Minor Field Studies No. 74

The Baobab tree in Kondoa Irangi Hills, Tanzania

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Part I: Field study

Key words
Adansonia digitata, regeneration, size distribution, spatial distribution

Abstract

A short study was made on the regeneration and distribution of the Baobab tree, *Adansonia digitata*, in Kondoa Irangi Hills, Tanzania. About 300 individuals were mapped and measured in areas with different vegetation and land management, to try to find out what environmental factors influence population structure, the growth, regeneration and survival. Core samples were taken to calculate growth rates for different size classes, and to see if they correlate to rainfall data. Seed germination tests were carried out to simulate what the seeds may be exposed to naturally, e.g. fire, animal digestion or the common practice of making an alcoholic brew from the Baobab seed. Baobab population densities and regeneration were significantly higher in areas dominated by cultivated fields than in other areas. This was suggested to be due to protection against fire and grazing animals. Young Baobab individuals, ca. 20-70 years old, had a significantly higher growth rate (annual radial increase) than older individuals. This means that a population may hold fewer individuals in small size classes, and still be constant over time. An estimation of the age distribution, however, suggests a period of very low regeneration rates some 60-110 years ago, and that more recent regeneration is not sufficient to keep the population from declining. The germination tests showed that the seeds do not need any special treatment to break seed dormancy, soaking for three days in cold water is enough.

Miti ya mibuyu katika masingi ya Kondoa Irangi, nchini Tanzania.

Maneno Vidokezi
Adansonia digitata, uhuishaji, ukuaji katika marika, ukuaji katika makundi tofauti

Muhtasari

Uchunguzi mfupi ulifanywa kuhusu uhuishaji na uenezi wa miti ya mibuyu katika maeneo ya masingi ya Kondoa Irangi nchini Tanzania. Kadiri ya miti 300 ilichunguzwa na kutathiminiwa, katika maeneo yenye uboreshaji wa ardhi wa aina mbalimbali, ili kujua sababu za kimazingira zinazoadhiri ukuaji na ustawi wa mimea. Sampuli vidokezo zilitobolewa kutoka kila mti ili kupima mwendo wa ukuaji wa miti ya mibuyu yenye miaka tofauti kwa nia ya kuoanisha na hali ya mvua. Majaribio ya uotaji wa mbegu yalifanywa, ili kujua ni mbegu zipi huchipuka asilia, kwa mfano, zilizounguzwa na moto, zilizonyewa na wanyama, au zilitokanazo na machicha ya pombe itokanayo na tui la mbegu za mibuyu. Uwingi na uhuishaji wa mibuyu ulikuwa wa hali ya juu sana katika maeneo ya kilimo ukilinganisha na sehemu nyingine. Imependekezwa kwamba hali hiyo inatokana na maeneo hayo kutokuunguzwa moto na kutolishiwa mifugo. Mibuyu ya umri wa miaka 20-70 ilionekana kukua haraka zaidi kuliko mingine iliyokua zaidi. Hii inamaanisha kuwa mibuyu michache yenye umri mdogo inaweza kuonekana kwa kipindi kirefu. Hata hivyo, makisio ya ukuaji katika marika tofauti ya mibuyu yanaonyesha usitawi mdogo sana kwenye rika la miaka 60-110 iliyopita, hivyo kwamba ustawi wa hivi karibuni hautoshi kuongeza idadi ya mibuyu ili isionekane kupungua. Jaribio la ukuaji wa mbegu limeonyesha kwamba mbegu za mibuyu hazihitaji kunyetishwa ili zichipue. Mbegu hizo zikirowesha ndani ya maji baridi kwa muda wa siku tatu inatosha kuzifanya zichipue.

Introduction

This study concerns the Baobab tree (*Adansonia digitata*), in Kondoa Irangi Hills, Tanzania. Kondoa is an area with locally severe erosion problems, commonly believed to be due to deforestation and overgrazing. Since 1991 one part of a research program; Man-Land Interrelations in Semiarid Tanzania, has been focused on studying the recovery of degraded land in Kondoa. The succession of vegetation has been monitored yearly, and the ecology of some important tree-species has been studied. The Baobab tree is of interest since it is both ecologically important and valuable to man. There are very few studies concerning Baobab population ecology, and most of them are on Baobab distribution in relation to elephants in national parks situated at ca. 1000 m a.s.l. The Baobab is widespread in dryland Africa and its environment varies considerably throughout its distribution range. This study of the Baobab tree in Kondoa was made at altitudes between 1350 and 1750 m a.s.l. in an environment very different to the other studies. (A further presentation of the ecological and economic importance of the Baobab tree is included in the literature study.)

At Kondoa's altitude, the occurrence of Baobab trees seems to be closely associated with man, at least in the *Brachystegia* spp. dominated woodland (above 1600 m a.s.l), where earlier the natural vegetation was formed by tall trees with a closed canopy. The Baobab is a savanna tree, and it is possible that it was a natural member of the undisturbed *Acacia* woodland in the lower areas of Kondoa. In the cleared farmland and grazing land that encompass Kondoa today, the Baobab trees are frequent. Small individuals, however, seem to be very rare. Is this a natural population structure for this long-lived tree-species, or is the regeneration lower today than it was some 300-400 years ago, when the big trees we see today once germinated? And if this is the case, what environmental factors affect regeneration negatively? This study aims to find the answers to those questions by studying the Baobab's distribution, size distribution, growth, regeneration and mortality in different areas in Kondoa with different vegetation and land management.

