information Technology (i.e. B.Sc. Informatics) and Education.

SUA's main research objective is to provide leadership in basic and applied research in order to generate science evidence knowledge and innovations that respond to contemporary and emerging needs. SUA thus emphasizes that research becomes linked to development and societal issues. Research, outreach and consultancy services are driven by trained agricultural and natural resource manpower base that comprises 452 academic staff, out whom 50% have PhD qualifications. Research capacity at SUA is further enhanced through collaborative research projects, which are supported by more than 50 memoranda of understanding.

Universiteit Antwerpen and SUA have had strong links since the early 1980s, when Tanzania asked Belgium for assistance to set up a project studying the biology and control of rodents. The project was led by the late Prof. Walter Verheyen (Dept. Biology) on the Belgian side, and Prof. B.S.Kilonzo on the Tanzania side. Prof. H.Leirs collected data on the ecology of the multimammate mouse for his PhD between 1987 and 1989 in Morogoro. During that period, he came to know Prof. Makundi (then also a PhD-student, now the director of the SUA Pest Management Center) and they have maintained their relation and collaboration since that time. After a short break, UAntwerpen and SUA continued their collaboration with a European project (1993-1996), followed by a number of consecutive projects funded through the Flemish Interuniversity Council (VLIR-UOS) and the European Commission. VLIR-UOS supported a 10-year Interuniversity Collaboration between SUA and the Flemish universities in which, apart from rodent biology, other components included among others the development of the library and the campus internet access, support to develop a Faculty of Basic Sciences and research in soil science. This long-term project ended in 2006, but since then new projects have been obtained. Currently, UAntwerpen and SUA collaborate in the fields of rodent biology and control, the ecology of rodent-borne infections and wildlife management. (more information on [www.suanet.ac.tz](http://www.suanet.ac.tz))

### 1.2.3 APOPO

One of the best-known organizations based at SUA is APOPO, a non-profit organization that trains African giant rats to use their impressive sense of smell to detect landmines (and more recently also tuberculosis patients).



APOPO was initiated in the mid-1990s in response to the global landmine problem, by two young Antwerp product developers, Bart Weetjens and Christophe Cox. The idea of using rodents for mine detection was the outcome of a creative process, in which the goal was set to find an appropriate detector sustainable within the African environment, and enabling empowerment of African communities to reduce dependency on foreign aid. Laboratory rats had earlier proven to be able to discriminate explosives by smelling. In their search to develop this idea further, the two product developers contacted the late Prof. Ron Verhagen who pointed them to the Giant African Pouched Rat (*Cricetomys gambianus*), which is omnipresent in sub-Saharan Africa, has a long life span, and is resilient to most tropical diseases. It has the natural habit of hiding collected food in caches and finding them again by olfactory clues.

APOPO set out to develop an appropriate detection rat technology, based around the Giant African Pouched Rat. The results of a two-year initial research phase in Antwerp strengthened APOPO reasoning to use this species for humanitarian detection tasks in Africa. A group of wild rats were captured and put through a captive breeding program. They were domesticated, and a humane training protocol was developed based on the principles of positive behaviour reinforcement. Once proof of principle was achieved, APOPO transferred the project to Tanzania, to develop the technology together with the African partners in the cultural context the technology would be used in.

The heart of APOPO lies in Morogoro, Tanzania. APOPO is hosted by Sokoine University of Agriculture, where APOPO has established its main administrative, training and research centre at the foot of the Uluguru Mountains.

A few kilometres outside the University's main campus, APOPO has established 24 hectares of training and test fields for the training of Mine Detection Rats. Through the support of the Tanzanian Peoples Defense Force, more than 1,500 landmines and unexploded ordinance, among other control objects, are buried in the training fields. The field is a mosaic of more than 1,000 demarcated training boxes (typically 100 square meters each).

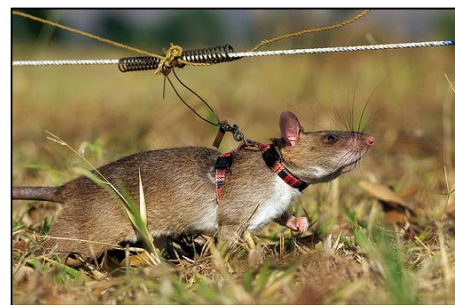


Figure 1-5: *Cricetomys* at work

In the vicinity of the minefield, at the University's isolation area, APOPO houses its tuberculosis research and training facility. Here the rats are trained on the detection of tuberculosis, and research is conducted toward the optimization of the detection system. Sample quality confirmation is done in the microscope laboratory.

At the central APOPO facilities at the SUA main Campus, the rats start their lives in APOPO's breeding kennels. The indoor facilities can house 55 breeding pairs in double-chambered breeding cages. APOPO also has more than 400 square meters of outdoor, concrete breeding kennels, where the rats' natural environment is imitated with about half a meter of soil, through which they can dig their tunnels and breeding nests.

After socialization, the young rats begin their training in one of the six pre-training rooms, with small training cages, where the animals learn odour discrimination. At a later stage they are brought either to the training field or to one of the advanced training and odour evaluation cages. APOPO has four training rooms with different configurations, where the rats can evaluate hundreds of odour samples on a daily basis.

Quality control of the samples and training environment is performed in the APOPO analytical chemistry laboratory, equipped with Gas Chromatography and Ion Mobility Spectrometry equipment.

Field-trained rats and those used for Remote Explosive Scent Tracing are housed in two separate indoor kennels and are given regular exercise using the outside playing kennels. Weekly visits by a veterinarian ensure the rats maintain their good health.

Administrative and financial management of APOPO, as well as the support for the operational projects is also centralized in Morogoro. The Belgian secretariat is located at the Universiteit Antwerpen.

Since 2006, APOPO is active in actual demining work in Mozambique, using the Giant Pouched Rats that have been bred and trained in Morogoro. In 2015, demining also started in Cambodia.

(more information on [www.apopo.org](http://www.apopo.org))

## **Chapter 2: Savannah and Miombo Woodland**

### **2.1 Savannahs**

#### **2.1.1 Introduction**

Simply put, savannahs are tropical and subtropical grasslands with scattered bush and trees. Often it is said that “although savannahs may have abundant grass, they do not seem to be a grassland, because there also have many trees; yet the trees are not sufficiently dense and tall to be called a forest.”

They are characterized by a high changeability both in time and over short distances. In total, savannah ecosystems cover around 40 % of the total land surface of Africa. Savannahs are well known for their diverse large mammal fauna, such as elephants, giraffes and lions. However, the diversity of grasses, small mammals, insects, birds and other animal groups is equally high. Moreover, most of Africa’s human population is also living in savannahs.

In general, we define a savannah as “a tropical mixed tree – grass community in which ecological processes (e.g. primary production, hydrology, nutrient cycling) are strongly influenced by both woody plants and grasses, and only weakly influenced by plants of other growth forms.”

Savannahs are dominated by herbivores, many of which eat grasses (grazers or either mixed feeders). The dominant grasses are C<sub>4</sub> plants and these are of extremely poor nutritional quality for most herbivores (vertebrate or invertebrate), unless the animal can break down cellulose. Hence, both ungulates and termites (very common!) possess symbiotic gut flora able to digest cellulose and most ungulates are ruminants. A list of the most common grasses in African savannahs can be found in Appendix 1.

#### **2.1.2 Gradients and subdivisions**

Savannahs are often subdivided in different sub-habitats, which are characterized by the amount of rainfall that the area receives per year:

– *Grass and shrub savannah*

- North Tanzania; bimodal rain pattern, mean annual rainfall 600-800mm
- *Acacia* & *Commiphora* trees and shrubs, high density of large mammal species
- There are 132 species of *Acacia* in Africa. Their leaves form an important food source for browsers (e.g. giraffe) despite the spines on the trees that should act as defence. Browsers have adapted to this by developing very tough tongues and lips. Some *Acacia* species now produce a sweet substance to attract symbiotic ants, who in their turn defend the tree against herbivores. *Acacia* is also very important for improving soil fertility: they are able to fix atmospheric nitrogen in their root nodules,

which contain nitrogen-fixating bacteria. This is a typical characteristic for the *Leguminosae* (Fabaceae) family, to which the *Acacia* sub-family (*Mimosoideae*) belongs.

- Tree and shrub savannah
- Mean annual rainfall up until 1000mm
- *Combretum* & *Terminalia* trees and shrubs + tall elephant grass *Pennisetum purpureum*

– *Woodland savannah*

- Miombo woodland in South Tanzania, mean annual rainfall 800-1200mm. Miombo is a particular form of woodland savannah, where the trees are mainly represented by *Brachystegia* (*B. boehmi* = Muuyombo).
- Large mammals in lower densities (poor soils)

– *Forest-savannah mosaic*

- Mean annual rainfall 1200-1600mm
- Encircling rainforest region

### 2.1.3 Savannah ecology

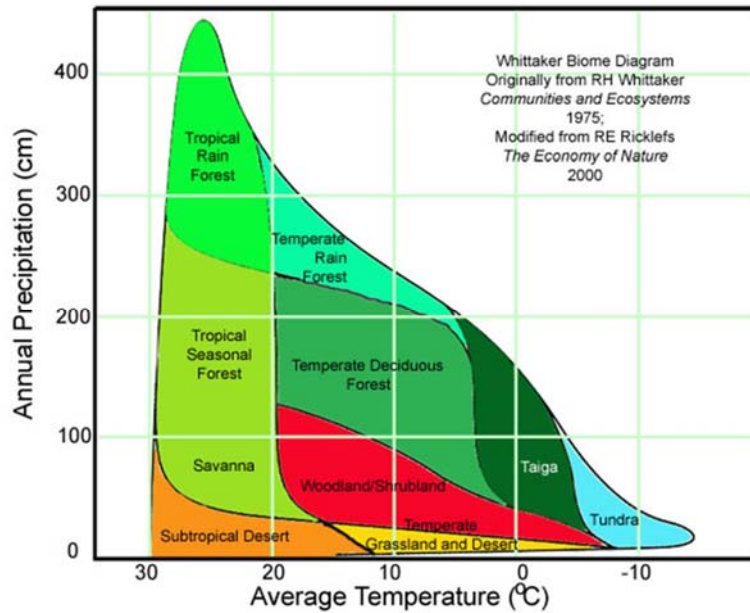
Four key factors play a role in savannah ecology: water (rainfall), nutrients (soil type), fire (frequency) and grazing or browsing (herbivory). We will discuss these factors below:

– ***Water: rainfall***

The amount and the seasonal distribution of rainfall, play a key role in determining the habitat present in a certain region.

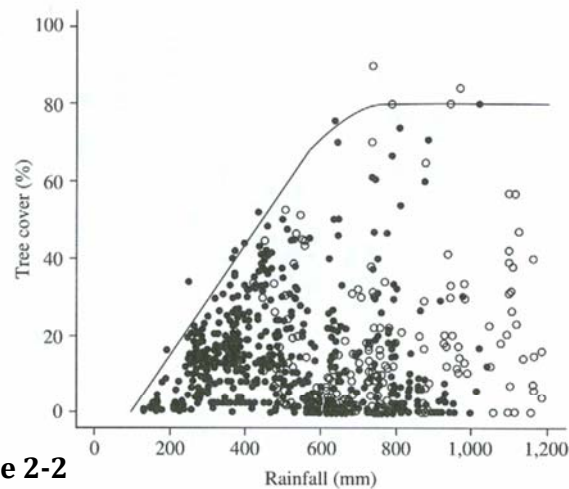


Factors include whether there are one or two rainy seasons, how long the wet season lasts, how severe and long the dry season is etc. A wet season is defined here as a season with a positive water regime: there is more rainfall present than there is evaporation, whereas this balance is inversed during the dry season. However, there is also an important temperature effect, e.g. for mountainous regions. Both rainfall and temperature influence each other and play an important role in defining the habitat present. The relationship between rainfall and temperature is depicted in a graphical representation on Figure 1. A lower limit of average temperature for savannahs is around 20 °C and the lower limit for annual precipitation depends strongly on average temperature: between 40 and 100mm per year.



**Figure 2-1:** Annual precipitation and mean annual temperature and their effect on the habitat.

More rain provides more opportunities for trees to grow and thus more chance that savannahs will turn into woodlands and forests. If the mean annual precipitation remains below 650 mm, savannah habitat will persist due to this climate limit (climatically determined savannahs). If rain gets more abundant however, savannahs can still exist because disturbance factors maintain the savannah habitat (disturbance driven savannahs). Two main disturbance factors are herbivory and fire, discussed below. The relationship between rainfall and fire in savannahs is shown on Figure 2.



**Figure 2-2**

Tree cover as a function of mean annual precipitation (MAP), as related to the fire regimes of 854 African savannah sites. The line representing maximum tree cover was obtained from a regression analysis that used the 99th quantile of  $y$ , rather than the mean, as in conventional regression (Cade and Noon 2003). Filled circles represent savannahs with low fire frequencies (average fire return times of  $>3$  years), and open circles represent sites with high fire frequencies (fire return intervals of  $\leq 3$  years). Fires typically tend to be more frequent in sites with greater rainfall. For sites receiving  $<650$  mm MAP, the upper bound on tree cover exists despite low fire frequencies (some of the sites had not burned for  $>50$  years) (from Sankaran *et al.* 2005, Determinants of woody cover in African Savannahs. *Nature*. Reprinted by permission of Macmillan Publishers Ltd.).

– **Frequency of fire**

Fire frequency influences the survival of the woody plants, less fires will lead to more woody plants surviving. Therefore, fire is a determinant of habitat and savannah is a fire subclimax to woodland and forest. However, plants can adapt to fire. Fire will modify the vegetation structure but does not determine its distribution; other factors do (e.g. rainfall).



Fire controls the balance between trees and grass, amongst other factors. The effects of fire on the different plant and animal groups are as follows:

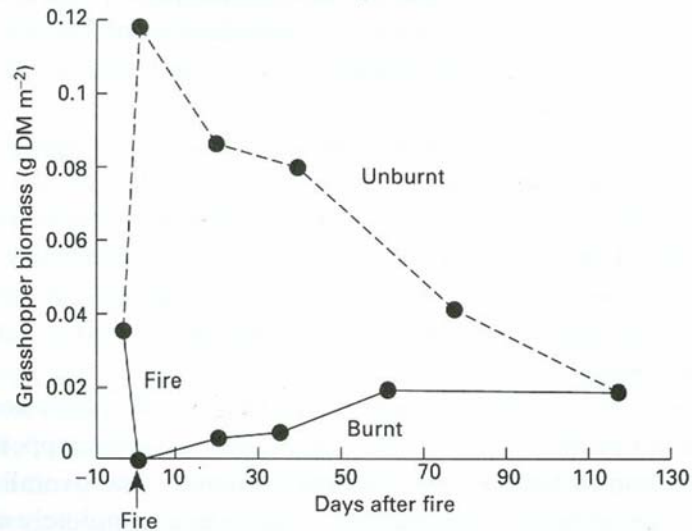
- Effects on woody plants:
  - There is a reduction of leaf mass in main canopy, but a proliferation of new basal shoots with more leaves compared to older, unburned shoots.
  - Fire kills existing basal shoots but replacement shoots compensate loss (more leaves!)
  - Mean plant height decreases
  - Some tree species are adapted to fires, see additional article (in appendix): Djibril Dayamba *et al.*, 2009, Seed germination of herbaceous and woody species of the Sudanian savanna-woodland in response to heat shock and smoke, *Forest Ecology and Management*: 256 (462-470).
- Effects on herbaceous layer:
  - There is a weak negative long-term effect on total grass cover
  - Fire changes composition but this is highly variable between patches
  - Productivity on burned sites is higher than on unburned sites
    - ❖ 2/3 of the increase in productivity following fire explained by removal of necromass which shades new growth
    - ❖ 1/3 is due to nutrient flush released from the ashes
- Effects on insects and small mammals
  - A higher frequency of fires leads to a lower biomass
  - Decreased food availability and cover are causing this longer term effects, not direct mortality during fire
  - After burning of the habitat, the population size and composition alters (caused by mortality or dispersion)
  - Insectivorous birds are attracted to burning and burned plots because of fleeing & dead insects
- Effects on grazing larger mammals
  - 10 days after burning, more impalas are attracted to the burned area, to benefit from the new grown grasses

In general, there is a temporary redistribution of faunal communities:

- a) Away from burning and recently burned patches
- b) Towards burned areas during regeneration

**Figure 2-3**

Biomass of grasshoppers in a small-scale mosaic consisting of 89% burned patches and 21% unburned patches, following a fire in September 1978 (Gandar 1982c).



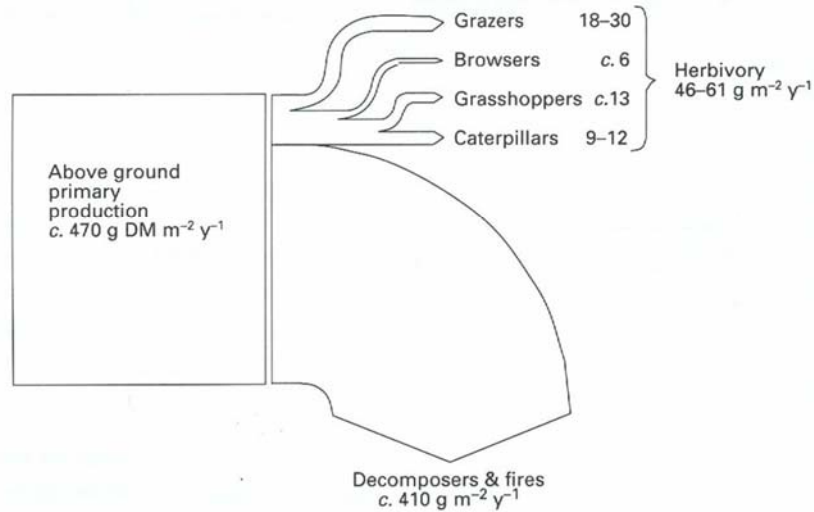
– ***Herbivory: grazing, browsing***

In a natural ecosystem, large wild mammals make out most of the herbivory pressure for a savannah. However, in savannahs with a high human population, livestock makes up for an important part of the herbivory pressure. The consumption of herbivores mounts to about 22% of the aboveground grass production (AGP) and about 3.4% of the woody plant leaf production in a case-study of a broad-leafed savannah in South Africa. For fine-leafed savannahs, 50 to 80% of the aboveground grass production can be predated, since these grasses are preferred by Impala and cattle. Insects are important consumers of grasses (mostly grasshoppers may consume up to 6% of the AGP). Tree-leaf eating lepidopteran larvae can eat up to 1.7 % of the woody plant leaf production, but during outbreaks this can mount up to 33 %.



**Figure 2-4**

Pathways of disappearance of plant leaf material in the broad-leaved savanna at Nylsvley, and their approximate magnitudes.



#### – *Nutrient & soil type*

There is an effect of soil particle size distribution ('texture') on the availability of water to plants. After a storm, each soil layer is filled with water to its maximum capacity, until all available rainfall has been used by the plants. Afterwards, evaporation extracts water from each layer until the next rainfall. The soil hydrological characteristics thus play an important role in maintaining savannah habitat. Next to this, there is an effect of soil fertility. Two key elements, nitrogen and phosphorus, are the building blocks essential for growth of any organism. In nitrogen poor soils during the dry season, even less nitrogen is available so that there will be more fibres in plants. These plants become non-digestible for ruminants because their nitrogen content remains below the threshold for ruminant digestion. Therefore, atmospheric N fixation in *Acacia* is very important for the maintenance of savannah habitat.