Kondoa Irangi Hills

(For a more thorough description of the area, see part II, literature study.)
Kondoa Irangi Hills are situated in north central Tanzania (Lat. 4° 55´ S, Long. 35° 45´ E). The altitude ranges from 1000–2100 m a.s.l. The valley floors are typically situated at an altitude of 1300-1600 m a.s.l. The bedrock consists of deeply weathered precambrian gneisses and is highly erodible. The hills are characterised by pediment slopes from which inselbergs rise, and by ephemeral streams that cut into the erodible soils and form large gully systems. In the lower areas, the streams broaden out into wide sand fans (Östberg 1986). The climate in the Irangi Hills ranges from semi-arid to sub-humid with 600-900 mm rainfall per annum. Years with considerably less rainfall are common, resulting in crop failures and food shortage. The rainy season lasts from November to May and the rainfall regime is highly erosive (Payton et al. 1994). At altitudes between 1000-1600 m a.s.l. the valley floor is used for cultivation and the steeper slopes are used for grazing. The vegetation in the grazed slopes is wooded grassland, dominated by *Heteropogon contortus*, *Rhynchelythrum repens*, *Hyparrhenia filipendula* and *Acacia tortilis*. Higher altitudes are characterized by woodlands dominated by *Brachystegia spiciformis* and *Julbernardia globiflora* (Backéus et al. 1994).

In 1973 the Tanzanian government launched the land rehabilitation project HADO (HADO stands for Hifadi Ardhi Dodoma, which means, "soil conservation in Dodoma"). Its main focus was in Kondoa Eroded Area (KEA) covering 125 600 ha. of Kondoa Irangi Hills. In 1979 the area was closed to livestock since no conventional conservation methods worked to rehabilitate the devastated lands, and some 90 000 domestic animals were moved out of the area (Christiansson et al. 1991). At present, no free grazing is allowed and in the future only a strictly regulated grazing would be sustainable (Backéus et al. 1994).

Fig. 1. Map of Tanzania showing the location of Kondoa Irangi Hills. (from Backéus et al. 1994).

The Baobab tree

(For a more thorough description of the species, see part II, literature study.)
The Baobab, *Adansonia digitata*, is a deciduous tree widespread in semi-arid Africa. It grows up to 25 m tall and 8 m in diameter. Single individuals can reach an age of more than 1000 years (Swart 1963). The growth of an individual can be divided into four different growth phases (hereafter referred to as size classes) with different growth rates (annual radial increase) (Breitenbach 1985). The approximate age, height and girth at breast height (GBH) in the size classes according to Breitenbach are listed in Table 1. The range of growth rates is put together from all available data (Breitenbach 1985, Barnes 1994, Caughley 1976, Guy 1970, Owen 1974, Swart 1963, Wickens 1982, Wilson 1988).

Table 1. Approx. age, height, GBH and growth rates in the different size classes

Size class	Sapling	Cone	Bottle	Old
Upper limit age, years	10-15	60-70	200-300	500-800
Upper limit height, m	3-6	5-15	10-20	10-20
Upper limit girth at breast height, m	0.2-0.8	2.5-6.9	8-16	9-26
Range annual radial increase, mm	1.3-6.5	5-16	2-10	0.1-1.5

In areas with a distinct dry season the Baobab tree produces annual rings. Ring counts from trees of known age have been shown to be within 2 % of the real age (Wickens 1982). According to Wickens (1982) the Baobab occurs at altitudes up to 1000 m a.s.l., according to Wilson (1988) it occurs up to 1500 m a.s.l. in some areas of Tanzania and Ethiopia. In semi-arid environments the Baobab grows as a solitaire, with population densities between 3 to 723 individuals per km^2 (Barnes 1980). Mean densities typically lie between 10 to 20 individuals per km^2 (Wilson 1988). Many authors have reported a skewed size distribution in Baobab populations, with few individuals in smaller sizes (1 meter GBH size classes). In national parks, this is mainly due to destruction of small individuals made by elephants.

Method

Fieldwork

The fieldwork was carried out between January 1st and March 6th, 1998, in co-operation with Helena Munkert, who made a study on the relation between soil nutrient contents and leaf nutrient contents. Sample plots used in both studies were sited in different areas within Kondoa Eroded Area, referred to as Gongo (1), Chakwe (2), Mission (3), Kwantisi (4), Kondoa (5), Bicha (6) and Ausia (7). Sample plots in one area outside KEA, Goima (8), were used only for this study. The areas are marked in the map of KEA in Fig. 2.