## 2.2 Miombo woodlands

### 2.2.1 Introduction

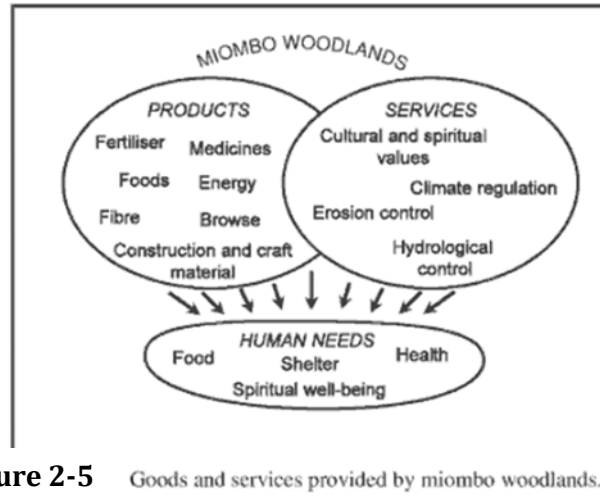
Central, southern and eastern African woodlands are dominated by shrubs and trees from the genera *Brachystegia* (21 species, deciduous), *Julbernardia* and/or *Isoberlinia* (3 sp each), all member of the *Fabaceae*, subfamily *Caesalpinioideae*. Generally they grow on geologically old, nutrient-poor soils in the uni-modal rainfall zone; where fires are a characteristic feature. The shrub layer and grass cover are variable in density and composition.

#### **The feel of Miombo**

“A month before the rains set in, the miombo covered hills burst all at once into reds, salmons, pinks and coppery tinges of all hues as the *Brachystegia* trees flush into young leaf and, within a week, all this riot of colour has blended into a forest of the freshest green carpeted with legions of flowers. In full leaf the miombo is delightfully cool and shady, and the scanty grass a pleasure to walk through. In the dry season, what a change! The whole miombo forest becomes entirely leafless, while grass fires burn up all the grass and leaf litter. The sun beats down unmercifully and whichever way one turns there is the same view, the grey stems of miombo trees fading into the shimmering distance. The buzz of insect life has vanished, except for the sharp hiss of the tsetse fly.”

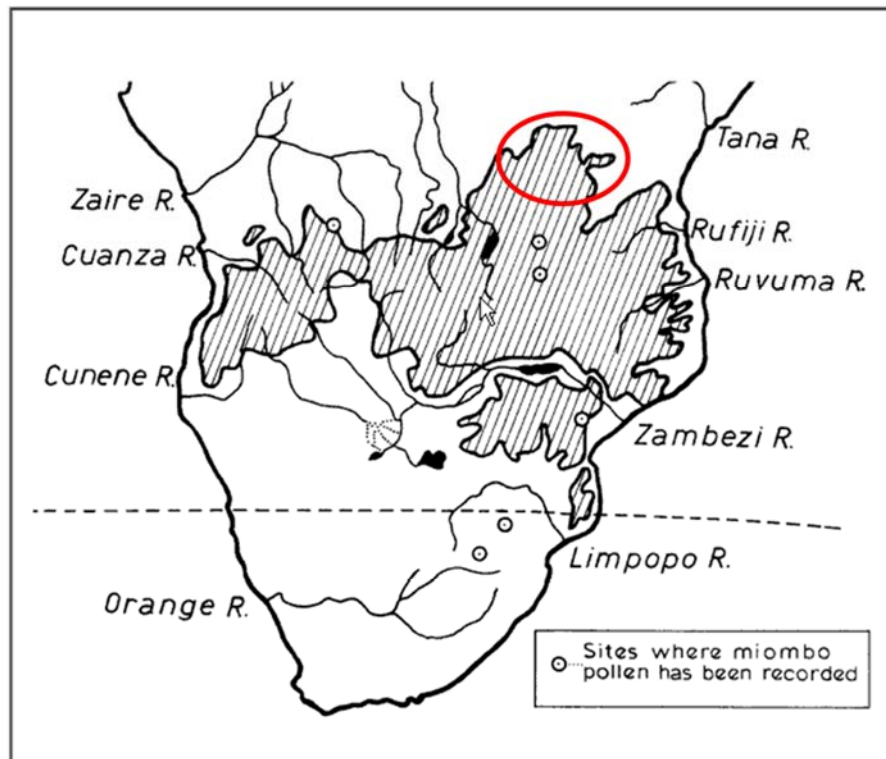


There is a relatively low density of people and livestock present in Miombo woodland compared to other woodlands in Africa. In 1990, 40 million people were living in areas of Miombo or former miombo woodland and an extra 15 million people depend on firewood and/or charcoal from miombo. Services and products from miombo woodland are shown on Figure 5.



**Figure 2-5** Goods and services provided by miombo woodlands.

Miombo woodland is present in a large part of Southern Africa. We will visit miombo woodland in the extreme north of its range (Ruaha ecosystem, encircled on Figure 6).



**Figure 2-6** Distribution of miombo woodland. Sites where pollen of miombo woodland has been recorded are shown.

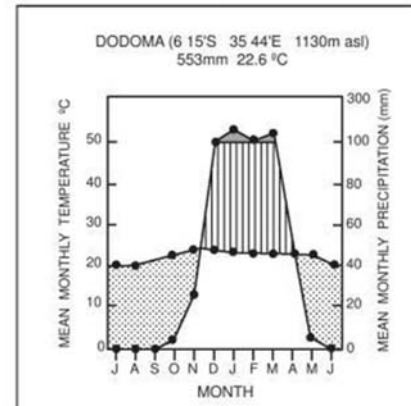
### 2.2.2 Climate characteristics of Miombo woodland

Mean annual precipitation in 115 rainfall stations inside miombo woodland is reported in Table 2.1. Figure 7 shows the mean monthly precipitation (in mm) in Dodoma (Tanzania), city close to Ruaha National Park. The length of the dry season in miombo woodland sites varies between three and seven months. Mean annual and monthly temperatures are shown on Table 1 and Figure 7.

**Table 2-1**

Average climate characteristics of miombo woodland, based on an analysis of 115 rainfall stations and 62 temperature stations situated throughout the miombo region (source of date: Lebedev 1970).

	Median	Range	Percentiles		N	
			10%	90%		
Mean annual precipitation (mm)	973	541	1721	710	1365	115
Length of dry season (months)	6	3	7	4	7	115
Rainfall in five driest months (% of mean annual precipitation)	2.5	0.2	14.6	0.5	7.4	115
Mean annual temperature (°C)	20.6	14.9	25.3	18.0	23.1	62
Mean temperature (°C)						
coldest month	16.9	10.7	24.6	13.6	20.5	62
hottest month	23.3	17.1	27.5	20.4	25.9	62



**Figure 2-7**

### 2.2.3 Miombo woodland ecology and dynamics

Four phases exist during miombo woodland regeneration after a fire (Figure 8):

- Initial regrowth: woody plants smaller than 1 metre grow, together with grasses
- Dense coppice (Dutch '*kreupelbos*'): 1 to 3 metres tall woody plants suppress the growth of grasses
- Tall saplings: woody plants from 3 to 6 meters high are growing
- Mature woodland: a thinning of saplings takes place.

The flowering and ripe fruit stages of some of the miombo's most abundant trees and shrubs are shown on Figure 9.

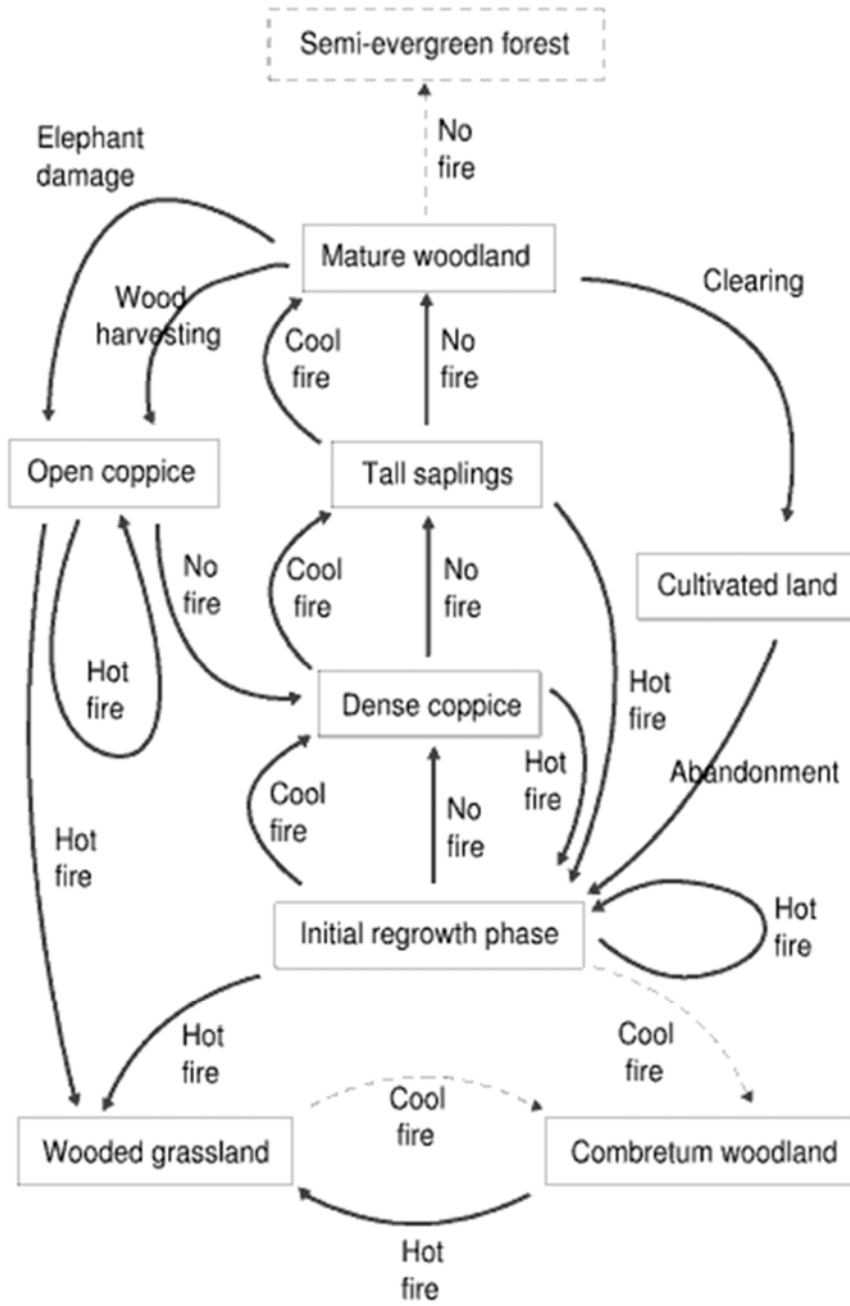
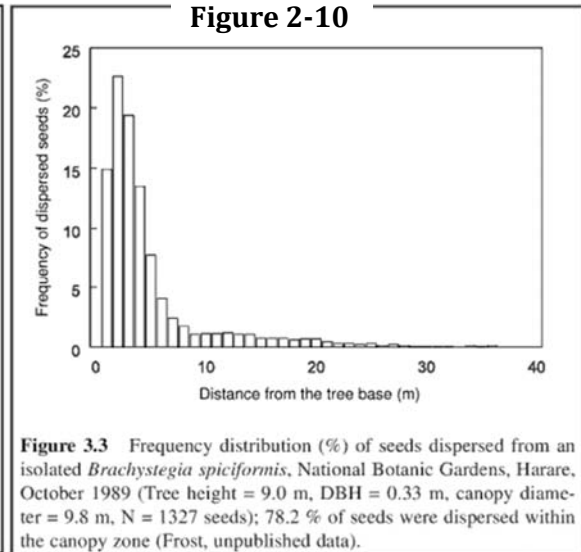
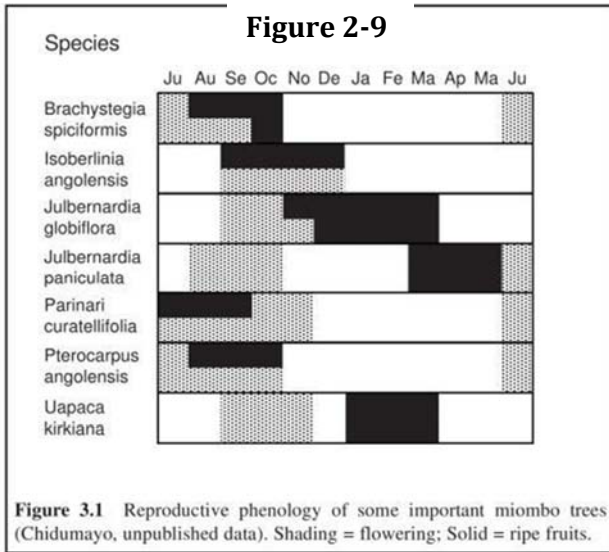


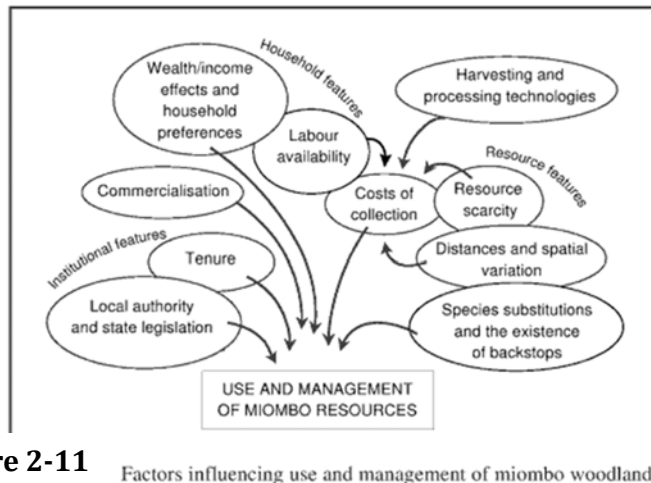
Figure 2-8



### 2.2.4 Management of miombo woodland

It is important to note that miombo woodland plants have a low seed dispersion capacity. Therefore, complete clearing will almost irreversibly change the woodland composition (Figure 10). To perform sustainable management of miombo woodlands, we have to take into account the characteristics of trees (phenology, resistance to fire, ability to resprout, seeding patterns and browsing quality) and the characteristics of the ecosystem itself (low soil-nutrient status, regular occurrence of droughts, fire and insect outbreaks). The main management issues are (Figure 11):

- Harvesting,
- Regeneration
- Coppice, fire and grazing management
- Access rights to woodland resources



### Trypanosomiasis in miombo woodlands

Tsetse fly (*Glossina spp.*) transmits *Trypanosoma* parasites causing sleeping sickness.

This sickness has had a major impact on land use in miombo. Trypano-tolerant wildlife are the reservoirs together with some indigenous cattle breeds. Exotic breeds and humans become sick and die from the disease if left untreated, therefore humans do not inhabit high risk areas. Bush clearing eradicates the tsetse fly locally (on dry soils).

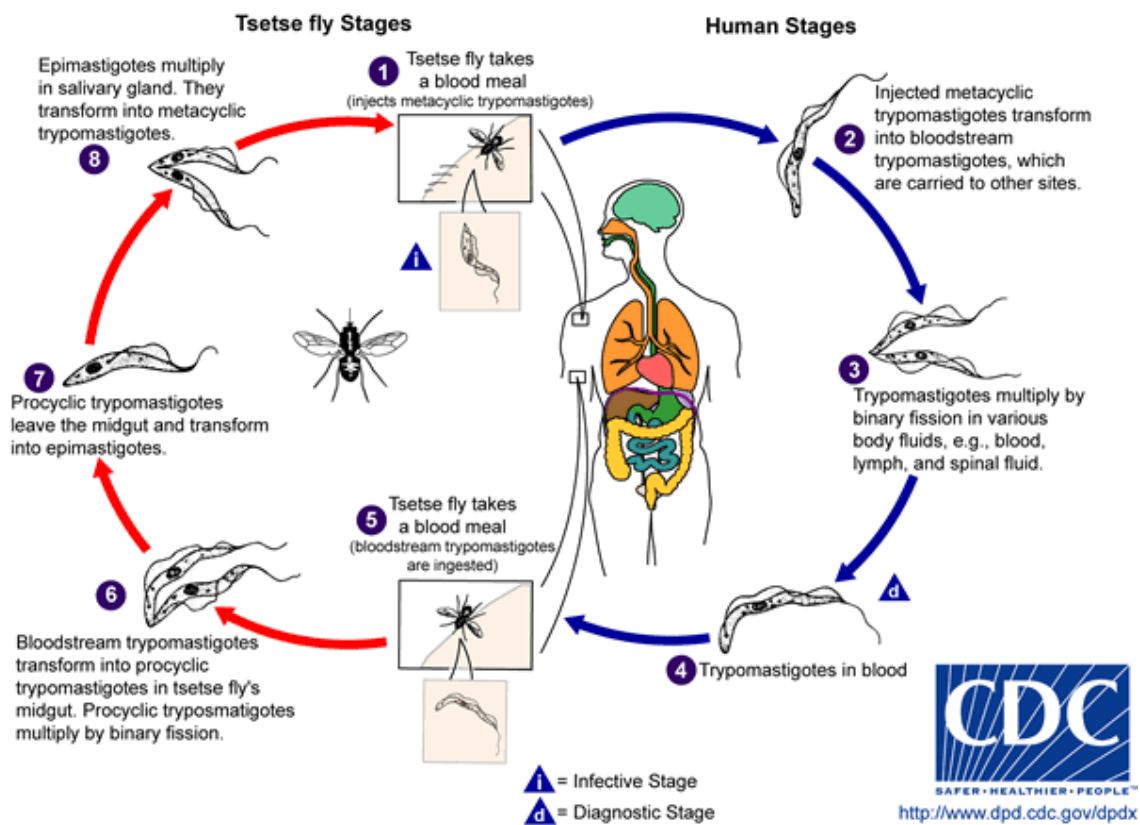
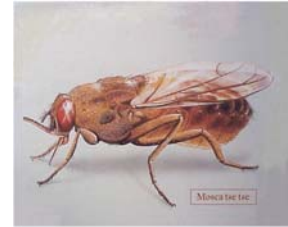
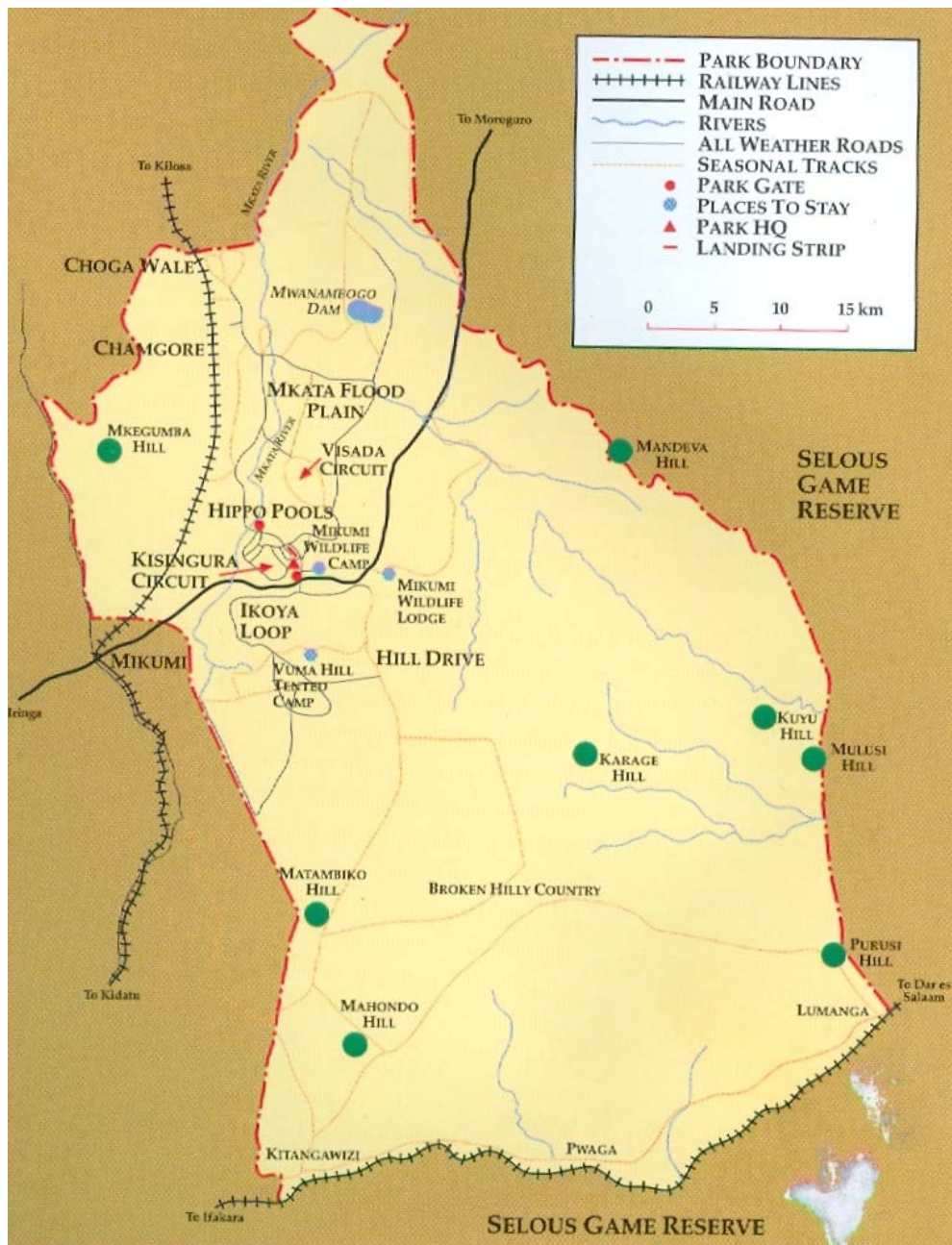


Figure 2-12: African *Trypanosoma* life cycle

### 2.3 Mikumi National Park

During our trip, we will come across savannahs and woodlands several times (Mikumi NP, Ruaha NP, parts of Saadani NP). We will spend most time visiting both habitats during our stay at Ruaha National Park. Before arriving in Ruaha NP however, we will pass by bus through Mikumi National Park, without leaving the main road. During this short passage, some larger animals could already be seen from the main road. If we can stop somewhere safe, we will, so to have a first glance at some of the larger mammals we will be seeing at Ruaha NP.