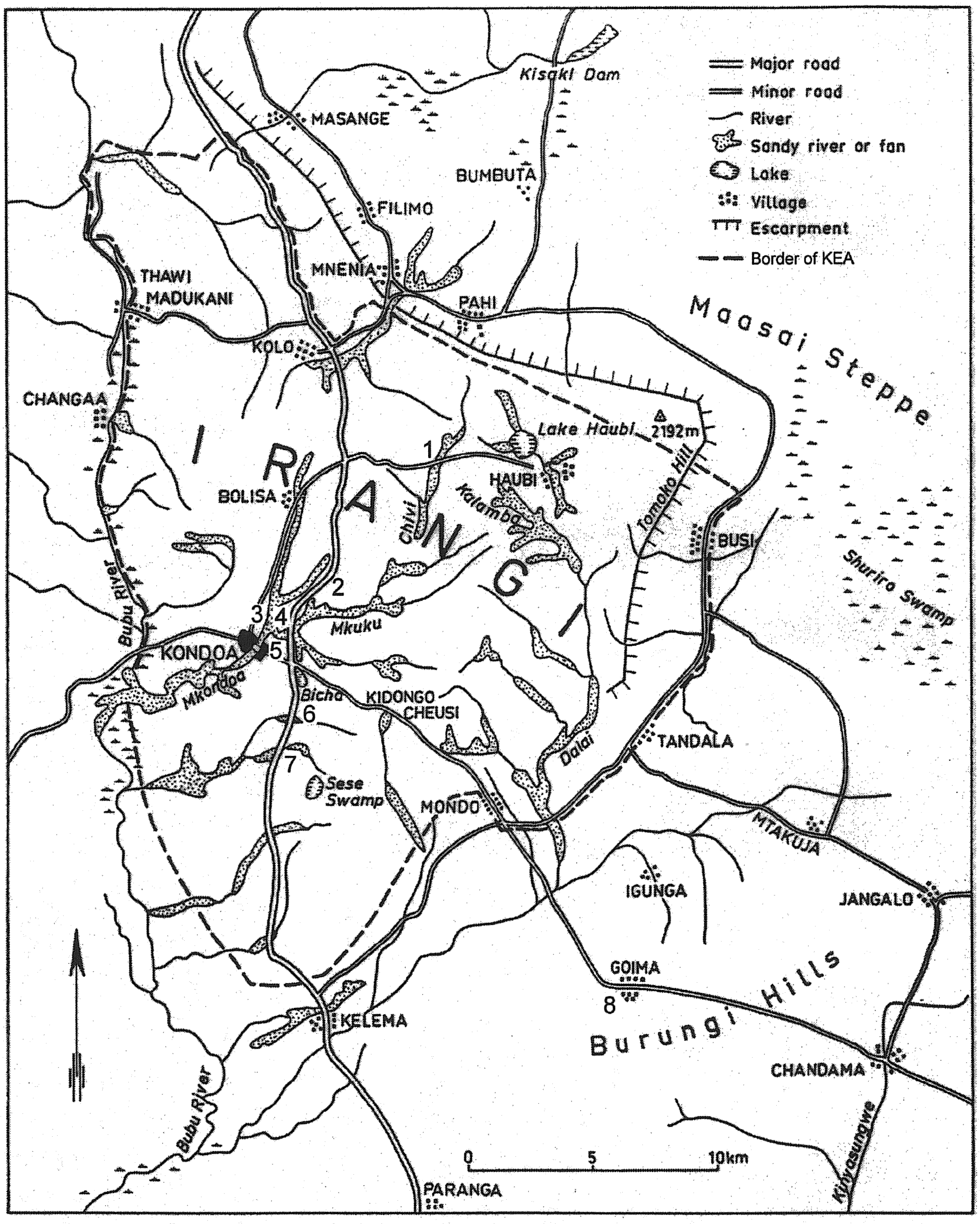


Fig. 2. Map of Kondoa Eroded Area (KEA), showing the study areas (from Christiansson et al. 1987).

The sampling covered different vegetation types and different kinds of land management, mainly cultivated fields and grazing land. Despite the prohibition of grazing within KEA, trespassing occurs and oxen for ploughing are allowed in the rainy season. Hereafter, the term grazing land is used for areas that are not cultivated, where the traditional landuse would be grazing land, and where occasional trespassing occurs. Gongo, at ca. 1700 m a.s.l., consists mainly of grazed, degraded *Brachystegia-Julbernardia*-woodland, severely eroded with big gullies. Chakwe is degraded *Acacia*-woodland, eroded and used for grazing in the hillsides (ca 1550 m a.s.l.) and for cultivation in the lower slopes (ca 1450 m a.s.l.). Ausia was farmland until the state moved the farmers from there in the Ujamaa-reform in the early 70's. Towards the Kuni hill in the south-east of Ausia there is degraded *Brachystegia-Julbernardia*-

woodland, now severely eroded. The areas between Kondoa, Bicha and Kwantisi (1350-1450m a.s.l.) have been cultivated for a long time except for the steeper slopes, like Bicha hill (1500m a.s.l) where the natural vegetation was *Brachystegia*-woodland (Matari pers. comm.). All areas have been under the influence of man for hundreds of years. The less disturbed areas are not accessible during the rainy season since there are no bridges across the sand-rivers (Fig. 2).

A total of 99 sample plots, 50x50 m and 500 m apart, were selected using the national grid system (ARC 1950) of the maps, Tanganyika government 1963. A satellite navigation aid (Garmin GPS) was used to locate the plots in the field. The locations of the plots are shown in maps in Appendix 1a and 1b. In the 50x50 m plots soil samples and leaf samples were collected for Helena Munkert's study and notes were taken on: tree-, shrub- and field-layer cover, slope, stone cover, soil type, catena position, severeness of erosion, number of years since last fire, and current landuse. The most common plant species in the different vegetation layers were also recorded. Five additional plots were established for the Baobab study in Goima and Ausia.

The Baobab trees within a radius of ca 250 m from the plot centre were mapped and measured for girth at breast height (GBH). The individuals were categorized into four different size-classes as Sapling, Cone, Bottle and Old. Altogether 246 Baobabs were measured and another 112 were only classified to size class due to shortage of time. In areas with high Baobab densities, like Kwantisi, some individuals were missed due to shortage of time. For 96 individuals, the height was measured with a clinometer.

From 20 individuals in different size-classes core samples were extracted using an increment borer of 5.15 mm diameter and 800 mm length. The core samples were taken at 1 m height for individuals less than 5 m GBH, and at breast height for bigger individuals. The individuals in the Sapling phase were cored all the way through. The borer and the bark were sterilized before boring, and the hole was plugged with a 15 cm stick of hardwood soaked in methylated spirit, to avoid risk of infection of fungi. The number of year rings in the core samples was counted in the field. Year ring width was measured on resoaked core samples using a stereo microscope. Fruits were collected (last years' fruits) and the number of seeds per fruit was counted in the field. The 50x50 m plots were searched thoroughly for seedlings. The environmental factors recorded in the 50x50 m plots are used as an average for the 250 m radius circles.

<u>Seed germination tests</u>

Three seed germination tests were made in Sweden. The seed pulp was removed from the seeds except for treatments 3 and 6 below. The seeds were treated in seven different ways, 20 seeds per treatment. The seeds were placed on damp sand, in the dark, at 20^{o} or 30^{o} C.

Table 2. Seed pretreatments for germination tests

No.	Treatment
1.	Untreated = control
2.	Soaking in cold water, 3 days
3.	Soaking in cold water with the pulp still remaining, 3 days
4.	Soaking in HCl, pH=2.5, 8 hours
5.	Boiling in hot water, 5x1 minute, cooling down in-between
6.	Boiling with pulp still remaining, 5 minutes
7.	Dry heat treatment, 5 minutes 250° C or 100° C

Seeds were considered germinated when the root emerged out of the seed coat. After 40 days, the viability of seed that did not germinate was verified through dissection.