**Figure 2-13:** Map of Mikumi National Park. In dark black, the main road from Dar Es Salaam to Zambia is indicated.

## 2.4 Ruaha National Park

Ruaha NP covers an area of 22,000 square km<sup>2</sup> and is part of a bigger ecosystem consisting of four game reserves and two protected areas around the NP, bringing the total protected area to 50,000 km<sup>2</sup> (as a comparison: Belgium has a total area of 30,528 km<sup>2</sup>). These areas serve as buffer zones for the wildlife in the park (Figure 14). Three big rivers flow through Ruaha NP: the Ruaha, Mzombe and Mwagusi rivers (Mwagusi, dries up and flows below ground during dry season, called 'sand river'). The rainfall is limited to +/- 500 mm/year (Udzungwa Mountains form barrier for rainfall coming from the ocean in the east). River water level in the park is reduced due to agricultural practices before the rivers enter the park causing ecological problems in the park and economical problems downstream (electricity & agriculture). Ruaha NP has a very large elephant population of around 10,000 individuals. African wild dogs are present in the park in thick bush habitat (between Mwagusi Sand River & Jongomeru). Because of their habitat preference, wild dogs are quite difficult to see in Ruaha NP.

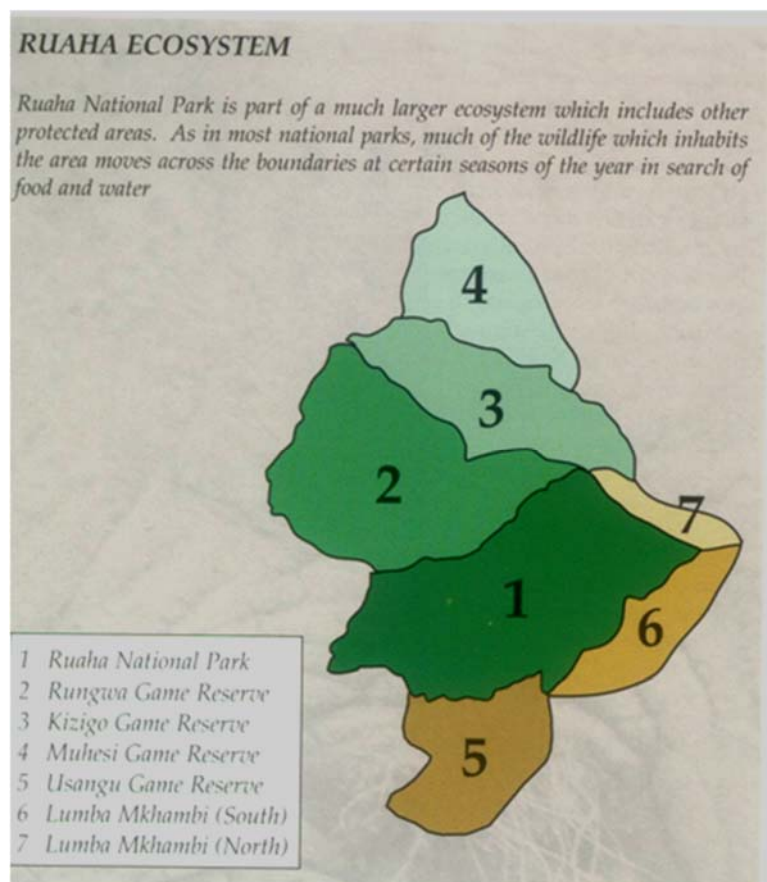
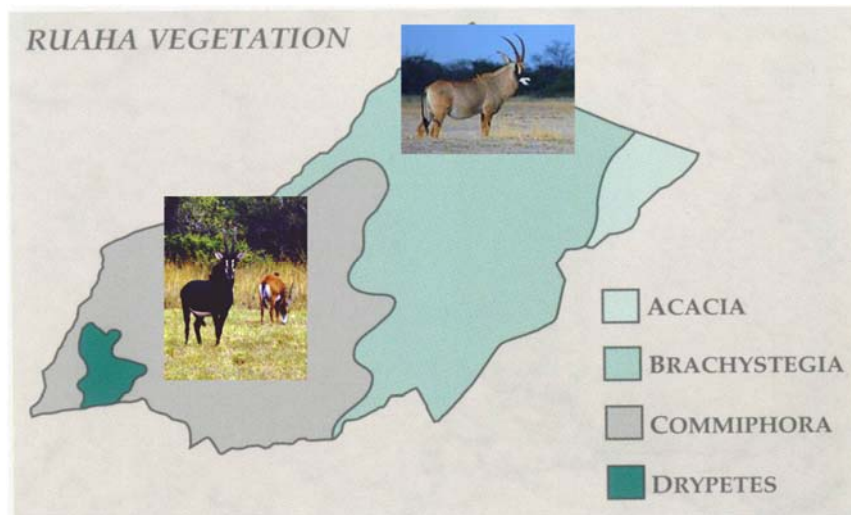


Figure 2 -14

The fauna of the Ruaha NP is very diverse and we are not able to discuss individual species here. However, in the bibliography, there is a list of must-reads if you are interested in the large mammal fauna of Ruaha NP. Below we will discuss in short the niche partitioning and the trophic web present in African savannahs and some of the animal species implicated in this.



**Figure 2-15:** Map of the vegetation of Ruaha. Four main vegetation types exist, each with its particular flora and fauna. Sable antelopes (*Hippotragus niger*) will be found in the *Commiphora* dominated part of the park, whereas Roan antelopes (*Hippotragus equinus*) reside in the *Brachystegia* dominated part of the park.

Both greater Kudu (*Tragelaphus strepsiceros*) and lesser Kudu (*Tragelaphus imberbis*) occur in Ruaha, making it the only park in Africa where these both species occur naturally.

#### Fauna of savannah and miombo woodland

- Birds:
  - Acacia savannahs: 1500 individuals/km<sup>2</sup>
  - Miombo woodland: 3500 individuals/km<sup>2</sup>
  - Lakes, rivers, swamps: 7000 individuals/km<sup>2</sup>
- Mammals:
  - Ungulates, nonruminants: zebra, rhinos, warthogs, hippopotamus
  - Ungulates, ruminants: giraffe, buffalo, antelope, hartebeest, impala, dik dik
  - Subungulates: African elephant, hyrax
  - Carnivores: lion, caracal, leopard; hyenas; genets, civets & mongooses; jackal, African wild dog
  - Primates: vervet monkey, baboon, bush babies
  - Rodents: squirrels, porcupine, ...
  - Elephant shrews

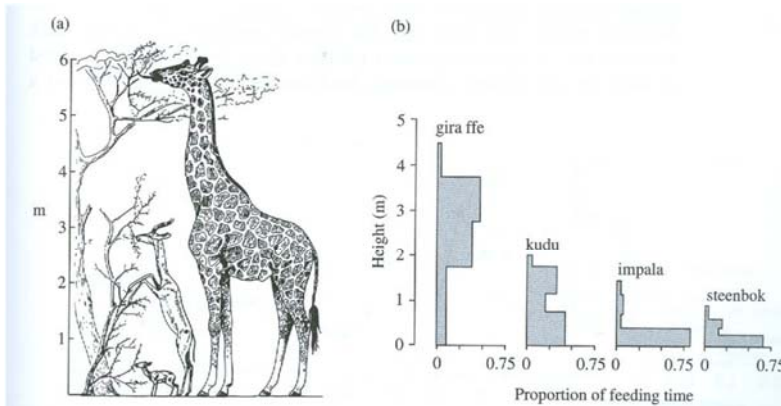
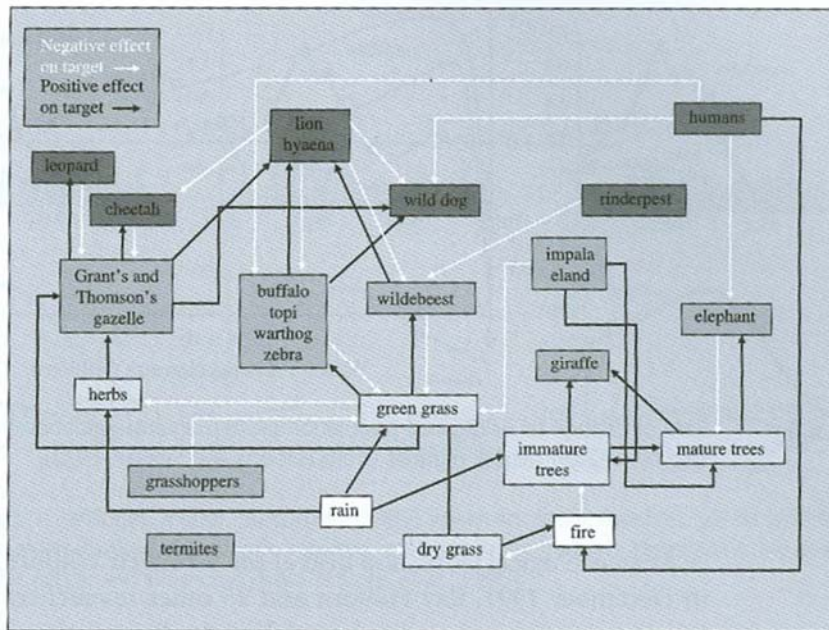


Fig. 5.27 Niche separation of savannah browsers. (a) the popular view (from Orbis Publications 19xx), (b) data from Kruger National Park, South Africa (from du Toit 1990).

**Figure 2-16:** Niche separation of savannah browsers. Because of the differences in physical appearance (height) but also in morphology of the mouth parts (tongue and lip toughness), the different large mammal herbivores occupy other niches with regards to their main food sources.

If you want to read more on this, a very good chapter on species interactions in African savannahs is written down in the book 'The Biology of African Savannahs' by Bryan Shorrocks (see bibliography).



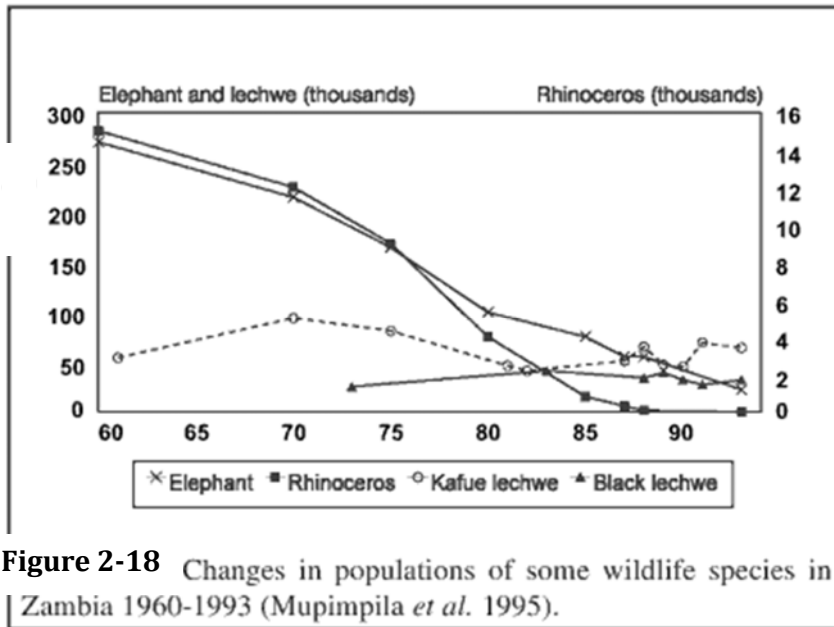
Simplified trophic web of the Serengeti-Mara ecosystem. □ physical factor, ▒ plants, ▒ herbivores, ■ carnivores

**Figure 2-17:** Simplified trophic web of a typical savannah (example from northern Tanzania). No strengths of interactions are indicated, only their positive and negative effects, and many species are absent. However, it shows how complex a savannah ecosystem is and how many interactions exist. As an example of an indirect interaction, consider what is implied if rinderpest is reduced or eliminated from the system. With the removal of rinderpest, wildebeest numbers will increase, green grass will decrease and consequently there will be less dry grass to burn. This will result in fewer fires (or less extensive/intense fires), and therefore greater survival of young trees. More young trees will mean more mature trees, which should have a positive effect on the giraffe population. The implication of the trophic networks presented here, is that many years after the removal of rinderpest there may (other things being equal!) be an increase in numbers of giraffe. This effect has already been reported from the Serengeti ecosystem (Grimsdall 1979, Pellow 1977).

## 2.5 Conservation and human – wildlife conflicts in and around Ruaha NP

### 2.5.1 Decline in the numbers

As can be seen on Figure 18, the numbers of larger wildlife species are decreasing over time (example from Zambia). Factors influencing this are local climate and habitat change, foraging competition between different species and poaching. However, in Ruaha specifically, habitat change is induced by the diminishing of the water level in the Ruaha river flowing through the park.



**Figure 2-18** Changes in populations of some wildlife species in Zambia 1960-1993 (Mupimpila *et al.* 1995).

### 2.5.2 The drying of the great Ruaha river (source: [www.friendsofruaha.org](http://www.friendsofruaha.org))

The Great Ruaha River runs along the eastern boundary of Ruaha National Park, and is the lifeblood of the park and surrounding areas. However, as a result of intensive rice farming and livestock grazing in the Usangu catchment area the river has been drying up earlier and earlier every year since 1994. The reduced water flow is of great concern to everyone from conservationists to economists alike, as the Great Ruaha flows into the Mtera Dam, source of much of Tanzania's electricity. In early 2008 the Tanzanian Government added the Usangu Wildlife Management Area to Ruaha National Park, thus protecting the catchment area and making Ruaha the biggest park in all of Africa. After monitoring changes in water level and discharge of the Great Ruaha River for more than 30 years, it has become obvious that with each passing year, the amount of water that reaches Ruaha Park from the Usangu basin is decreasing at an alarming rate. In previous years the Usangu floodplain (4,400 km<sup>2</sup>, containing the permanent Utengule swamp 518 km<sup>2</sup>) was the 'source' of the Great Ruaha River (480 km long, flows 160 km in the Ruaha National Park). Each wet season, the Usangu water would begin its journey from Usangu to the Rufiji Delta, via the Great Ruaha River. At

the start of the rains, the water table in the swamp rose, until it overflowed from the vast reed beds of the swamps, into the Ruaha River. However, during the mid-1970's a large commercial rice scheme started in the Usangu Plains, (Mbarali) which has put the Usangu water catchment area under tremendous pressure. In the height of the dry season, when the water is at its lowest, the rice schemes flood their paddies. Recently, the time of flooding has been brought forward (earlier in the dry season) because it enables the stakeholders to obtain higher prices for their rice, while the actual annual yield remains constant. This means that because the water reserves upstream are depleted sooner the Great Ruaha River located downstream dries up earlier, causing increasingly longer periods of drought. The lower water flow was imperceptible at first, but by the mid 80's when a second large rice farm was established (Kipunga), the flow began to diminish more drastically than ever before. In November, 1993, the river stopped flowing completely for about 3 weeks, in 1994, it was dry for 4 weeks, in 1995 it was dry for 8 weeks and so on. The situation is now extremely serious with the river being dried for up to 3 months per year. Prior to 1993, there are no records of the Great Ruaha River drying up completely for any period of time! But the rice fields are not the only threat to the Usangu swamp as there are also thousands of cattle present in the area. The animals damage the swamp heavily by trampling down the soft spongy surface (thus reducing the surface area of the swamp) and drinking a vast amount of water each day. Both rice fields and cattle, are results of increasing human population in the area and have led to one of the most severe human-wildlife conflicts in Tanzania. Of course hippopotamus, crocodile and elephant populations have declined following longer periods of drought in the park, but the actual fact is that small animals are affected first. For example, the fresh oyster beds and endemic fish of the Great Ruaha River that once thrived in the river are no more and the White Crowned Plover, whose only breeding ground in Tanzania is on the Great Ruaha River, is now severely threatened due to the effect of the drying river.

### **2.5.3 Tanzania carnivore project (source: [www.tanzaniacarnivores.org](http://www.tanzaniacarnivores.org))**

Human-wildlife conflict is more than ever an issue of critical conservation importance around the world, and is one of the main threats facing large carnivores today, particularly in areas near reserves. Large cats and other carnivores can impose significant costs on households through livestock depredation, and they are also often feared due to the possible risk of attacks on humans themselves. Frequently, the response to this conflict is lethal control of the carnivores concerned, which can have a significant impact on carnivore populations.

Successfully addressing this conflict, however, depends on accurately identifying sources of conflict and developing the most appropriate and effective resolution techniques. This is exactly what the Tanzania Carnivores project does. They focus on five large carnivore species (lion, cheetah, leopard, African wild dog and spotted hyaena) and quantify the levels of conflict experienced with



these species by pastoralists in villages adjacent to Ruaha National Park in Tanzania, assess which factors significantly affect attitudes, to finally examine which techniques are most effective in mitigating conflict. Assessing where conflicts occur is being done by interviewing local pastoralists living in villages around the park about livestock husbandry methods and analysing reported conflicts and sightings of large carnivores. Moreover, driving transects are performed to assess relative abundances of wild prey and livestock and to examine the relationship between human-carnivore conflict and wild prey densities. Furthermore, faecal samples (scats) are collected to identify prey preference, to identify species and thus population structure and movements. Scats are also used to construct a spatial map of carnivore distribution which is compared with the spatial map of conflicts across the whole area using GIS. Other important aspects of the Tanzania Carnivore study around the Ruaha National Park include the training and capacity-building of local people. They have so far trained three research assistants and 19 carnivore monitors in villages in Idodi and Pawaga, who visit local households every month to collect information on stock losses and provide information on how best to reduce predator attacks. Also presentations are given at local villages on carnivore ecology and behaviour and the most effective methods of livestock husbandry, as well as discussing issues with wildlife with local people. If you want to know more about Tanzanian carnivores, including distribution maps and pictures of all carnivores present, visit <http://www.tanzaniacarnivores.org/carnivores>. See Figure 19 below for the distribution map of *Panthera leo*, the lion.