Data analyses

Density and size distribution

Individuals were assigned to size classes, using the following girth (GBH) limits: Sapling (0-0.49 m), Cone (0.5-5.99 m), Bottle (6-15.99 m) and Old (>16 m). Plots within the study areas were grouped into units with more uniform conditions, and the size distribution was plotted for each unit.

Table 3. The altitude, main landuse, at present and before 1975 and an estimation of the degree of erosion in units. Information about main landuse before 1975 is provided by Matari (pers. comm.)

Unit	Altitude, m a.s.l.	Landuse system		Degree of erosion
		Present	Before 1975	
Ausia E	1360-1420	Grazing land	Cultivation	big gullies
Ausia W	1350-1360	Cultivation	Cultivation	sheet erosion
Bicha	1390-1470	Cultivation and grazing	Cultivation and grazing	big gullies in some plots
Chakwe E	1490-1570	Grazing land	grazing land	gullies
Chakwe W	1490	Cultivation	Cultivation ?	sheet erosion
Goima	1400	Cultivation	Cultivation	sheet erosion
Kondoa	1370-1410	Cultivation	grazing land	sheet erosion
Kwantisi	1370-1400	Cultivation	Cultivation	sheet erosion
Mission	1370-1390	Cultivation	Cultivation	sheet erosion
Gongo	1670-1770	Grazing land	grazing land	big gullies

The distribution of Baobab trees for each plot was compared with other data for the plots. Number of individuals in each size class and the data on environmental factors is shown in Appendix 3.

For present landuse, the difference between "cultivated" and "grazed" plots in mean Baobab density, mean density of Saplings + Cones, and mean percentage of Saplings + Cones out of total number of individuals in each plot, was tested with Mann-Whitney U-test. For landuse before 1975, the difference between "cultivated" and "grazed" plots in mean Baobab density was also tested with Mann-Whitney U-test.

The correlation between density of Saplings + Cones and percentage of Saplings + Cones, and cover of tree-, shrub- and field layer in the plots was tested with Spearman Rank Correlation. The correlation between Baobab density and altitude was tested for all plots and for "cultivated" and "grazed" plots separately, with Spearman Rank Correlation.

Core samples and age distribution

Year ring widths for each individual were plotted against year, counted from cambium and inwards. The outermost ring was excluded from calculations because it was unproportionally big in most individuals. The mean growth rate for all individuals was tested with One-way ANOVA. Thereafter the ring width data were divided in two size classes, Cones and Bottles, and analysed with One-way ANOVA using log transformed values. To take the difference between different years and different individuals within the groups into consideration, the data were also analysed as repeated measures ANOVA, where a covariance was taken between year and individual. Ring widths were also compared with rainfall data from Kondoa meteorological station, obtained from Eriksson (1998). For each individual, year ring widths were correlated with mm rain the same year the ring was produced, the year before, and with three-year running means of mm rain. Three-year running means of year rings were also tested.

The total size distribution for all Baobab trees in the study was plotted in 1 metre GBH size classes, for comparison with other studies. (The 112 individuals only classified to size class were all Bottles, so they were included in the 1 metre GBH size classes in the same portion as the measured ones.) This size distribution was converted into an age distribution by calculating the age of each individual, using growth rates obtained in this study.

Results

Within the 50x50 m plots in Kondoa 13 Baobabs were found. The total area of the 104 plots is 0.26 km^2, this gives an average density of 50.0 individuals per km^2. Within the ca. 250 m radius circles around the plots, a total of 358 Baobabs were found, which gives an average of ca 17.5 individuals per km^2. Comparing the small plots with the big circles, Baobab density and the percentage of saplings seem to be underestimated in the whole study (Table 4). No seedlings were found in the study, the smallest individuals were 15 cm in girth at breast height. One dead individual was found in KEA, it died in 1997. It was ca. 9 m in GBH and ca 220 years old, according to ring counts to the pith at 2 m height. One dead individual was found in Goima, it died in 1989 (Matari pers. comm.).

Table 4. Total density and size distribution of Baobab trees in two sampling units

	Ind./km^2	% Seedlings	% Saplings	% Cones	% Bottles	% Old
50x50m plots	50.0	0	15.4	23.1	61.5	0.0
250m radius plots	17.5	0	3.6	24.6	69.8	2.0

Density and size distribution

Maps of the spatial arrangements of individuals in different study areas are shown in Appendix 2a and 2b.

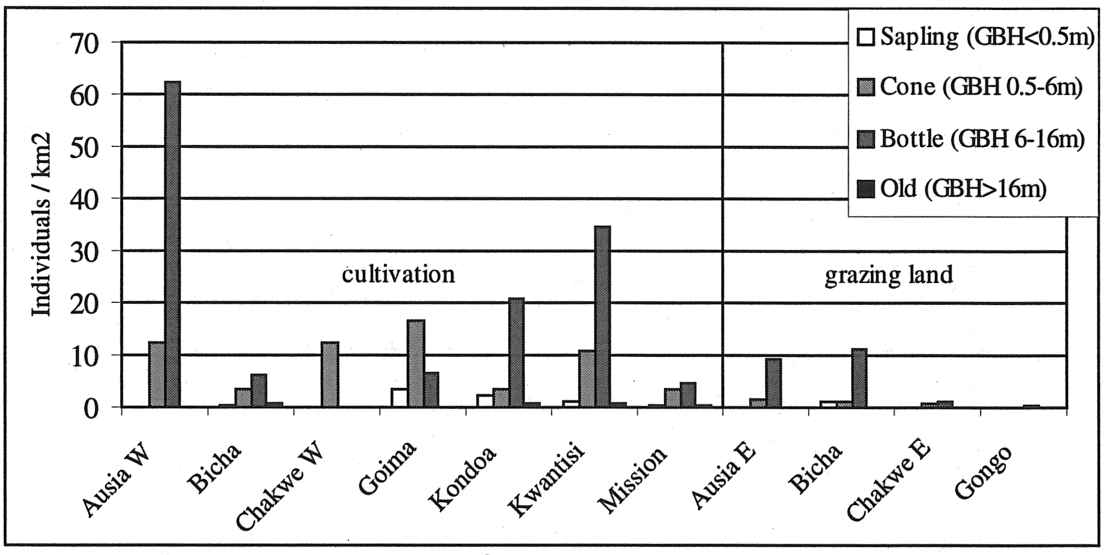


Fig. 3. Number of individuals per km^2 in each size class in the different areas. The areas are classified according to main landuse, into "cultivation" and "grazing land". (Bicha is divided into a "cultivated" and a "grazed" part)

Mean Baobab density, mean density of Saplings + Cones and mean percentage Saplings + Cones of the total number of individuals in each plot was significantly higher for plots with current landuse "cultivation" than for "grazing land" (P<0.001) (Table 5). Mean Baobab density was also significantly higher for plots classified as "cultivated" before 1975 than for plots classified as "grazed" before 1975 (P<0.001).