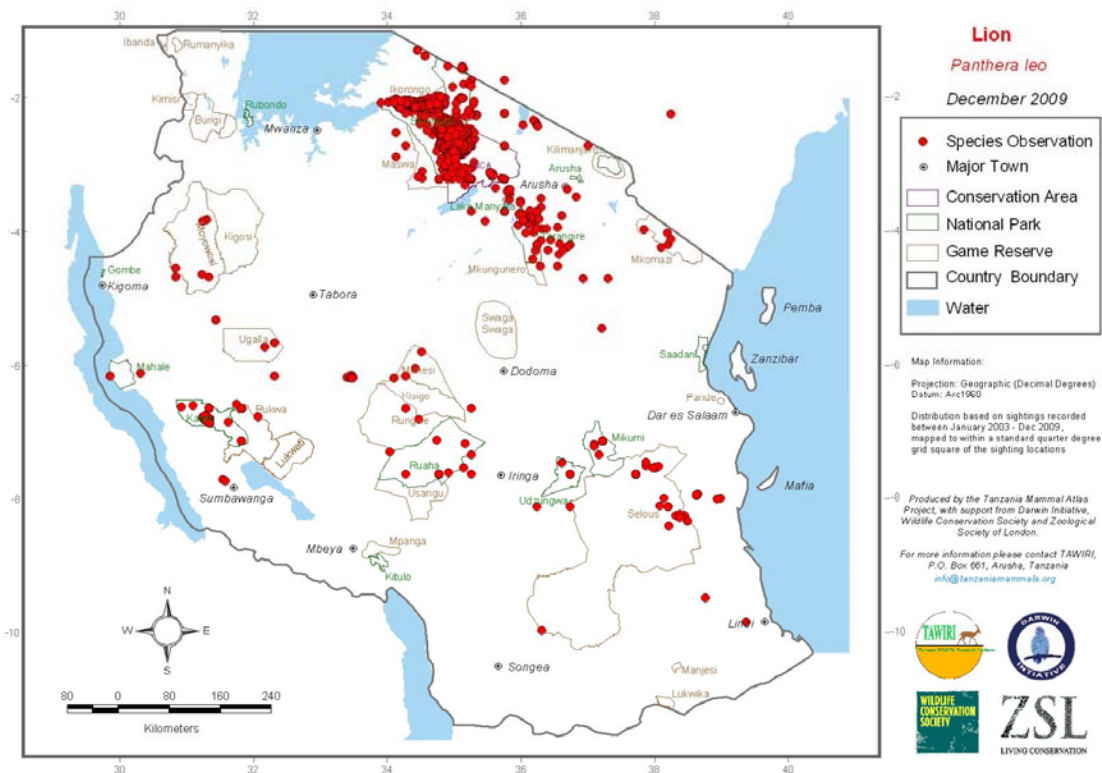


Figure 2-19

### 2.5.4 Community education: Friends of Ruaha (FORS)

The Friends of Ruaha NGO makes communities participate to protect the Ruaha NP, through:

- Environmental Education in rural Tanzanian primary schools, FORS aims to spread environmental knowledge to thousands of students.
- Community Education in the villages bordering Ruaha National Park, FORS aims to change attitudes and habits that are destructive to the environment. Figure 20 below shows the villages where FORS is active. More information on [www.friendsofruaha.org](http://www.friendsofruaha.org).

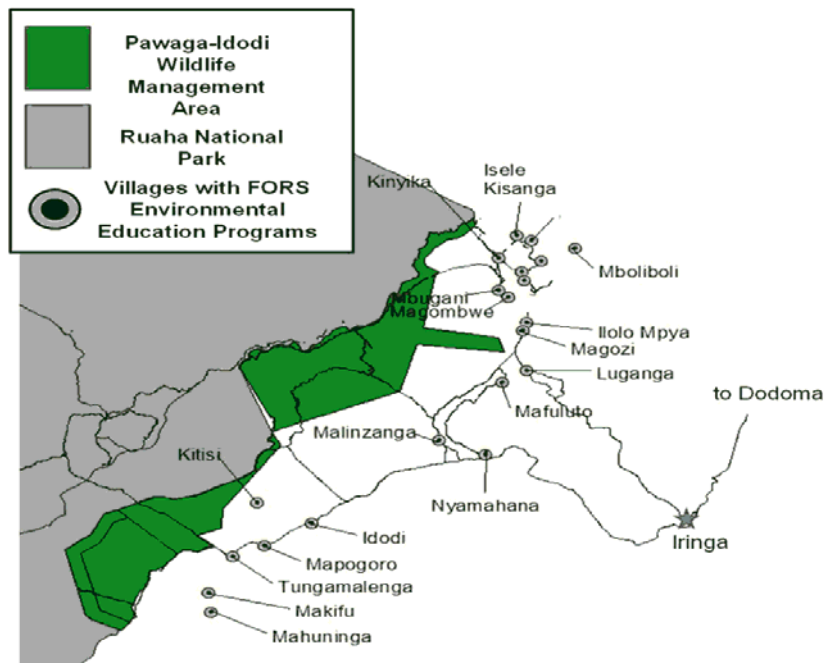


Figure 2-20

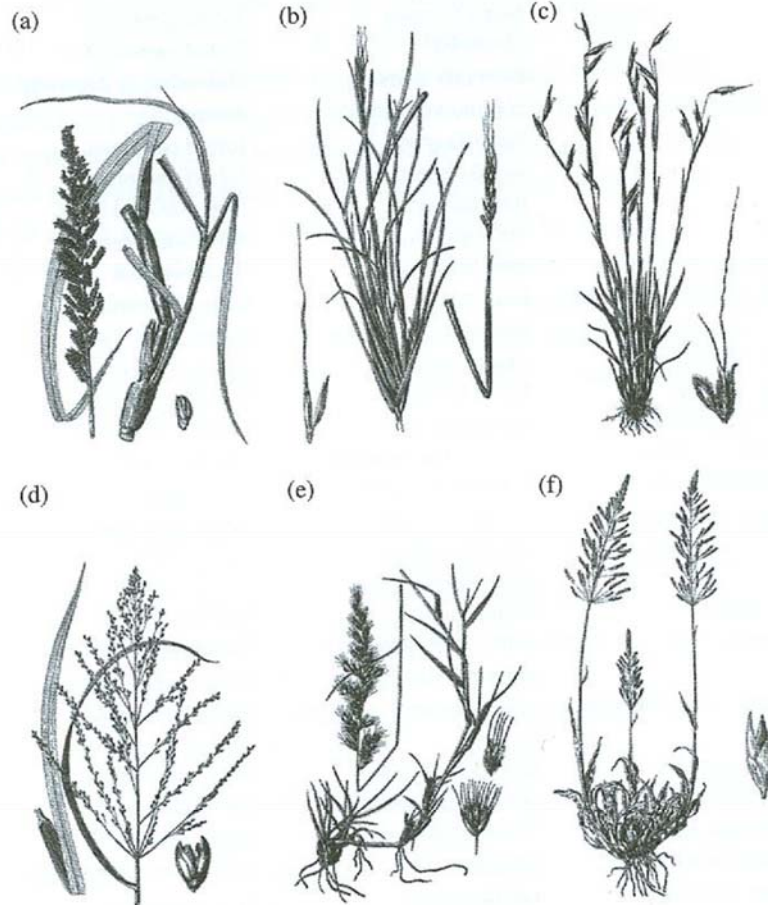
## Appendix 1: List of grass species common in African savannahs

**Table 2.3** Some principal grass species of African savannahs (g = open grass and shrub savannah, t = tree and scrub savannah, w = woodland savannah, m = miombo).

Scientific name	Common name	Type	Height (cm)	Savannah type
<i>Aristida adscensionis</i>	common needle grass	Annual or perennial	10–100	g
<i>Aristida stipoides</i>	needle grass	Tufted annual	60–100	t
<i>Andropogon gayanus</i>	bluestem grass	Tufted perennial	up to 300	t w m
<i>Andropogon greenwayi</i>	bluestem grass	Tufted perennial	45–60	g
<i>Brachiaria brizantha</i>	common signal grass	Erect perennial	up to 120	w
<i>Brachiaria deflexa</i>	signal grass	Annual	up to 45	t w
<i>Cenchrus biflorus</i>	African foxtail	Tufted annual	up to 90	t
<i>Cenchrus ciliaris</i>	common African foxtail	Rhizomatous perennial	20–110	g t
<i>Chloris gayana</i>	Rhodes grass	Stoloniferous perennial	30–120	g m
<i>Chrysopogon aucheri</i>	Aucher's grass	Tufted perennial	up to 50	t
<i>Ctenium newtonii</i>	sickle grass	Tufted wiry perennial	up to 100	g
<i>Cymbopogon afronardus</i>	blue citronella	Tufted perennial	200	g w
<i>Cymbopogon plurinodis</i>	citronella	Tufted perennial	40–100	g
<i>Cynodon dactylon</i>	Bermuda grass	Stoloniferous perennial	8–180	g t
<i>Dactyloctenium aegyptium</i>	common crowfoot	Annual	up to 60	g
<i>Digitaria eriantha</i>	Pangola grass	Tufted perennial	50–250	g
<i>Digitaria macroblephora</i>	woolly finger grass	Tufted perennial	40–100	g t
<i>Echinochloa colonum</i>	barnyard grass	Tufted annual	up to 60	g
<i>Echinochloa pyramidalis</i>	antelope grass	Reed like perennial	up to 500	g m
<i>Enneapogon cenchroides</i>	grey head grass	Tufted annual	30–60	g
<i>Enteropogon macrostachyus</i>	bush rye	Tufted perennial	90	g t
<i>Eragrostis lehmanniana</i>	Lehmann's lovegrass	Tufted perennial	45–61	g t
<i>Eragrostis patens</i>	desert lovegrass	Tufted annual	15–30	g t
<i>Eragrostis superba</i>	Masai lovegrass	Tufted perennial	30–90	g t w
<i>Heteropogon contortus</i>	spear grass	Tufted perennial	up to 90	g t w
<i>Hyparrhenia cymbaria</i>	coloured hood grass	Tall perennial	180–600	g w
<i>Hyparrhenia diplandra</i>	sword hood grass	Tufted perennial	150–300	g
<i>Hyparrhenia dissoluta</i>	yellow hood grass	Tufted perennial	up to 300	g w m
<i>Hyparrhenia filipendula</i>	fine hood grass	Slender perennial	up to 300	w m
<i>Hyparrhenia rufa</i>	brown hood grass	Variable perennial	up to 300	w m
<i>Imperata cylindrica</i>	cotton grass	Perennial	up to 120	g w
<i>Loudetia kagerensis</i>	sour russet grass	Tufted perennial	up to 110	g
<i>Loudetia simplex</i>	common russet grass	Tufted perennial	up to 150	g m
<i>Monocymbium ceresiiforme</i>	wild oatgrass	Tufted perennial	up to 120	g
<i>Oryza barthii</i>	wild rice	Tall annual	60–200	g w
<i>Panicum coloratum</i>	blue guinea grass	Tufted perennial	8–100	g
<i>Panicum maximum</i>	slender guinea grass	Tufted perennial	70–150	g w
<i>Panicum turgidium</i>	Taman guinea grass	Tufted perennial	up to 100	g
<i>Pennisetum clandestinum</i>	Kikuyu grass	Stoloniferous perennial	up to 46	g
<i>Pennisetum mezianum</i>	bamboo grass	Tufted perennial	40–160	g
<i>Pennisetum purpureum</i>	elephant grass	Tufted perennial	up to 450	g
<i>Pennisetum schimperi</i>	wire grass	Tufted perennial	up to 120	g
<i>Pogonarthria squarrosa</i>	herringbone grass	Tufted perennial	up to 120	w m
<i>Schizachyrium semiberbe</i>	crimson bluestem	Tufted perennial	60–150	g w
<i>Schmidtia bulbosa</i>	Zand Kweek grass	Tufted perennial	up to 80	g t w
<i>Schoenefeldia gracilis</i>	spiky grass	Tufted annual	70–120	g t
<i>Setaria incrassata</i>	setaria	Tufted perennial	60–100	g

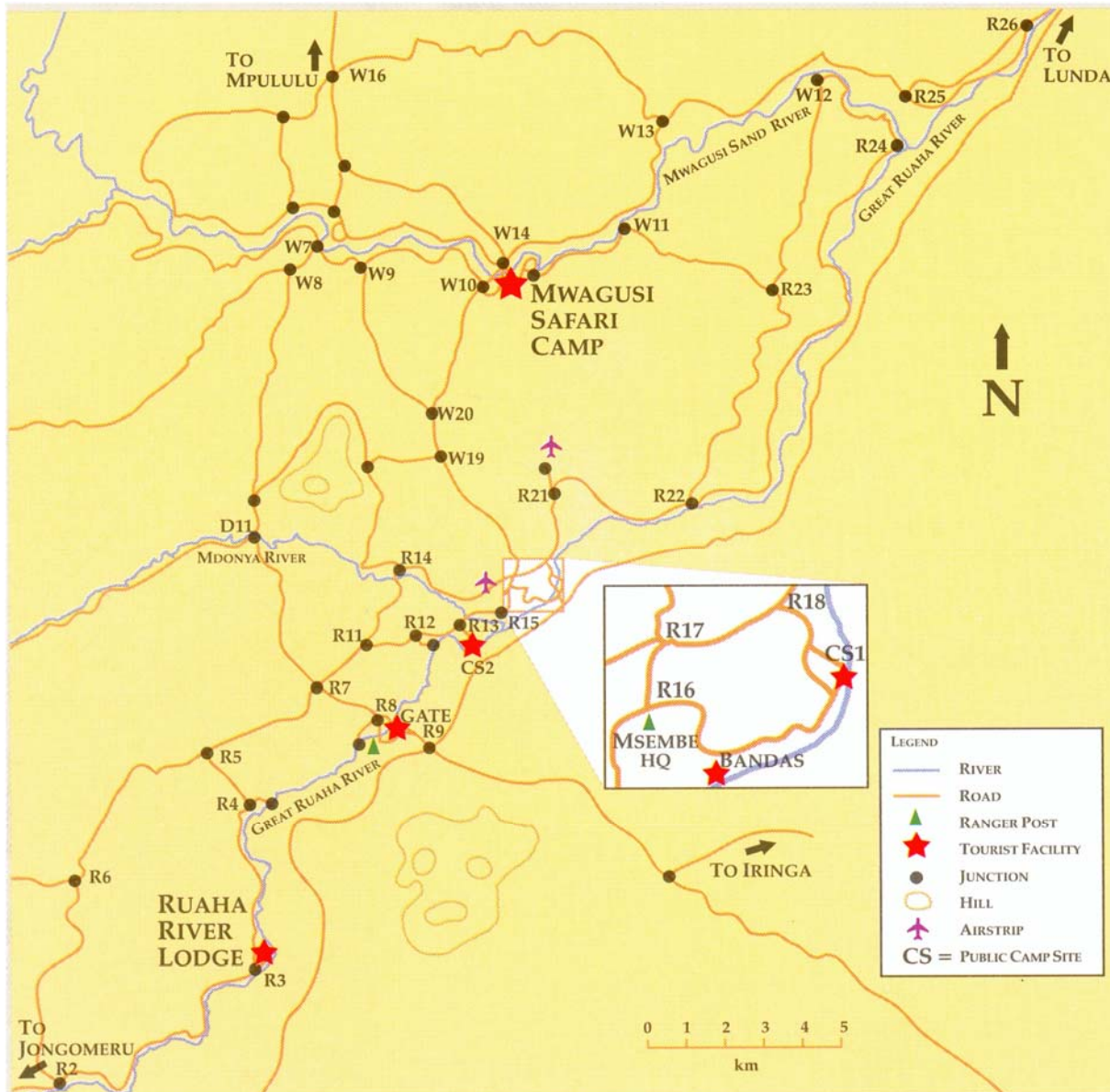
**Table 2.3** (Continued)

Scientific name	Common name	Type	Height (cm)	Savannah type
<i>Setaria sphacelata</i>	common setaria	Tufted perennial	45–180	g w
<i>Sporobolus pellucidus</i>	dropseed	Tufted perennial	up to 60	g
<i>Sporobolus pyramidalis</i>	pyramid dropseed	Tufted perennial	45–150	g t w
<i>Sporobolus robustus</i>	reed dropseed	Tufted perennial	100–200	g
<i>Sporobolus spicatus</i>	spike dropseed	Stoloniferous perennial	9–30	g
<i>Stipagrostis uniplumis</i>	silky bushman grass	Short-lived perennial	up to 75	g t
<i>Themeda triandra</i>	red oat grass	Tufted perennial	30–200	g t w
<i>Tragus koelerioides</i>	creeping carrot grass	Stoloniferous perennial	12–95	g

**Fig. 2.7**

Some African grasses. (a) *Echinochloa pyramidalis*, (b) *Heteropogon contortus*, (c) *Monocymbium ceresiformis*, (d) *Panicum maximum*, (e) *Schmidtia bulbosa*, (f) *Sporobolus nitens* (drawings by Cythna Letty, from Bews 1929).

Appendix 2: Game viewing roads in the central part of the Ruaha NP



## Chapter 3: Eastern Arc Mountains

*“De kans is groot dat de mangabeys aanvankelijk in heel het Tanzaniaanse gebergte overleefden. Na verloop van tijd stierven ze echter uit - overal behalve hier, op de bergtop die wij vandaag gaan beklimmen.” - Ramsey Nasr*

### 3.1 Introduction

The Eastern Arc Mountains are a collection of unique evolutionary mountain islands that have been formed by the same geological process. With the exception of the Taita Hills of Kenya, they lie entirely in Tanzania as 11 geologically separated mountain blocks, which together form a broken chain running from Southern Kenya across Tanzania in an arc or crescent shape, from which the name ‘Eastern Arc’ arose.

Each block of mountains harbours its own tropical rainforest, and because of the fragmented nature of these mountain patches, long-term evolution has resulted in large numbers of endemic species that still survive in the isolated forest patches. The Eastern Arc Mountain forests are therefore unique and valuable, and regarded as one of the world’s important hot spots of forest biodiversity.



Figure 3-1: Eastern Arc Mountains

### **3.2 Geological and natural history**

The mountains are thought to have been formed over 200 million years ago (Oligocene) by upward faulting of the earth's crust which resulted in periods of uplifting. This period coincided with the adjacent down faulting that created the Eastern Rift Valley running through Kenya and Tanzania, which is part of the Great Rift Valley. This formation, and the drift of Africa into its present position, followed the break-up of the Pangaea supercontinent. The Eastern Arc is comprised of heavily metamorphosed Pre-Cambrian basement rocks, and the soils derived from the sediments are typically less rich than those of the volcanic mountains of East Africa, but the consistent rainfall in the area increases the agricultural potential. The topography of the Eastern Arc is characterized by rugged mountain blocks rising from the more subdued topography of the coastal plain of eastern Africa. Some mountain blocks are so steep that there are substantial areas of exposed rocks, yet slopes of up to 50-70 degrees still support forest vegetation. These mountains rise up to 2,635 meters in elevation (Kimhandu peak in the Ulugurus), although maximum altitudes of 2,200-2,500 meters are more typical. The tops of the Uluguru and Udzungwa mountains are plateau-like, and support forest grassland mosaics, which in the Udzungwas have been heavily altered by man.