Table 5. Differences in performance of Baobab populations in plots with different landuse, at present and before 1975

Landuse	Present		Before 1975	
	cultivation	grazing land	cultivation	grazing land
Mean density ind/km^2 (s.d.)	30.1 (25.9)	4.3 (6.3)	22.1 (21.7)	4.0 (7.3)
Mean density Saplings + Cones ind/km^2 (s.d.)	6.8 (9.0)	0.9 (2.2)	-	-
Mean % Saplings + Cones (s.d.)	31.7 (33.6)	11.5 (29.4)	-	-
N	53	51	47	39

Cover of shrub layer and cover of field layer were significantly negatively correlated with density of Saplings + Cones (Spearman's rho= -2.9 and -1.8, n=97, P<0.05). Cover of shrub layer and cover of field layer were also significantly negatively correlated with percentage Saplings + Cones in the plots (Spearman's rho= -20.9 and -26.9, n=97, P<0.05). Cover of tree layer was not significantly correlated with density or percentage Saplings + Cones.

Baobab density (ind/km^2) was significantly negatively correlated with altitude when tested for all plots (Spearman's rho= -0.66, n= 104, P<0.001). When tested separately for "grazed" and "cultivated" plots there was a significant negative correlation only for the "grazed" plots (Spearman's rho=-0.75, n= 51, P<0.001) (Fig. 4).

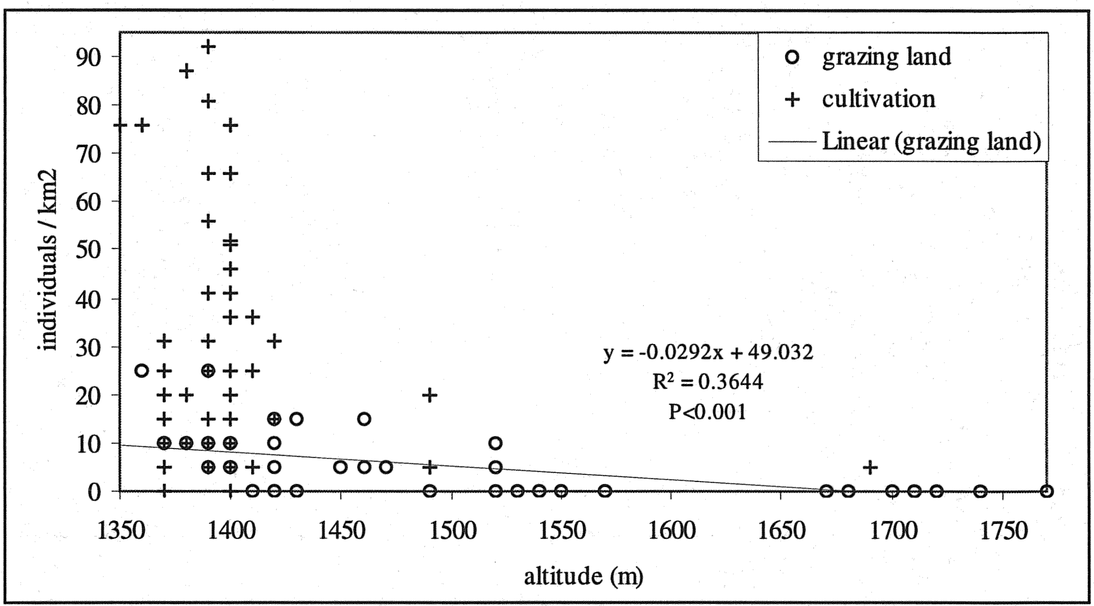


Fig. 4. Number of Baobab trees per km^2 in "grazed" and "cultivated" plots at different altitudes.

Core samples and age distribution

Year ring width plotted against year, counted from cambium and inwards, for each cored individual, is shown in Appendix 4.

Table 6. Mean ring width and s.d. for the outermost 20 and 10 years in core samples.

			20-years		10-years	
			Ring width mm		Ring width mm	
Ind. no.	Size class	GBH cm	mean		s.d.	
53	Sapling	18	-	-	2.6	1.3
256	Sapling	20	-	-	6.4	-
161	Sapling	38	-	-	6.0	3.9
43	Cone	80	4.3	2.1	5.0	2.2
37	Cone	98	4.6	2.0	6.2	1.2
104	Cone	115	5.4	2.0	5.1	1.2
89	Cone	170	9.9	3.3	10.6	4.2
23	Cone	350	15.5	6.6	16.4	7.7
20	Cone	485	9.0	4.6	8.5	3.7
133	Cone	558	7.7	6.9	11.5	8.1
87	Cone	599	5.6	1.9	5.0	1.8
171	Bottle	660	10.4	4.3	11.1	4.5
10	Bottle	860	5.5	1.8	5.2	1.8
60	Bottle	885	6.1	3.1	6.6	3.3
51	Bottle	895	3.2	1.5	2.5	1.0
80	Bottle	900	8.0	3.5	8.8	4.1
105	Bottle	900	3.1	0.8	2.8	0.8
242	Bottle	1080	4.3	2.3	5.3	2.8
231	Bottle	1200	-	-	5.1	1.7
36	Bottle	1365	4.0	1.8	5.0	2.3
16	Bottle	1440	8.6	5.0	10.5	4.9

There was a significant difference in ring-width between all individuals (One-way ANOVA; P<0.001). Mean ring width for Cones is significantly higher than for Bottles (One way ANOVA; P<0.001). The repeated measures ANOVA-test, where a co-variance was taken between year and individual, did not change the outcome of the analysis. (Individual no. 231 was excluded from the test due to lack of data.) The mean ring width for Cones is 7.7 mm p.a. (s.d.=5.4). The mean ring width for Bottles is 5.9 mm p.a. (s.d.=3.8).