The forests of the ecoregion might have persisted up to 30 million years, and hence been formerly connected to a forest belt that stretched across the tropical region of Africa and connected the forests with those of the Congo Basin and West Africa. They likely survived the driest and coldest periods of the Ice Ages, as the Indian Ocean did not cool appreciably and rainfall patterns may not have been greatly disrupted. This stability is viewed as one of the main reasons for the biological importance of the ecoregion. The current climate of the mountains is much wetter than the surrounding lands, with perhumid (rain every month) conditions and rainfall up to 3,000mm per year recorded in the eastern Uluguru Mountains. In most of the other mountains the wet and dry seasons are more clearly defined, with two seasons in the northern forests and one in the southern forests.

### **3.3 Ecology**

As mentioned above, the Eastern Arc Mountains have long been the base of extensive areas of rain forest. The term rain forest was first used by Schimper in 1903, who defined it as 'a forest that is evergreen hygrophilous (moisture loving) in character, at least 30m high, rich in thick-stemmed lianas and in woody as well as herbaceous epiphytes". Although this is a broad definition, it does characterize a typical rain forest.

Although the stretches of rain forest have in the past been very large, in most of Eastern Africa they are now confined to the higher altitudes of the Eastern Arc Mountains. Starting almost 5000 years ago, clearing and burning for agriculture have destroyed enormous areas of forest, and even though most of the remaining forest is now officially protected, illegal clearing is still a problem, even at high altitudes.



**Figure 3-2: Agriculture vs. rain forest, Uluguru Mountains**

A variety of rain forest types exists. In general, the higher (non-coastal) closed forests of East Africa can be divided into medium altitude forests and montane forest. The distinction between these two types is however unclear, and both can be considered transitional between lowland rain forests and non-forest montane habitats. The forest formations have been divided into upper montane (2635-1800 m), montane (1250-1800 m) and submontane (800-1250 m) forest. At higher altitudes, the trees become dwarfed, and are covered with lichens. Additionally, open vegetation bog and grassland habitats can be found in the higher areas of the Ulugurus, whereas grasslands and stands of bamboo can be found in the Udzungwas. The altitude where medium-altitude forests stop and montane forests start is not clearly defined, but is considered to be between 1700 and 2300 m. This large range in boundary altitudes is probably due to the different properties of each mountain and the direction of monsoon wind and rain. All medium-altitude forests, which are usually the types of forests that can be found on the Eastern Arc Mountains, are **closed-canopy tall evergreen or semi-deciduous rain forests with canopies generally over 30 m**. Although mid-altitude forests are found to differ between areas, very little is known about what environmental factors determine the nature of a certain forest. One possibility is that differences in altitude, temperature and rainfall completely account for differences between mid-altitude forest types. Alternatively, the differences may be the consequence of the rich history of disturbance and regeneration the forests have known. This may then cause the forests to be in different succession stages and thus exhibit different species compositions.



**Figure 3-3: Edge of a typical mid-altitude rain forest, Uluguru Mountains**

There are a large and yet unknown number of forest tree community associations in these forests– with more elevated regions being more temperate and lower regions more tropical. Upper montane forests are characterized by high rainfall and large trees such as *Ocotea usambarensis*. The upper altitudinal limit of these strata is determined by regular occurrence of frost. Tree species here include *Aphloia theiformis*, *Cassipourea malosana*, *Dombeya torrida*, *Olea capensis*, and the endemic *Allanblackia ulugurensis*. The montane forests are much taller and contain bigger trees. The shrub layer is dominated by Rubiaceae and Acanthaceae. A number of tree species are endemic to this region, including *Allanblackia stuhlmannii*, *Beilschmiedia kweo*, *Isoberlinia scheffleri*, and *Polyceratocarpus scheffleri*. Submontane forests often overlap with montane forests, but are distinguishable by the presence of lowland species such as *Afrosersalisia cerasifera*, *Milicia excelsa*, and *Parkia filicoidea*. Endemics include *Anisophylla obtusifolia*, *Cephalosphaera usambarensis*, and *Englerodendron usambarensis*.

Although the forests of the Eastern Arc Mountains cover less than 2% of the area of Tanzania, they contain up to 40% of the country's species, and have the second highest bird diversity in Africa. Because of the long period of stability of the forests, they exhibit large levels of endemism, often even between forest patches themselves.

In terms of the phytogeographical classification of White (1983), the ecoregion forms a part of the Afromontane archipelago-like regional center of endemism. The Eastern Arc subregion of this Afromontane center of endemism is unique in its long term stability and isolation, and shares affinities with both the East African Montane Forests and South Malawi Montane

forests – and to a lesser degree with the Albertine Rift Montane Forests and Ethiopian Montane Forests.

### 3.4 Biodiversity

Where hunting has not greatly affected large animal populations, the forests harbour a diversity of large animal species including Forest elephant (*Loxodonta cyclotis*), Giant forest hog (*Hylochoerus meinertzhageni*), African golden cat (*Profelis aurata*), Leopard (*Panthera pardus*) and various primate species. Many of these species are endangered, and their only sustaining populations can be found in the Eastern Arc Mountain forests. The Kibale forest for instance is the only place in Uganda that still contains sizeable populations of the rare Red colobus monkey (*Procolobus rufomitratu*s). There are no known endemic large mammals, but six strictly endemic small mammals are known, including five species of shrews and one species of galago (*Galagoides orinus*). Other threatened mammals occurring in the forests include Abbot's duiker (*Cephalophus spadix*), Eastern tree hyrax (*Dendrohyrax validus*) and Black and rufous elephant-shrew (*Rhynchocyon petersi*).



**Figure 3-4: Red colobus monkey**

Bird endemism in the Eastern Arc forests is high, with both strict and near-endemic species. Some of the near-endemic species exhibit disjunct distribution patterns indicating formerly widespread populations in the mountains of eastern Africa. Species with limited distributions include the Taita thrush (*Turdus helleri*) and Taita apalis (*Apalis fuscigularis*) that only occur in a few square kilometers of forest in the Taita hills. The Udzungwa partridge (*Xenoperdix udzungwensis*) is known only from a single forested area on the Udzungwa Mountains, and the Uluguru bush shrike (*Malaconotus alius*) is confined to one forest reserve on the Uluguru Mountains, which covers less than 100 km<sup>2</sup> forest area. Others occur on several mountains.

These include the Usambara eagle-owl (*Bubo vosseleri*), banded sunbird (*Anthreptes rubritorques*), and Mrs Moreaus warbler (*Bathmocercus winifredae*). Other more wide ranging species are generally shared with mountain forests further to the south in Malawi and Zimbabwe, or with lowland coastal forests of the Zanzibar-Inhambane coastal mosaic.

Amphibians and reptiles also exhibit high levels of species endemism. Notable among the 25 species of strictly endemic amphibians are species within the reed frogs (*Hyperolius* – five endemic species), forest treefrogs (*Leptopelis* - two endemic species), tree toads (*Nectophrynoides* – five endemic species), species in the Microhylidae family (four endemic species), and the Caeciliidae family (five endemic species). New species continue to be discovered in this ecoregion. The strictly endemic reptiles include ten species of chameleons (seven *Chamaeleo* and three *Rhampholeon*), three species of worm snakes (*Typhlops*), and six species of colubrid snakes in four genera.

Up to 80% of the invertebrate fauna of a single eastern Arc Mountain can be strictly endemic, with the next mountain along containing a similar high rate of strictly endemic species.

As well as many endemic animals species there is also a rich collection of endemic plants. It has been estimated that there are over 2000 plant species in 800 genera (Lovett and Wasser 1993). At least 800 of these species are believed to be endemic to this ecoregion. The forests are the centers of global endemism for the African violet (*Saintpaulia* sp.) and Busy Lizzies (*Impatiens* sp.), which have been widely cultivated for houseplants in Europe and America. When considered together with the Northern Zanzibar-Inhambane coastal mosaic ecoregion, the density of plant species endemism is among the highest in the world (Myers et al. 2000). There are also high rates of endemism in the non-vascular bryophytes, including 32 known strict endemics and a number of near-endemics, some shared with Madagascar. These endemic plants are not only found in the forests, but also in the montane grasslands, wetland areas, and on rocky outcrops.



**Figure 3-5: African purple violet**

### 3.5 Conservation

Uganda, Kenya and Tanzania, where the Eastern Arc Mountains are located, are experiencing rapid ecological and economic changes. These countries are striving for sustainable economic growth, while simultaneously advocating both the conservation of existing habitats and protection of the processes and species that maintain ecosystem stability. Currently, these goals are not compatible, as demand for food and materials are growing at a rate that exceeds the growth in the sectors that provide these products. The East African forests are especially vulnerable because they provide important resources.

Deforestation in East Africa averages 1.2% per year, mainly because of the demand by local people for building material, firewood and agricultural land. Forest habitat has generally been lost on all lower slopes in the Eastern Arc, and has also been lost at higher elevations in some blocks (e.g., for tea plantations in the Usambaras and the Udzungwas). The German administration's creation of forest reserves in the late 1800s was an important step in protecting the forests, which at that time were described as 'largely vanished' and 'very sad'. These measures have helped prevent the total loss of forest in some areas, although losses of significant areas of forest have continued (for example, in the West Usambaras when forest was degazetted and converted to farmland). Evidence from the Udzungwas also indicates settlement on land that is now forested, and hence there currently may be more forest in this area compared to 100 years ago.



**Figure 3-6: Slash-and-burn forest clearing**

The habitat is naturally fragmented in the main forested blocks. However, it has also become substantially more fragmented in recent centuries due to the activities of man. The favourable climate, good supply of water and building materials, and reasonable soils have attracted humans to these mountains for the last 2000 years. Reliable access to markets (to sell agricultural products) is an important driving force in these movements both to and from the mountains. The human population is also increasing in many areas at around 2.8% per annum, which is placing increased pressure on existing farmland, and is spurring the conversion of unprotected forest and grassland areas to farmland.

Estimates suggest that more than 70% of the original forest cover has been destroyed and only about 5400km<sup>2</sup> of forest remain on the mountains. Conserving these forest habitats is very important for the global community and for the people of Tanzania. Most of the

remaining forests are within government forest reserves. These government forest reserves are poorly funded and have few staff, however they provide the mainstay for conservation in the area. Since 1998 local people often supported by civil society organisations have been increasingly involved in the management of the Eastern Arc Forests.

An important motivation for conservation of forests and attractive ecosystems in general is ecotourism: it is non-extractive, and has the potential to yield large profits. Additionally, there is an important economic motivation to maintain and invest in biodiversity.

### 3.6 Udzungwa National Park



Udzungwa is the largest of the Eastern Arc blocks stretching across four Districts in central Tanzania. The Udzungwa Mountains rise to 2230m and there is a large plateau area above 1500m. There are at least 146 villages in the Udzungwa Mountains, containing at least 700000 people. The Udzungwas contain a number of reserves in different management categories. The highest level of protection is found in the Udzungwa National Park which is located in the Kilombero and Kilolo Districts and covers 190000ha. Lower levels of protection are found in Forest Reserves under central, local and village government management.

The vegetation of the Udzungwa Mountains ranges from lowland forests, through sub-montane, montane and to upper montane forests. There are also extensive areas of montane grassland of various types, montane wetland areas, and heath lands. At lower altitudes the vegetation grades into various forms of woodlands.

An extract from the Udzungwa NP website: *“Udzungwa Mountains National Park is one of Tanzania’s most outstanding, pristine, paradise and unique exciting wilderness mountains forested with greatest altitudinal range of forest. It is one of thirty-four “World Biodiversity Hotspot” and one of 200 WWF Ecoregion of global critical importance. The park is home of primate and known from the treasure of high biodiversity of plants and animals. The park has high density of endemic species with some plants and animals that are only found in these mountains nowhere else in the world can be found hence center for endemism in the eastern arc mountains. Udzungwa Mountains National Park is part of the Eastern Arc Mountains, which is a series of mountains ranging from Taita Hills in Southern Kenya to the Makambako Gap in Southern central of Tanzania... .. “Udzungwa” which is the name of the area is probably a linguistic corruption possibly by the Germans of the word “wadsungwa” one of the tribe who live on the slopes of the Mountains. The park has Cultural and Historical sites such as Bokela*

(mountain God), Mwanaruvele cave, Magombereka cave, Nyumbanitu and Ndundulu mountains.” (www.udzungwa.org)



**Figure 3-7: Grey Faced sengi**

Udzungwa contains several endemics such as the Udzungwa red colobus monkey (*Procolobus gordonorum*), the Sanje crested mangabey (*Cercocebus galeritus sanjei*), the Udzungwa partridge (*Xenoperdix unzungwensis*), the *Galago galagoides* and the Rufous-winged sunbird (*Nectarinia rufipennis*). Even as recently as 2008, a new endemic species of giant elephant-shrew or Sengi was described: the Grey Faced sengi (*Rhynchocyon udzungwensis*). This was the first discovery of a new giant elephant-shrew since 126 years.

The National Park combines nature conservation with an important social role. It aims to incorporate the values and interests of conservationists as well as the local people, and recognizes cultural traditions. For instance: leaves, bark and roots from many plants are allowed to be collected for medicinal use, but under supervision of the National Park organisation.



**Figure 3-8: Map showing Uluguru, Mikumi and Udzungwa**

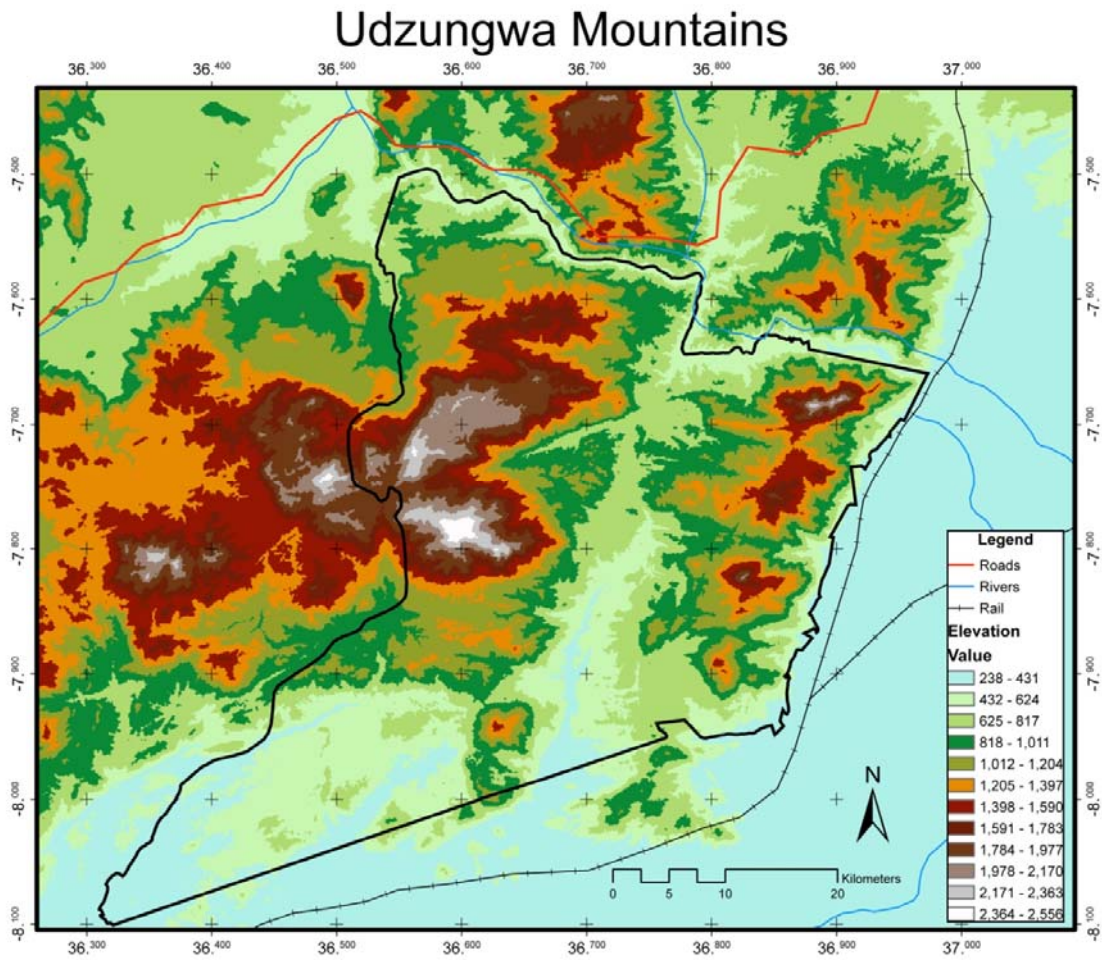


Figure 3-9: Udzungwa Mountains National Park

## **Chapter 4: Coastal Forest**

*“ Het is een bizarre, vrijwel verzonnen wereld waar we doorheen waden;  
één grote bomen- en struikenfabriek, ingenieus van ontwerp en met allerhande  
oplossingen voor onleefbare omstandigheden.. ” -Ramsey Nasr*

### **4.1 Introduction**

Coastal forests are ancient tropical forests that have occurred on the coast of Eastern Africa for millions of years. Originally stretching extensively from the south of Somalia to the south of Mozambique, they now only occur in isolated patches, with a total area of about 3167km<sup>2</sup> (Somalia: 2km<sup>2</sup>, Kenya: 660km<sup>2</sup>, Tanzania: 697km<sup>2</sup>, Malawi: 16km<sup>2</sup>, Zimbabwe: 3km<sup>2</sup>, Mozambique: 1790km<sup>2</sup>). Most of these patches are small (< 20km<sup>2</sup>), and all but 19 are under 30km<sup>2</sup>.

Although these forests are tropical, they are not rainforests because of the large annual variation in rainfall: most rain falls during a period of 4-5 months, which is in stark contrast with a period of 3 months (July-October) that is very dry. Actually, this is the main feature that separates the tropical coastal forests from the tropical rainforests, and as we shall see this difference has some important consequences.

Coastal forests are important but threatened ecosystems. They are centres of biodiversity on a global as well as a local scale, and exhibit high levels of endemism.

### **4.2 Description**

A forest can be defined as “a continuous stand of trees, with a canopy layer more than 6 meters high and where crowns overlap or touch”. Additionally, tropical forests often contain lianas, usually have a shrub layer, a sparse or absent ground layer, and a wealth of epiphytes. Below then are the qualities that define *coastal* forests:

- Located on the coastal plains bounded by the Eastern Arc Mountains on the west and the Indian Ocean on the east.
- Patches separated by semi-arid ecosystems
- Lowland (max. alt 500m near the coast, max alt. 1000m more inland)
- Under influence of the Indian Ocean climatic system. This translates into:
- Annual rainfall between 800-2000mm
- Rainfall strongly seasonal with 1 dry season of 3-5 months
- Temperatures between 25-30°C year-round
- High levels of floral and faunal endemism and near-endemism



**Figure 4-1: Giraffes in Saadani National Park**

### **4.3 Current conservation status**

It is unknown exactly how extensive the area of coastal forest has been in the past, but it is clear that starting around 200,000 years ago and increasing ever since, the growing number of humans has not left the coastal forests unscathed. Because of the dry nature of the forest it has always been more susceptible to burning and thus more attractive for agriculture. Logging and burning has strongly influenced the forest. For this reason, the coastal forests are now found only as islands surrounded by savannah-woodland, coastal thicket, the occasional wetland, and farmland.