Nine individuals were cored at least to the middle. Their estimated age at 1 m height is shown in Fig. 5. For the individuals that were cored all the way through, the number of year rings differed 1-5 years between both sides. The average is used in Fig. 5. The real age of the individuals is perhaps ca. 1-2 years more.

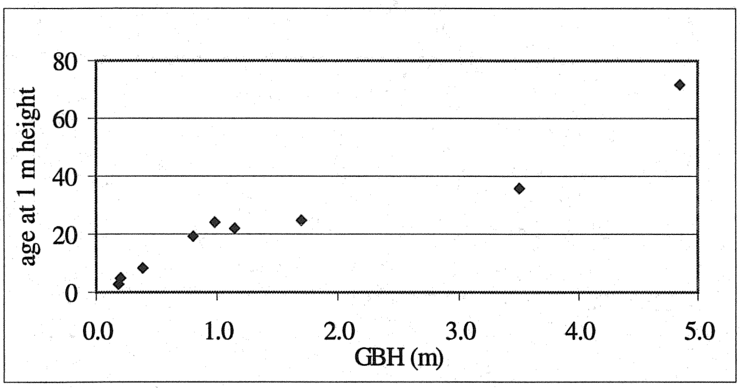


Fig. 5. Estimated age at 1 m height of nine individuals cored to the middle.

None of the cored individuals showed any significant correlation between year ring width and mm rain.

The total size distribution for the whole study (Fig.6) was converted into an age distribution (Fig.7) by calculating the age for each individual using mean growth rates obtained from the core samples. (The mean growth rate for: GBH 0-0.49 m = 5.0 mm, GBH 0.5-5.99 m = 7.7mm, GBH 6.0-15.99 m = 5.9 mm.) For GBH > 16 m an average growth rate of 1.0 mm was taken from literature (Swart 1963, Breitenbach 1985).

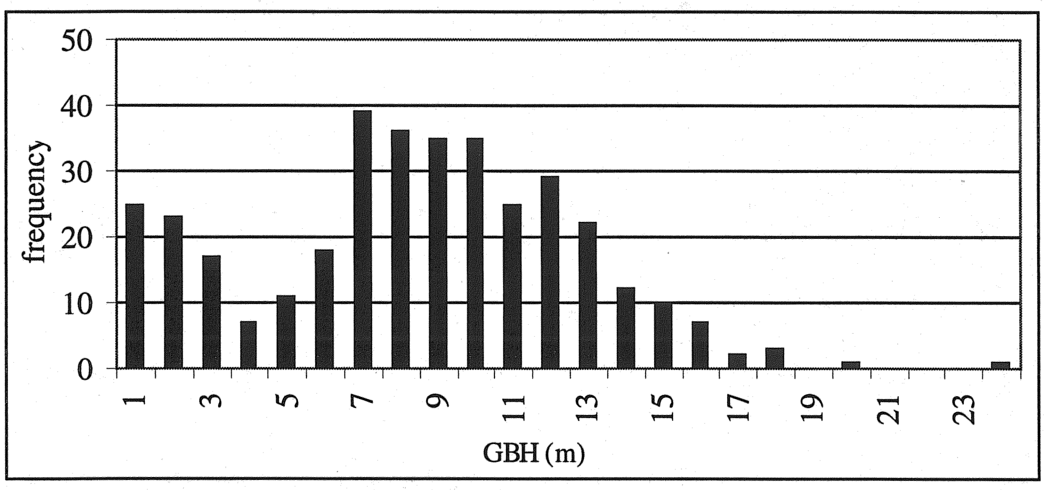


Fig. 6. GBH size distribution for all Baobab individuals in the study in 1 m GBH size classes.

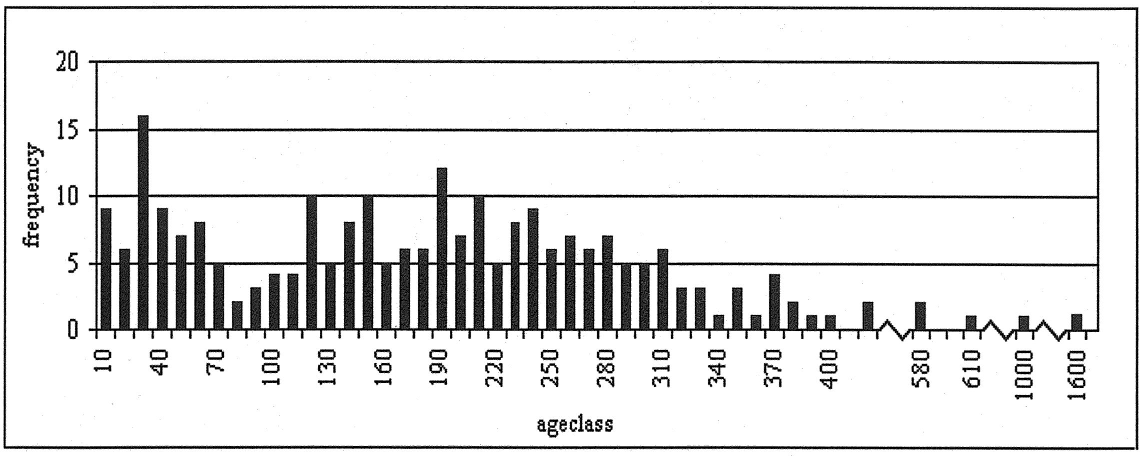


Fig. 7. Distribution in 10-year age classes for all Baobab individuals in the study. GBH measurements are converted to age using mean growth rates obtained from core samples.