### **4.4 Why coastal forest?**

This paragraph explains how climate, topography, geology and soil are collectively responsible for determining the distribution and type of coastal forest.

#### **4.4.1 Climate**

History: Because there have been variations in African climate in the long passed past, coastal forests have at times been able to reach more inland and connect to the Central- and West-African rainforests, which can still be seen in a number of shared plant species. This tropical connection ceased to exist about 20 million years ago, when the uplift of the Central Tanganyikan Plateau isolated the coastal forests from the rest of the African forests.

Another important factor influencing the ecosystem has been the occurrence of stressful dry

periods. During these periods, the coastal climate always ensured wetter conditions than many other parts of Africa, which has allowed the coastal forests to persist. This isolated persistence made the coastal forests into a refuge for many forest species, consequently allowing the evolution of large numbers of endemic animal and plant species.

Currently: because of the strong seasonality and the occasional extremely long dry periods (sometimes the rains fail), coastal forests experience very stressful conditions. Furthermore, the forests have a somewhat different microclimate than their surrounding grasslands: while in the adjacent areas temperatures change quickly during the day and night but stay within 25-30°C limits (> 20°C at night), they fluctuate less strongly within the forests and during daytime generally are about 10°C cooler than the surrounding, more open areas. A similar pattern is seen for humidity: whereas humidity in forests remains around 100% after rains, humidity in the surroundings decreases rapidly after rains. Near the end of the long dry season however, these differences fade and the forest microclimate becomes less different to that of the surroundings.

Considering this unique nature of the forests, it is not surprising that many plant and animal species living in this ecosystem have evolved adaptations to these specific conditions. Combined with the isolated nature of the forest patches, this resulted in high levels of endemism, as discussed below.

#### **4.4.2 Topography**

Because rainfall increases at higher grounds (uplifted air cools down causing relative humidity to drop and rain to form) forest vegetation can develop in those areas. At altitudes below ±500m this has coastal forest development as a consequence, while at higher altitudes midaltitude forests will develop. This can clearly be seen in the Eastern Arc Mountains (e.g. Udzungwa, Uluguru, Usambara): the coastal forest occurs at the somewhat lower altitudes and gradually changes into midaltitude forest and eventually afro-montane forest. Another consequence of the high rainfall and harsher mountain conditions is that farming is more difficult, which in turn discourages clearing of forest for agriculture.

In low-altitude areas with sufficient rainfall, conditions can also be good for coastal forest growth. This is either associated with the presence of rivers, or with a higher-rainfall-location which can be the base of mountains or the region immediately adjacent to the Indian Ocean where rainfall is higher (e.g. Saadani).

#### **4.4.3 Geology and soil**

Rock type influences soil formation, which in turn can have an influence on vegetation. The limestone that occurs near the coast has been deposited during the last interglacial 130000 years ago, and the rocks further inland generally originate from the Miocene-Pleistocene (27 to 2 million years ago) but there are also patches of Jurassic and Cretaceous silts and limestones (206-65 million years ago). This geological variation, combined with rainfall regime, position, past disturbance and fire regime causes the soils to vary strongly, which in turn causes vegetation to sometimes vary in parallel. In the Arabuko-Sokoke forest in Kenya for instance the vegetation on dry sandy soils (deciduous *Brachysyngia spiciformis* forest) is

very different from the vegetation on adjacent red lateritic soil (semi-evergreen *Cynometra webberi* and *Manilkara sulcata* forest).

#### 4.5 Ecology and biodiversity

Coastal forests contain over 4500 species in 1050 genera, of which 3000 species are confined to the forest habitats. About 768 endemic species have so far been inventoried. The highest rates of endemism are found in the forest molluscs (68%, n=86), reptiles (55%, n=26), plants (37%, n=550), butterflies (20%, n=79) and amphibians (14%, n=2). Mammal (5.5%, n=11) and bird (10.5%, n=9) endemism is lower. There are about 4050 plant species, 633 bird species, nearly 200 mammal species (11 endemic), 250 reptile species, 85 amphibian species, 220 fish species (>30 endemic). Numbers of invertebrates are unknown, but are thought to be very large, going in the tens of thousands, with high levels of endemism. The coastal forests further contain a number of iconic threatened species such as the black rhino (*Diceros bicornis*), the Savanna elephant (*Loxodonta africana*) and the Wild dog (*Lycaon pictus*).



**Figure 4-2: Hymenaea verrucosa**

Coastal forests contain about 0.2% of global species. Although in itself a small number, this does mean that biodiversity in the coastal forests is highly related to the land area. Again because of the patchy forest distribution, most of the endemic species have a focal distribution and do not occur widely throughout the coastal forest area. There are currently 333 coastal forest species categorized as globally threatened (IUCN Red list), 307 of which occur in Tanzania.



**Figure 4-3: Procolobus kirkii**

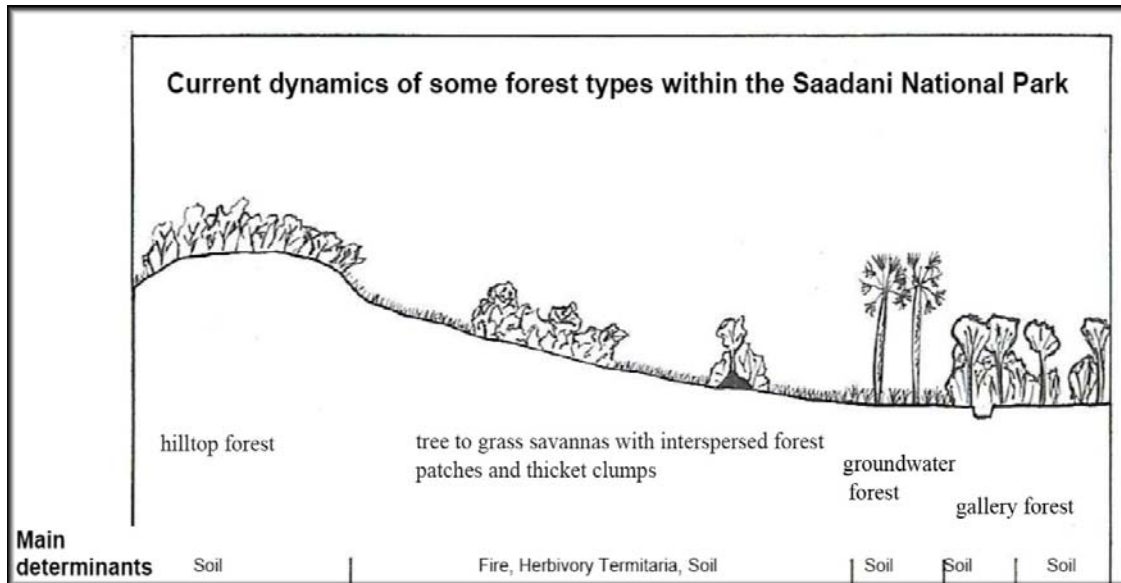


**Figure 4-4: Rhynchocyon petersi**

Of the coastal forest flora, 44% of plants are endemic, and 48% of the species are trees, which is what gives the forests their typical nature. It is therefore not surprising that the forests can be categorized into several different types of forest, where the dominant species change between types and patches:

- Hilltop forests: usually 1-5ha, containing gaps made by elephants; soil here is the driest of all forest soils; over 18 possible tree species, but each forest patch has its own dominant tree species.

- Forest patches and thicket clumps: variable size and on different slopes; heterogenous structure; dominant species differ from those found on the hilltops.
- Gully forests: consist of forest patches and thicket clumps.
- Groundwater forests: occur on permeable sandy silt valley soils; high groundwater level; highest biodiversity (average of 35 species); can also occur on sandy well-drained soils, in which case monospecific stands of African fan palms (*Borassus aethiopum*) can be found.
- Gallery forests: occur along watercourses in flat areas; narrow bands of forests (10-20m); plant composition is highly variable depending on the riverbed and scree; stand height is about 20m with a low canopy density; dense shrub layer.
- Large isolated trees: within the open patches of savanna-woodland and grassland, often *Sterculia appendiculata*.



**Figure 4-5: Coastal forest types**

#### 4.6 Conservation and human impact

As is the case with many other (tropical) ecosystems, coastal forests are threatened and their conservation has become a high priority. Human-caused problems and threats are numerous. Forest clearance for agriculture occurs in most unprotected areas as well as in a few reserves, unfortunately. Clearing is done by ring-barking large trees and then burning using shrubs and small trees piled around it. After the burning, crop yields are high during the first years but decline afterwards. Removal of timber for building material, touristic carvings and fuelwood is another big threat, which seriously damages the ecosystem through the negative effects on structure, regeneration potential and species composition. Because of changes in canopy structure for instance, many canopy-dwelling animals are affected and being replaced by non-

forest species. Additionally, coastal forests are particularly poor in native pioneer species, which gives the forest an inherent low regeneration potential. Removal of larger trees further increases fire risk because of an increased abundance of smaller, less fire-resistant tree and shrubs.

Bushmeat hunting is unfortunately still common in the forests, and a wide range of animals is considered possible prey (yellow baboon, Sykes monkey, colobus, hippopotamus, duiker, primate, elephant-shrew, bushpig, giant pouched rat, ...).

#### 4.7 Saadani National Park

An introduction cited from the Saadani National Park website:

*“Located in the centre of the historic triangle of Bagamoyo, Pangani and Zanzibar, Saadani National Park covers 1100 km<sup>2</sup>. It is the only wildlife sanctuary in Tanzania bordering the sea. The climate is coastal, hot and humid. It offers a unique combination of both marine and mainland flora and fauna in a culturally fascinating setting. About 30 species of larger mammals are present as well as numerous reptiles and birds. Besides many species of fish, Green turtles, Humpback whales (nyangumi) and dolphins (pomboo) also occur in the ocean nearby. Gazetted in 2005, it encompasses a preserved ecosystem including the former Saadani game reserve, the former Mkwaja ranch area, the Wami River as well as the Zaraninge Forest. Many villages exist around the boundaries of the Park. In 1969, when Saadani Game Reserve was officially created, Saadani village elders were consulted and the loss of cultivated land was compensated for. Before being included in the national park, the Zaraninge Forest was managed by the World Wide Fund for Nature (WWF) whose goal was to preserve the extremely high botanical diversity of one of the last coastal rain forests remaining in Tanzania. The Mkwaja area is the reminder of a large cattle ranch which has been run from 1952 to 2000. The presence of many dams and paddocks attest to the former existence of the ranch.”* (saadanipark.org)

Some animals occurring in the area: elephant (*Loxodonta africana*), leopard (*Panthera pardus*), Greater Kudu (*Tragelaphus strepsiceros*), the small Suni antelope (*Neotragus moschatus*), Duiker (*Cephalophus sp*), Colobus monkey (*Colobus guereza*), galago (*Galago sp.*), buffalo (*Syncerus caffer caffer*), hartebeest (*Alcelaphus lichtensteinii*), waterbuck (*Kobus ellipsiprymnus*), warthog (*Phacochoerus aethiopicus*), giraffe (*Giraffa camelopardalis*), lion (*Panthera leo*), hyena (*Crocuta crocuta*), vervet monkey (*Cercopithecus aethiopicus*),... Not all large mammals that can be seen in Saadani NP are indigenous: for some time the Game Reserve included a zoo and when that was closed down in 1977, some of the species originally from other regions in Tanzania were simply released: White-bearded wildebeest (*Connochaetes taurinus albojubatus*), Plains zebra (*Equus burchelli*) and Eland (*Tragelaphus oryx*).

Hilltop forest, gallery forest, and gully forest are the forest types that can be found in the area besides *Brachystegia* and *Acacia* woodland, coastal thicket, swamps and mangrove.

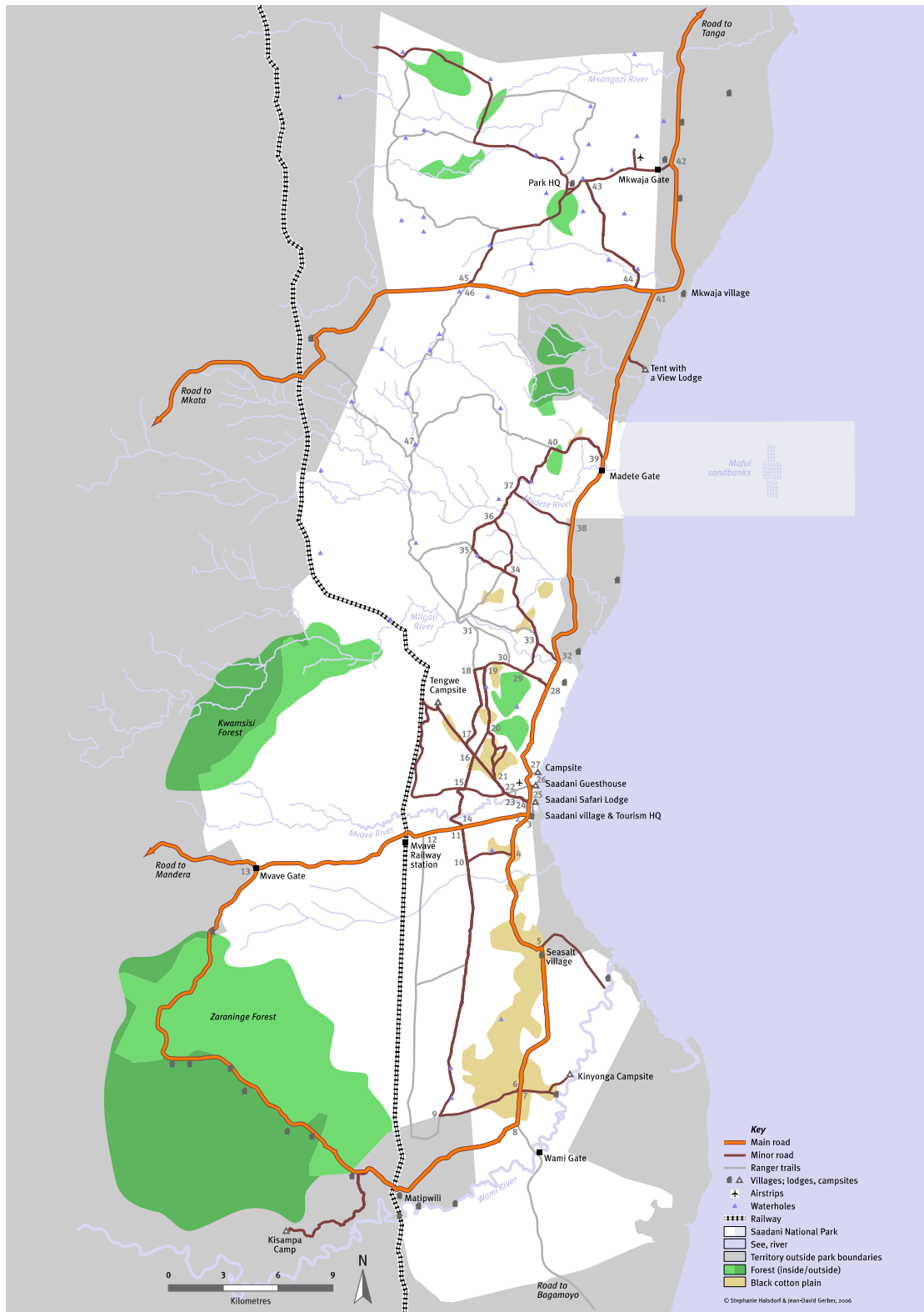


Figure 4-6: Saadani National Park

## **Chapter 5: Mangrove Forests**

### **5.1 Introduction**

Mangroves are trees that live in the intertidal region and have developed special adaptations to cope with this challenging environment. The intertidal region is the zone of the shore between spring and neap tide. Daily, the sea level changes between high tide and low tide, so that plants occurring in the intertidal zone are inundated for varying hours per day with salt water. At full moon occur spring tides, which are even higher than the usual high tides, while at new moon there is a neap tide, when the water level is at its very lowest. Depending on the climate, wind and wave action, different ecosystems develop in the intertidal region. Where there are a lot of waves, the earth's surface is eroded until rocky shores are left, and the erosion particles create sandy beaches elsewhere. In areas that are sheltered by wind, plants can establish and flourish. In tropical areas these plants are mangroves.

There are 54 species of mangrove trees acknowledged worldwide, grouped in 20 genera and 16 families. They do not form a monophyletic group; the mangrove habit evolved many times independently and not via common evolutionary descent.

Species from the Atlantic coast of Africa are different from those of the Indian Ocean coast; no species occur on both coasts. This is probably due to the barrier of cold water around the Cape of Africa, inhibiting dispersal, as you can find West African mangrove species on the Atlantic coast of the Americas and East African mangroves throughout the Indian Ocean and South-east Asia.

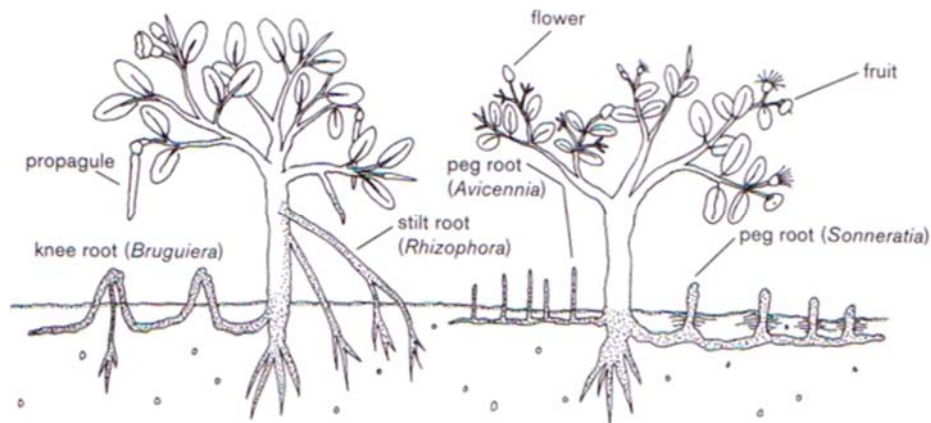
Only eight species of mangrove, from 8 different genera, occur in East-Africa, a relatively low level of diversity when comparing to other forest types.

### **5.2 Mangrove strategies**

The challenges that mangrove trees have had to overcome are not easy; maybe that is why relatively few species have evolved with these capacities and radiation never took place.

#### **5.2.1 Inundation**

In the intertidal zones, plants are inundated twice a day and the water level varies even more between spring and neap tide. To cope with these variations many mangroves need to anchor themselves well, not just for this vertical difference in water levels, but also against wave action and sometimes because the soil in which the plant grows may be a soft sediment, such as thin mud. Silt or prop roots, such as those in *Rhizophora*, give a very stable support system (fig. 1). In *Avicennia*, underground root systems spread far and wide - wider than the crown. To a lesser extent do buttresses give additional stability and occur in many species such as *Ceriops*, *Heritiera* and *Lumnitzera*.



**Figure 5-1: Schematic morphology of mangrove trees, showing different root types**

### 5.2.2 Varying salt concentrations

The eight East African mangrove species all have developed different ways of either getting rid of all the excessive salt or avoiding taking it up in the first place. A good first step is to reduce the amount of water the tree needs. *Lumnitzera*, for example, has almost succulent leaves with a thick cuticula so that water loss through evaporation is severely reduced. They also have loosely packed cells to store water, so that finally the salt concentration inside the tissue does not exceed the limits.

*Avicennia* and *Laguncularia* actually secrete very high salt concentrations actively through their leaves using special secretory glands. During the dry season the salt crystallizes on the leaves and at night, when humidity is higher, the salt dissolves and drips off (fig. 2).

*Rhizophora* have special suberine membranes through which water can flow in, but cannot flow out. Because of the negative osmotic pressure inside the root tissue only water can pass through the tissue side, excluding the salt from the sea water.

*Lumnitzera* and *Laguncularia* store salt crystals inside the leaves, eventually shedding the leaves with the excess salt.

Mangroves on the sea margin of the mangrove forest obviously have to cope with high salt levels. On the landward margin of the mangrove, sea water comes in only at the highest spring tides. However, the sea water then evaporates, leaving a salt concentration in the soil that is much higher than in the sea itself. But then when the rain comes the salt is leached away so that the soil returns to a low salt concentration. Therefore these plants have to deal with an enormous range of salt concentrations. *Avicennia* and *Ceriops* have the highest resistance against fluctuation in salinity, *Rhizophora* and *Sonneratia* have an average resistance, and *Brughueira* and *Lumnitzera* do not resist variation in salt concentration well at all.



**Figure 5-2: Leaf of *Avicennia* with excreted crystallized salt**

Much of the salt disappears through evaporation or transpiration, but this costs water; in high rainfall areas there might be enough fresh water to cover for this, but in low rainfall zones other sources of fresh water, such as rivers, are needed. Therefore in the drier parts of Africa mangroves are restricted to river estuaries.

### 5.2.3 Low oxygen levels

Mangrove trees, like most plants, can only get oxygen and carbon dioxide from air. During high tide, conditions are virtually anaerobic but even at low tide the soil can get waterlogged so that very little oxygen is available for the roots. In the stem and twigs you can find special aerenchyma tissue that can store air, and there are pores in the bark (lenticels) through which gases can flow. Many mangrove trees have parts of their roots above the surface. Aerial roots, which you can also find in other plants such as epiphytes, are called pneumatophores. They come in various shapes and forms (Fig. 1). Stilt roots start from the stem and find their way to the ground (e.g. *Rhizophora*). Knee roots are bent with the bends protruding from the soils (*Bruguiera*, *Ceriops*, *Lumnitzera*). True pneumatophores occur in *Avicennia*, *Sonneratia* and *Laguncularia*; these peg roots are composed of hundreds of finger like structures that prop up from the ground surrounding a mangrove tree. Some species roots are very big and ribbon like, so that they are never completely submerged under the soil. However they are not always aerial, as is the case with *Xylocarpus* and *Heritiera*. All these root types serve multiple roles in gas exchange and anchoring.

### 5.2.4 Dispersal and establishment

Naturally, all mangrove fruits or seeds are dispersed by water, but the part that is dispersed differs between species. In *Heritiera* and *Lumnitzera* it is the fruit that is the unit of dispersal; in *Heritiera* the dorsal ridge of the fruit actually functions as a sail. The fruit of *Sonneratia* and *Avicennia* splits soon after falling, and so both fruit and seed act as dispersal units. In *Xylocarpus* the fruit splits on the tree, so that the seed is the unit of dispersal.

Some mangrove trees take it one step further and optimize the chances of their offspring surviving in this variable, salty and anaerobic environment. It is one thing for an adult plant to survive this hostile environment, but another for a young seedling. The strategy of *Rhizophora*, *Ceriops* and *Bruguiera* is to have their seedlings develop for quite a reasonable time on the parent tree. The dropped seedlings will either hit ground under the parent tree and grow there, or float away in the tide. Either way, they will develop roots at a very fast rate as soon as they're stranded. The roots pull the seeds into an erect position.

Several other mangrove plants follow this strategy to a lesser degree, and can be called subviviparous: *Avicennia* and *Xylocarpus* have fruits in which the embryo will germinate before a quickly after release from the parent plant.

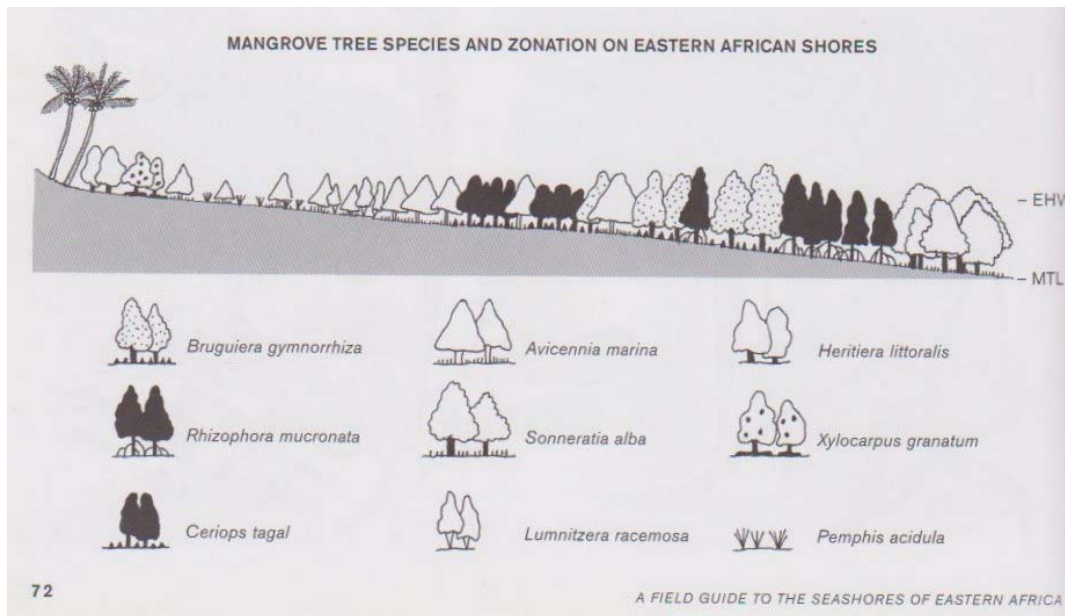
### 5.3 Zonation

The different strategies that the mangrove species have developed to overcome the intertidal environment resulted in subtle differences in preferences and tolerance towards soil type, salinity, lack of oxygen and the variation of these. This leads to a typical zonation pattern when a gradient of these conditions exist. Therefore the most diverse and complicated zonation pattern happens on shallow slopes by river estuaries. Along rivers there is less scope for zonation, and usually only a few species occur.

Dwarf and tall mangrove trees of the same species may also occur within a relatively small area, the first occurring in flat areas with high salinity, little fresh water flow and the second along river banks where fresh water lowers the salt concentration of the sea.

In the most diverse mangrove areas of the Indian Ocean coast, *Avicennia* and *Sonneratia* are generally the pioneers, though usually only one of these forms the seaward zone: *Avicennia* seems to prefer sand, while *Sonneratia* prefers fine silt, mud and firm substrates. *Rhizophora* is dependent on mud, and will not tolerate salinity higher than sea water, therefore it often forms stands at river mouths. *Bruguiera* is most tolerant of fresh water and occurs where the water table is high; it can be very common in rain-rich coasts. *Ceriops* is the main species of drier areas, while *Lumnitzera* and *Xylocarpus* are the most landward, though stunted *Avicennia* can occur where there is a zone of very high salinity, which are mostly rarely inundated areas.

A typical zonation pattern is formed by pure stands of *Sonneratia alba* in deepest water, followed by a belt of *Rhizophora mucronata* where there is slightly higher salt concentration. Sometimes a narrow belt of *Ceriops tagal* is present, also along small channels far into the next zone. In brackish water along river mouths *Rhizophora* is often the most common species. Along creeks there is a fringe of *Rhizophora* and *Xylocarpus*. *Bruguiera gymnorhiza* occurs scattered throughout the *Rhizophora*, *Ceriops* and *Avicennia* zones. The most landward zone, with the shortest inundation period, is formed by bushy *Avicennia marina*, together with some *Lumnitzera racemosa*, *Heritiera littoralis*, *Xylocarpus granatum* and *X. moluccensis*. In this *Avicennia* zone salt concentration is similar to that of the sea during high tide, but can be much higher during low tide. Behind the *Avicennia* zone, on the soil side, the salt content of the soil varies so greatly that vegetation is often almost absent; this zone is flooded only twice a year. Please see fig. 3 for a general zonation picture and the appendix for an overview of the different species that occur in East Africa.



**Figure 5-3: Typical zonation pattern of an East African mangrove**

## 5.4 The mangrove ecosystem, its services and its threats

Mangrove forest ecosystems exhibit a high net productivity, especially when compared to other intertidal systems. Many small animals, such as crustaceans, molluscs and fish are a permanent part of the mangrove ecosystem, feeding on fallen leaves, seeds and detritus. They probably also play an important role in the maintenance of the mangrove forest and its composition. Because animals such as crabs make burrows and crevices they increase the oxygen levels in the soil. Many intertidal animals exhibit zonation pattern themselves, obviously due to the differences in tolerance towards varying salt concentrations and oxygen levels. Their burrowing activity and the predation on mangrove propagules may play an important role in mangrove establishment along the intertidal inundation gradient. Therefore, the zonation patterns we see in mangrove species are most likely caused by complicated interaction between abiotic and biotic components of the ecosystem.

During the high tide, masses of marine animals move into the mangrove to feed and reproduce. Many coral reef species and crustaceans such as lobsters and prawns rely on the mangrove as nursery grounds for their juveniles. After a protected youth with lots of food they move into the open water as adults, only to come back to the mangrove to reproduce. In the Caribbean it was shown that the presence of mangroves strongly influences the community structure of neighbouring coral reefs. Moreover, the biomass of several commercially important fish species increased enormously when mangrove forests (that these fish use as nursery grounds) were connected to the adult habitats.

Apart from nursing many edible fish, mangrove also provide other important services to humans, but these are often only visible after the mangrove have disappeared. Like other

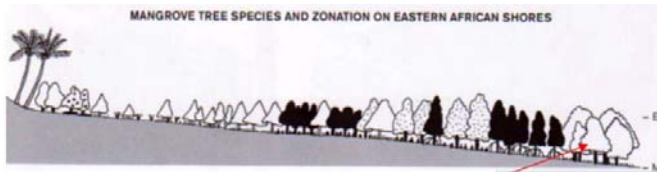
wetland ecosystems, mangrove forests provide a strong buffer zone against coastal storms. They prevent erosion from coasts and actually cause sedimentation, thus building new land. The mangrove wood provides a good source of timber and charcoal.

Nevertheless, mangroves are one of the most threatened ecosystems in the world. In the last 50 years between 33% and 50% of all mangroves have been lost, and currently the rate of mangrove deforestation exceeds that of rainforests at 2.1 per year %.

Coastal habitats are always threatened by human expansion. Many human urban areas are built on the coast and preferably sheltered from too much wind and wave action and near a river mouth. In the tropics, it is the same area that mangroves grow in. Many coastal towns in Africa, such as Freetown, Abidjan, Lagos, Durban and Dar es Salaam have developed at the expense of mangrove forests. Nowadays many tourist hotels are built in mangrove areas; and the growing population has led to increased pollution from industry and agriculture. The most pressing problem however is tree felling for fuelwood and building material; at the moment the mangrove is over-exploited. The wood cutting is hardly ever done in a sustainable way: deforestation is possible when you allow time for natural regrowth, perhaps in combination with replanting. In Kenya for example, around 70 percent of the people living on the coast rely on mangrove poles for construction.

Changes in the land use of mangrove areas can be detrimental to the mangroves. Dam construction results in irregular fresh water supplies reaching the coast, while salt pan construction and salt extraction alters the salinity level of the water.

## 5.5 Mangrove species



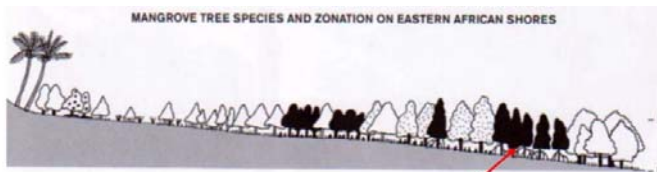
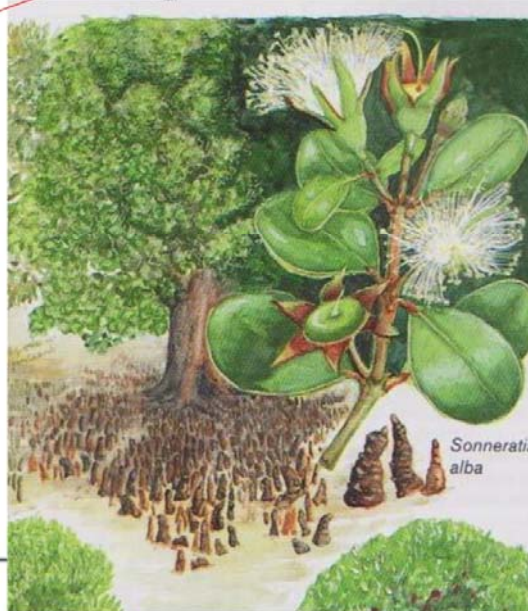
### 1) *Sonneratia alba*

MANGROVE APPLE

Swahili : Mlilana

Pioneer species

Extensive root system (peg roots) traps and collects the sediment  
⇒ soil becomes more compact and firm  
⇒ favourable to species succession



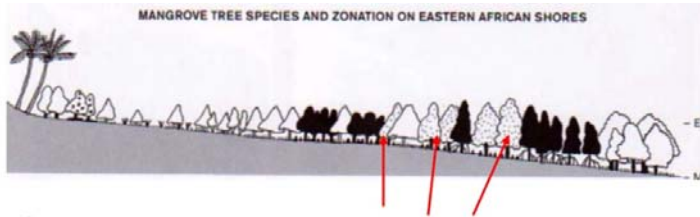
### 2) *Rhizophora mucronata*

RED MANGROVE

Swahili : Magoni

Prop/silt roots : octopus-leg appearance  
⇒ trap silt and mud , creating a much firmer soil  
⇒ ground (or bank) get higher and less submerged by sea water  
⇒ favourable to species succession

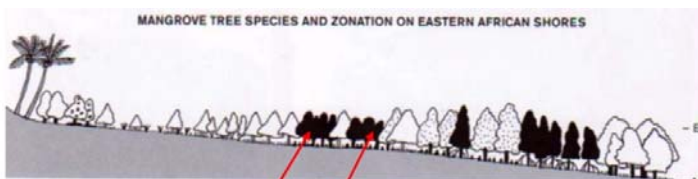




### 3) *Bruguiera gymnorhiza*

**BLACK MANGROVE**  
Swahili : Mshinzi, Muia

**ROOT :**  
Knee roots  
Sponge structure :  
keep air for efficient respiration even submerged  
=> trap silt and mud and modify the soil structure

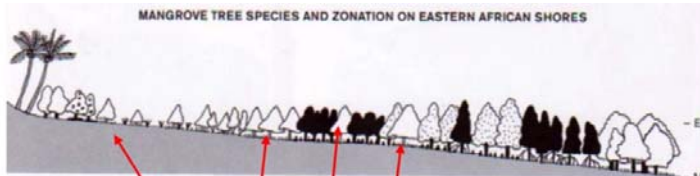


### 4) *Ceriops tagal*

**INDIAN MANGROVE**  
**YELLOW MANGROVE**  
Swahili : Mkandaa mwekundu

**ROOT :**  
Small buttress and knee roots

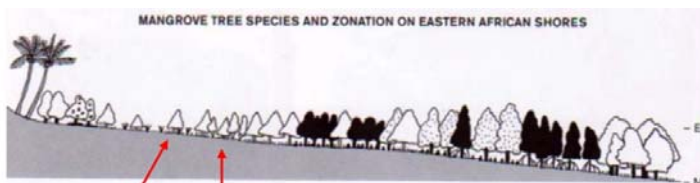




## 5) *Avicennia marina*

**WHITE MANGROVE**  
Swahili : Mchu

**ROOT :**  
Numerous narrow pneumatophore roots lenticel-equipped (+ closure)  
**SPECIAL FEATURE :**  
excretion of excess salts from the glands on leaf surfaces.

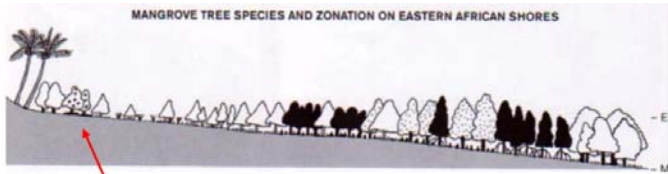


## 6) *Lumnitzera racemosa*

**SPRING-TIDE MANGROVE**  
**SANDY MANGROVE**  
Sawhili : Kikandaa

- No above-ground roots
- ⇒ More oxygen in soil
- Not viviparous





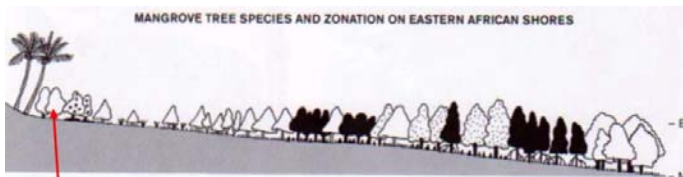
## 7) *Xylocarpus granatum*

**MANGROVE MAHOGANY**

Swahili : Mkomafi

**ROOT :**

Plank/ribbon roots, not aerial



## 8) *Heritiera littoralis*

**MOCAMBIQUE MANGROVE  
LOOKING-GLASS MANGROVE**

Swahili : Msikundazi

large plank roots, not aerial



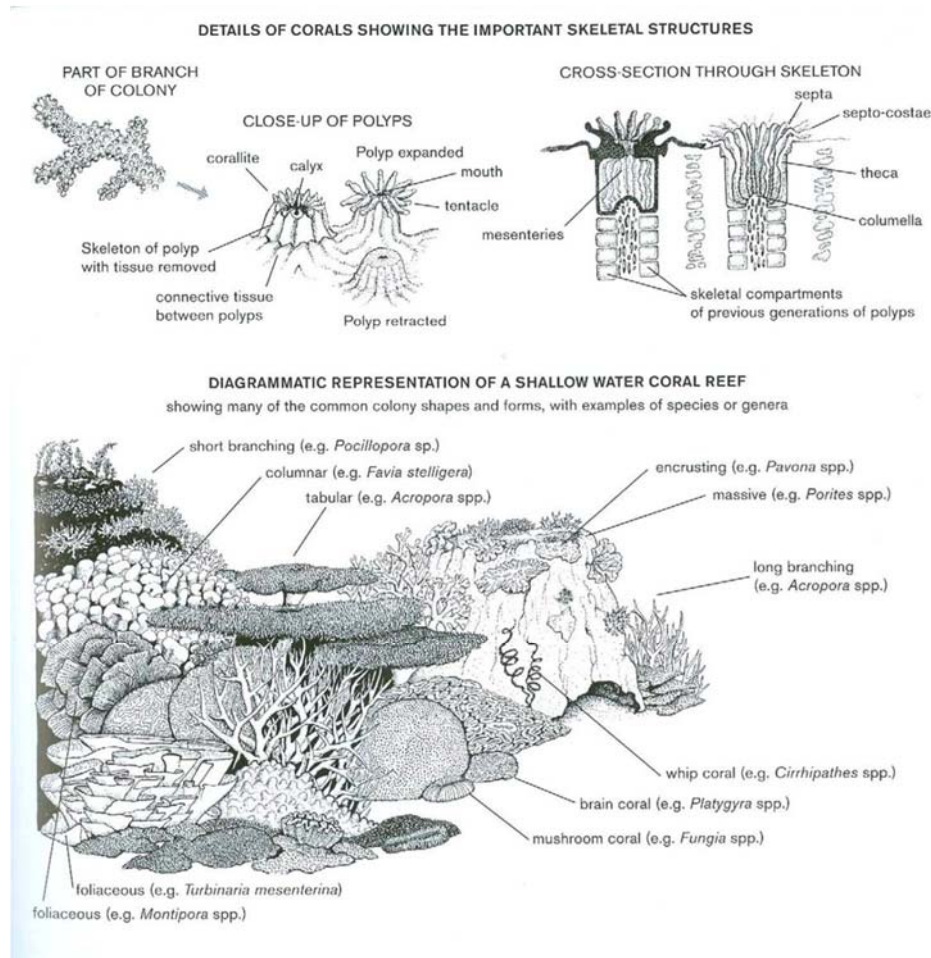
## **Chapter 6: Coral Reef**

### **6.1 Introduction**

Everybody knows coral reefs as highly colourful and vibrant ecosystems, in stark contrast to the large masses of dark, near empty deep-ocean. Indeed, coral reefs are hotspots of marine biodiversity; over 25 % of all marine species are thought to inhabit coral reefs. Thirty-two out of the 34 animal phyla occur in coral reefs; in comparison only 8 phyla occur in rainforests. They are also one of the most productive ecosystems in the world. Coral reefs consist of large formations of calcium carbonate (limestone), deposited by living marine organisms over thousands of years, its complex structure providing the foundation for an even more complex ecosystem.