Height

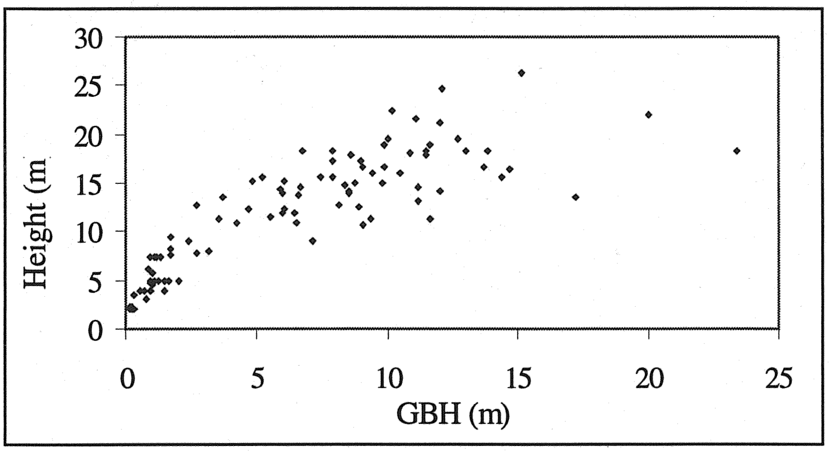


Fig. 8. The relation between height and GBH of 96 measured Baobab individuals.

Fruiting and seed germination tests

About 70 % of the adult Baobab trees, Bottles and Old, had fruits. Some of them had ripe fruits from 1997, some unripe from 1998 and some had just flowered. Of the Cones, ca. 25 % had fruits. They usually start fruiting at a GBH between 1-2 m
The collected fruits contained between 10-80 seeds per fruit.

In the germination tests, soaking the seeds for 3 days in cold water gave the highest germination percentage (Table 7) The column "Germin." shows the number of seeds that germinated in each treatment, the column "Dead" shows the number of ungerminated seeds that were dead. The dead seeds did take up water and swell, but the seedling did not seem to be able to break the seed coat. This condition seems to be dependent on the temperature. For the dry heat treatment in test no. 2, the dead seeds had not swelled, they were killed by the heat.

Table 7. Number of germinated and dead seeds in the different germination tests. Viability of ungerminated seeds in tests 2 and 3 was verified through dissection. Treatment no. 4, HCl, was used only in tests 1 and 2.

Germination test	1		2		2		3	
Date	26-May		26-Aug.		26-Aug.		29-Jan.	
Germination temperature, °C	20		20		30		30	
No. of seeds/test	20		10		10		20	
	Germin.	Dead	Germin.	Dead	Germin.	Dead	Germin.	Dead
1. Control	0	-	0	0	0	2	2	7
2. Cold water	0	-	1	5	6	4	5	3
3. Cold water with pulp	1	-	0	4	2	3	1	2
4. HCl	0	-	0	0	1	0	-	-
5. Boiling water	0	-	0	10	1	9	0	18
6. Hot water with pulp	0	-	0	2	1	9	1	16
7. Dry heat*	0	-	0	10	0	10	0	11

* 250 °C in tests 1 and 2, 100 °C in test 3.

Relative growth rate

Two seedlings grown in the greenhouse, at ca. 20 °C (fertilised with "Blomstra" plant fertiliser 1 ml/l once a week) reached a height of 59 and 46.5 cm respectively, and a girth at ground height of 14.4 and 8.0 cm in eight months. The relative growth rate (RGR) was calculated as: $\ln h_2 - \ln h_1 / (D_2 - D_1)$, where h = height in cm and D = number of days since germination. Their mean RGR between day 50-80 is 0.013 and between day 80-250 it is 0.001.

Interviews

Mr. Matari from the HADO-office assisted me in asking some questions about the Baobab tree to five elders in five villages in Kondoa Eroded Area. The interviewed elders' names are: Mze Ally Swaleke, Mze Issa Soloka, Mze Juma Yombe, Mze Mohamedi Kwamka, and Mze Hasani Yusuphu. The answers presented below are compiled from all answers given by the interviewees.

1. Do you know of any dead Baobab trees? Where? When did they die?

Table 8. Number of dead Baobab trees in 5 villages in Kondoa, 1978-1997.

Number of dead trees	Villages	Died in year
2	Mlua	1985
6	Tungufu	1978
2	Bicha	1996
7	Bama	1982 and 1996
5	Unkuku and Gayu	1996 and 1997

2. Do you know of any big old Baobab trees? Where, and how old do you think they are? - "Two in Kondoa town and one in Mlua village which is about 195-230 years, according to information from my grandfather".

3. Why are there so few young Baobab trees? – "The young ones are taken by animals, man and cattle and they are affected by fire during the dry season. The young Baobabs' leaves are preferred as a green vegetable. When old individuals die, or are removed, they are not replaced because they grow slowly and take a big space"

4. Why are there so many Baobab trees in the farm fields? – "Because people tend them in the Shambas and they are protected against fire and cattle. Some people plant Baobabs, a total of 26 young ones were planted in Mlua, Tungufu, Bicha, Unkuku and Gayu villages."

5. What products do you use from the Baobab tree? – "Leaves from young trees are eaten as a vegetable, the seed is used for making liquor, and the fruits are eaten. The bark is used for making ropes and brooms."

6. Do you want to have the Baobab in your Shamba? Why? – "Yes, they keep moisture in the soil, the soil under the tree is fertile, they act as windbreaks, the shade under the tree is good for the cattle, sweet potatoes grow well under the Baobab tree."

7. Are there any negative effects of the Baobab in the Shamba? – "They take up a big area, the shade is not good for cash crops, they hide birds which are harmful."

8. How do you tend the Baobab trees in the Shambas? – "If I found a small Baobab in my Shamba I would remove some of the branches so it can increase in height. I would also dig a ditch around it to keep water."

9. Why do you prefer to take fibre from young Baobabs? – "The string from young trees is better for making baskets and brooms."