### **6.2 The builders of the reef: Corals**

By far the most important group of organisms that create the limestone reef rock are members of the Scleractinia order (Class Anthozoa, Phylum Cnidaria). Like other calcium carbonate depositors, they convert calcium ions and carbon dioxide gases that are dissolved in seawater into solid calcium carbonate. These so called hard corals can be described as miniature sea-anemones embedded in their own secreted calcareous cup (figure 1). Most species occur in colonies that can become massive as they slowly deposit their exoskeleton at a pace of a few centimetres per year. These colonies and their deposits form the basis of coral reefs. The tiny living corals are all connected to each other, forming a sheet of tissue over the limestone surface. Each species deposits limestone into a unique shape, for example some coral colonies are tabular, some are branched into complex patterns, some resemble brains, and some are just amorphous crusts.



**Figure 6-1:** Close-up view of a coral colony and the polyyps it is made from; cross-section between a single coral polyp; overview of some typical coral shapes

Aside from the clonally growing of a coral colony, new colonies are started either by asexual reproduction through fragmentation (can be accidental by waves etc.), budding and the production of asexual planula larvae, but most often sexual reproduction is involved. Sperm and egg cells are released in great masses; so called spawning. Fusion and fertilization results in a planula larvae that will swim towards well lit surface water where it will start a new colony. In order to increase the chances of the gametes of different colonies to meet, spawning commonly occurs synchronously, with several coral species releasing their sperm and/or eggs at the same night triggered by a complex set of environmental cues.

Scleractinians fall into two main categories: Zooxanthellate and Non-Zooxanthellate. The former harbor symbiotic dinoflagellates, algae called the Zooxanthellae, in their endodermal cells. The algae get shelter and CO<sub>2</sub> from the corals, and provide them in turn with oxygen and sugar compounds. This enables the corals to grow as much as

three times faster than corals that do not harbor these symbionts; the Non-Zooxanthellate. The latter also often grow in typical coral structures, but they do not participate in actual reef building.

While the Zooxanthellae Scleractinia can be called the construction builders of the reef, Coralline algae living in non-zooxanthellae corals provide the cement to fill up all kinds of gaps and crevices. These algae deposit limestone in thin sheets over the reef surface, thereby strengthening it.

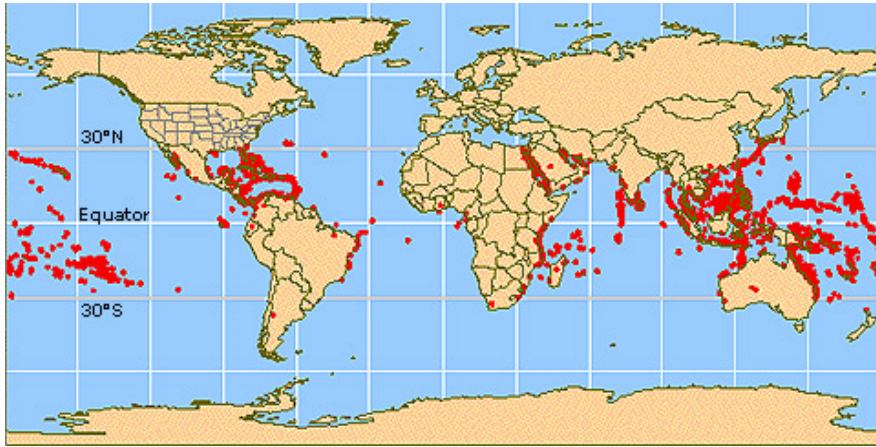
To a much lesser extent some other radiate animals (Phylum Cnidaria) contribute to the calcareous rock formations. The Gorgonacea colonies, the horny corals such as sea fans and sea whips, form large but slender and branched structures. Fire coral (*Millepora*) often looks like a mixture between coral and seaweed but actually belongs to the Hydrozoa class where species usually have a polyp or medusae shape. Like jellyfish, they contain nematocysts that shoot out venomous arrow-like structures when stimulated. When you touch a fire coral, you can have a painful burning patch for several days!

**Box 1.** Taxonomy of Cnidaria with reference to coral groups.

Phylum Cnidaria	
•	Cl. Anthozoa
–	Subcl. Hexacorallia
•	Sea anemones (o. Actinaria)
•	Stony corals (o. Scleractinia)
–	Subcl. Ceriantipatharia
–	Subcl. Octocorallia
•	Soft corals (o. Alcynacea)
•	Horny Corals (o. Gorgonacea)
•	Cl. Hydrozoa
–	Fire Coral ( <i>Millepora</i> )
•	Cl. Scyphozoa (Jellyfish)
•	Cl. Cubozoa (Box Jellyfish)

### 6.3 Distribution

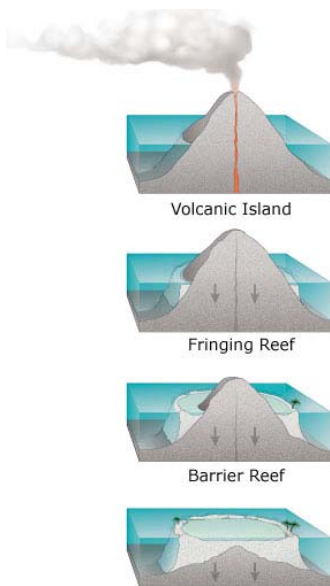
Coral reefs only occur where the appropriate conditions of light, temperature, salinity and nutrients are present. Indeed, light is needed for the algal symbionts to be able to perform photosynthesis. This restricts corals to live in clear, shallow waters in the tropics and excludes them from areas with an upwelling of cold water or near major river outflows (because of lower salinity and high turbidity). These restrictions are clearly visible on the map showing global coral reef distribution (figure 2). However, Non-Zooxanthellate corals do occur outside the tropics and at greater depths, as they are not dependent on photosynthetic symbionts.



**Figure 6-2:** Distribution of coral reefs around the world

Most current reefs were formed after the last ice age, which ended some 10000 years ago, when melting ice caused the sea level to rise, flooding the continents. The coral reefs that existed during this ice age became too deep, and thus perished. The breakdown and the erosion of these reefs is the calcium carbonate source of the white sandy beaches that occur around the tropics, attracting many tourists. Before the last ice age, sea levels were higher than they are today, so many ancient and eroded coral reefs occur on land nowadays. Large parts of the East-African coastline, including cities such as Mombasa and Dar es Salaam, were formed on calcium carbonate deposited by corals.

### 6.4 Types of coral reef



There are three main types of coral reef.

- *Fringing reefs* are close to a landmass with either no lagoon or a narrow lagoon between reef and shore.
- A *barrier reef* runs roughly parallel to shore and has a wider and deeper lagoon than a fringing reef.
- *Atolls* are reefs that encircle a lagoon, but no island is present. This strange appearance indicates the presence an ancient volcanic island.

Around a tropical volcanic island often a fringing reef will be formed. As volcanic islands are not seated on continental shelves, they tend to submerge. The fringing reef, however, stays put and while the island slowly submerges deeper and deeper down, the reef keeps on growing upwards, towards the light. Thus, a barrier reef is formed when just the tip of island is still above sea level and a wide lagoon is

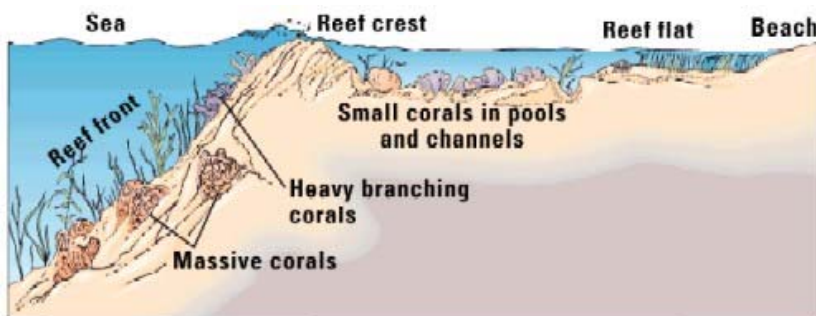
**Figure 6-3:** Atoll formation

separating land and coral reef. The final stage is the atoll, when the island is completely submerged below sea level and only the circular coral reef is still visible (Figure 6-3).

A common variant reef type is the *patch* or *bank* reef, which are isolated, quite small reef outcrops in places of the ocean where the sea bottom is elevated enough.

## 6.5 Reef zonation

Coral reefs can be divided into distinctive zones: the reef flat (or reef lagoon), the reef crest and the reef front (or fore reef). The reef flat is situated on the beach-side and is well sheltered from wind and wave action. Sand tends to sediment there and it is often exposed to air at low tide, so that it forms some kind of lagoon. Therefore, many sea weeds and sea grasses grow there together with small corals. The reef flat terminates in a shallow reef ridge or crest, which is exposed to a lot of waves, becomes dry at low tide and usually only algae grow there. Between the actual reef flat and reef crest there can be a somewhat deeper pool (that remains inundated at low tide) with a high diversity of small corals. After the reef ridge the coral reef gradually slopes down to form the reef front. This slope can be either very gradual or relatively abrupt. Corals grow bigger there as they do not risk to be exposed to the air at low tide, but also to reach the most light as possible. It's on the reef slope that you will find delicate plate coral forms, branching corals and sea fans. With increasing depth sponges get more dominant because lack of light limits corals to grow.



**Figure 6-4:** Schematic view of the major zones of a coral reef

## 6.6 Ecology

Coral reefs are one of the most diverse ecosystems in the world. Because of the complex physical structure of the coral-made limestone formations, a very diverse set of niches are available; this triggers speciation. However, the existence of the great diversity that we see today in coral reefs relies on a fine balance of a complex network of interactions

between the thousands of species and their physical and chemical environment. This balance and how a stable but diverse environment can lead to speciation is illustrated by an example in box 2.

Algae, corals, fish, snails, starfish, sea urchins and other invertebrates are among the most common animal groups on coral reefs and may number from just a few to hundreds of species per group.

Water motion, sunlight and nutrients are the most important physical and chemical sources for primary production. The main primary producers are benthic algae, the symbiotic dinoflagellates of coral, and, to a lesser extent, phytoplankton. Many species of algae fix nitrogen from dissolved  $N_2$  and nitrogen is frequently exported from coral reefs. Sea urchins are the dominant invertebrate grazers and parrotfish (of the Labridae family), rabbitfish (Siganidae) and surgeonfish (Acanthuridae) are the dominant fish grazers. Zooplankton, and fish that feed on it, such as damselfish (Pomacentridae), can be abundant in some reefs particularly on reef edges. Many species of fish such as sweetlips (Gaterinidae), scavengers or emperors (Lethrinidae), wrasses (Labridae), and triggerfish (Ballistidae) feed on invertebrates such as sea urchins, crabs and shrimp. Coral reefs also typically house a high diversity of piscivore fish, especially in deep open water reefs. These include groupers (Serranidae), sharks (Chondrichthyes), jacks (Carangidae) and barracudas (Sphyraenidae). Humans are also very effective predators of the coral reef inhabitants. As a final stage in the food web, detritivores such as sea cucumbers (Holothuroidea) eat the remains, the detritus, of other organisms.

Even though the reefs are one of the most productive ecosystems in the world, practically all the energy and nutrients are also consumed by its members and practically nothing is taken away to other marine areas.

### **Box 2. Many niches, many species**

A study of coexistence in sea urchins was undertaken in Kenya's reef lagoons to help determine how three closely related species manage to coexist while living close to each other and sharing similar food sources. The three species, *Diadema setosum*, *D. savignyi* and *Echinometra mathaei*, are the most common sea urchins of the Indo-Pacific. They eat the same food and occur in the same reef zones, but tend to reside in crevices that differ slightly in size, which corresponds to behavioural and morphological characteristics. Further, the species differed in their susceptibility to predation and competition power. The smallest species, *E. mathaei*, is solitary and defends self-created burrows from intruders. The intermediate sized *D. savignyi* is sometimes found in social groups but more frequently occupies larger, naturally occurring crevices and overhangs. The large *D. setosum*, lives most frequently in the open and in groups of individuals with intertwined spines.

Experiments on predation and competition showed there was an inverse relationship

between competitive dominance and predator susceptibility. The small *E. mathaei* is the top competitor but most susceptible to predation, so that it needs to stay hidden in burrows, making it possible for the larger, but less competitive species to thrive in the open.

So is predation a major force in promoting sea urchin coexistence, and therefore speciation? This idea was tested along a predation gradient. At lowest predation level, reefs were dominated by *E. mathaei* and other species were rare. At intermediate predation level, the highest number of species were found, each with an intermediate number of individuals. At the highest predation level, only a few cryptic species dominated the reefs. This experiment shows how a fine balance of interactions between the physical and biotic environment creates a subtle variation of habitat, competition and predation niches. When the presence of these niches is stable, a high species diversity is maintained.

## 6.7 Ecosystem services and threats

From a conservation point of view, coral reefs are the most important habitat of the ocean, as it contains the highest marine species diversity. Moreover, the reefs are a nursery habitat for many other fish that live elsewhere as an adult.

The ecosystem also serves humans in various ways. Reefs are natural protectors of beaches and coastlines from storm surges and waves, which reduces beach erosion severely. They also provide a good deal of the sediment that beaches and the soil underneath mangrove forests (whose roots are very efficient in capturing this sediment) are made of. Economically speaking, coral reefs provide the habitat for many commercially hunted fish as well as fish for the aquarium industry. Shells and reef pieces are often sold as ornaments. Nowadays, coral reefs form a very important tourist attractor. According to the WWF, the economic cost over a 25 year period of destroying one kilometer of coral reef is somewhere between \$137,000 and \$1,200,000. About 6 million tons of fish are taken each year from coral reefs. Well-managed coral reefs have an annual yield of 15 tons seafood on average per square kilometer. Southeast Asia's coral reef fisheries alone yield about \$ 2.4 billion annually from seafood.

As explained above, the high species diversity that coral reefs exhibit is entirely based on a fine balance of several factors. If one of the factors is disturbed, the whole ecosystem can collapse.

Many of the economic services the coral reef provides are also causing its destruction. Destructive fishing techniques (e.g. using dynamite), overfishing, over-collecting of ornaments and careless tourism are severe threats to the corals. Coastal people often use corals as building material; due to the slow growing rate of corals it is impossible to do this in a sustainable way.

Invasive predators can also cause serious damage to coral reefs. As sessile adults, corals spend their entire lives fixed to the same spot on the ocean floor. Certain predators have evolved to take advantage of this. Large sea stars like this Crown-of-thorns (*Acanthaster planci*) slowly crawl over coral reefs, consuming all of the living coral tissue that they come into contact with.

However, the biggest threat for coral reefs at the moment is global warming. Stress factors such as acidification of the ocean water, low tide air exposure, salinity changes, infectious diseases and in particular rises in temperature can reduce the coral's ability to maintain their zooxanthellate symbionts, which will lead to their expulsion from the coral's body. The result is called coral bleaching; the coral loses its colour and turns white, and will die as it no longer gets the necessary sugar compounds from its photosynthetic symbionts. Expulsion of the zooxanthellae occurs when the coral cannot provide them anymore with their share of the symbiotic deal (carbon dioxide and nutrients). Bleaching also occurs when the zooxanthellae die themselves, e.g. due to increased sedimentation levels and pollution and the resulting reduction of available light.

General estimates show that approximately 10% world's coral reefs are already dead. It is estimated that about 60% of the world's reefs are at risk due to destructive, human-related activities.

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## Selected Swahili words and expressions

GREETINGS AND EXPRESSIONS	
Hello (addressing a single person)	Hujambo? (the person answers: "Sijambo")
Hello (addressing more than one person)	Hamjambo? (the persons answer: "Hatujambo")
Hello (addressing an elderly person)	Shikamoo (the elder answers: "Marahaba")
What's up? (common and informal)	Mambo? (answer "Poa")
How are you?	Habari gani?
Goodbye	Kwaheri
Welcome	Karibu
Thank you	Asante
Please	Tafadhali
Excuse me	Samahani
No worries	Hakuna matata
Yes	Ndiyo
No	Hapana
Ok	Sawa
I like it	Ninaipenda
I don't like it	Siipendi
I am tired	Nimechoka
Give me...	Nipe..
What?	Nini?
Who?	Nani?
Where?	Wapi?
Toilet	Choo
Big	Kubwa
Small	Kidogo
Man	Mwanaume
Woman	Mwanamke (plural: Wanawake)
Boy	Kijana
Girl	Msitchana
Friend	Rafiki
Student	Mwanafunzi
Teacher	Mwalimu
Today	Leo
Tomorrow	Kesho
The day after tomorrow	Kesho kutwa
Yesterday	Jana
morning	asubuhi
midday	
late afternoon	jioni
evening/night	usiku
What is the time?	Saa ngapi?
07.00 h	Saa moja asubuhi
08.00 h	Saa mbili asubuhi
14.00 h	Saa nane mchana
17:00 h	Saa kumi na moja jioni
20.00 h	Saa mbili jioni

FOOD AND DRINKS	
Store/shop	Duka
Price	Bei
Money	Pesa
How much?	Ngapi?
To pay	Kulipa
Food	Chakula
Hot	Moto
Cold	Baridi
Water	Maji
Fruit juice	Maji ya matunda
Soft drink	Soda
Beer	Bia
Tea	Chai
Coffee	Kahawa
Milk	Maziwa
Sugar	Sukari
Chicken	Kuku
Meat	Nyama
Fish	Samaki
Eggs	Mayai
Rice	Wali
Potatoes	Viazi
Bread	Mkate
Pancake	Chapati
Bun	Andazi
Stiff porridge	Ugali
Cassava	Mhogo
Vegetables	Mboga
Fruits	Matunda
Banana	Ndizi
Oranges	Machungwa
I am vegetarian	Sili nyama
It is delicious	Ni tamu sana

FIELDWORK AND WILDLIFE	
Let's go!	Tuende
Stop!	Simama
danger	Hatari
by bus	na basi
on foot	kwa miguu
fast	haraka
slow	polepole
book	kitabu
telephone	simu
lamp	taa
mouse, rat	panya
bird	ndege
lizard	mjusi
insect	dudu
butterfly	kipepeo
ants	siafu
monkey	tumbili
baboon	nyani
buffalo	nyati
elephant	tembo
giraffe	twiga
zebra	punda milia
hippo	kiboko
lion	simba
leopard	chui
hyena	fisi
crocodile	mamba
snake	nyoka
tree	mti

COUNTING			
1	moja	10	kumi
2	mbili	20	ishirini
3	tatu	30	thelathini
4	nne	40	arobaini
5	tano	50	hamsini
6	sita	60	sitini
7	saba	70	sabini
8	nane	80	themanini
9	tisa	90	tisini
10	kumi	100	mia
		1000	elfu
11	kumi na moja		
12	kumi na mbili		
...	...		