Discussion

Density, size distribution and environmental factors

From this study the conclusion can be reached that young Baobab trees are not as rare as they seem just looking superficially at the population. Before they get their characteristic swollen trunk they are not easily recognised, and they often grow hidden in other vegetation. The difference in Baobab density and % Saplings between the 50x50 m plots and the 250 m radius circles (Table 4) is partly due to the fact that some individuals were missed in Kwantisi. The big circles were not searched as thoroughly as the small plots, so small saplings may have been overlooked in all areas. The Baobab density of 50.0 individuals per km^2 calculated for the 50x50 m plots, can not be assumed to be applicable to the whole area studied. The summed area of the 50x50 m plots is too small in comparison with the whole area and mere chance may have influenced the calculated density too much. My estimation is that the true mean density is somewhat bigger than the calculated 17.5 ind/km^2 but not as high as 50.0, but the clumped distribution makes it hard to say.

In Kondoa Eroded Area, most Baobab regeneration takes place in association with cultivated land. Plots classified as "cultivated" had significantly higher Baobab density and percentages Saplings + Cones. The youngest Saplings found were 5-10 years old. All of them were standing in fallow fields or in strips adjacent to cultivated fields. All areas classified as "cultivated" have probably been cultivated during different periods for a long period of time. Some of the areas classified as "grazed" probably also have been used for cultivation during different periods, at least at lower altitudes. The area called Kondoa is a hill between the road to Kondoa, and the river. It was recently cleared for cultivation (Matari pers. comm.), but was probably cultivated much earlier as traces of terraces, maybe built in the 1930's, can be seen on aerial photos from the sixties. The area called Ausia W had a very high Baobab density in a small area, and quite many cones. Ausia W is a flat hill that was cultivated before 1975 but has been left for ca. 20 years until quite recently, when it was cleared for cultivation again. This might explain the high density of Cones. Goima had the highest percentage of Saplings + Cones but is a special case, since all of them were standing in the same field. The biggest cone there was 218 cm in GBH today, and we were told by the farmer that it was young when the field was cleared in 1963. One big Bottle was standing ca. 350 m north-east of the field and it is probably the seed source for all the individuals there.

The plots and areas classified as "cultivated" had a quite modest slope (1-5.5 deg.) and were mostly situated at the valley floors in the catena zone called deposition (see Appendix 3). The plots and areas classified as "grazed" were often situated on the hillsides and had a greater slope, dense vegetation, high stone cover or were more severely eroded and not suitable for cultivation. There was a significant negative effect of altitude on Baobab density for the "grazed" plots. This altitude effect could not be proven significant for the "cultivated" plots because there are too few "cultivated" plots at higher altitudes in the study (Fig. 4). Landuse is also correlated with altitude, there is less cultivated land at higher altitudes. The effect of altitude in the "grazed" plots may be an effect of overall less cultivation at higher altitudes. The "grazed" plots at lower altitudes are closer in time and space to the agricultural landscape. The area referred to as Ausia E was cultivated before 1975 and some of the plots classified as “grazed” in Bicha have probably been cultivated at some time. This might explain why they have higher Baobab densities than Chakwe E and Gongo (Fig. 3). The plots at the highest altitudes were in Gongo where the landscape mainly consists of degraded *Brachystegia*-woodland, in which the Baobab does not occur naturally. No Baobabs were found in this area, except for one big individual in one plot situated in a cultivated field.

The Baobab distribution in Kondoa correlates with the occurrence of arable fields, but this study can not reveal if their presence is dependent on the occurrence of cultivated fields, because there is no land suitable for cultivation that with certainty has never been cultivated. The original natural vegetation of the cultivated land is not exactly known. If it was forest with a closed canopy, the Baobab would probably be excluded by light competition. If it was woodland or savanna the Baobab might have grown there at the same places as man later came to cultivate.

The limiting factors for Baobab regeneration in the plots and areas classified as “grazed” seem to be fire, grazing animals, competition with other vegetation, and lack of seed dispersal. All plots classified as “grazed” were burnt in the dry seasons of 1996 or 1997. It seems as if young individuals need some kind of protection against browsing animals. Of the 14 Saplings found in the study, 2 were in a “grazed” plot, growing in a dense thorny shrub together with *Opuntia* sp. and *Agave* sp. Of the saplings in the “cultivated” plots, 3 were growing in thorny shrubs and another 2 had signs of browsing, one of them was almost dead. The remaining 7 were standing in the middle of farmed fields, which also gives protection from fire and grazing. Even if the young individuals survive best protected by thorny shrubs, they seem to be sensitive to light competition by other vegetation. Bigger Baobabs never grow beneath other trees. One of the recorded individuals, 9.5 m in girth, was noted being suffocated by upgrowing taller trees. Density of Saplings and Cones and percentage of Saplings and Cones were significantly negatively correlated with cover of shrub layer and cover of field layer. There was no correlation to cover of tree layer, because the tree layer was practically the same for all plots. Seed dispersal may be a limiting factor in Kondoa, where Man has taken over as seed dispersing agent in the absence of wild animals. Regeneration is higher where there already are many old fruiting individuals. In Goima, all young Baobabs were growing close to one old individual, the rest of Goima had virtually no Baobabs at all. The single tree in Gongo shows that Baobabs can grow at 1700 m a.s.l but perhaps the less frequent seed rain there makes them rarer, besides the fact that cultivated fields also are rarer.

In the areas classified as arable, on the other hand, another limiting factor for Baobab regeneration is whether or not the tree is desired by the farmer. The farmers in Kondoa do not usually plant Baobab trees, but when a young sapling is found around the fields, the farmer may tend it or remove it. As is said in the interviews, the Baobab is desired for fibre, leaf vegetable and the fruits, but it also has negative effects, like occupying space and competing with the crop for sunlight and water. The practice of making fibre from the bark of the Baobab tree probably disturbs the young trees that are often completely ringbarked. The Baobabs in the cultivated areas of Kondoa live and regenerate in an ecosystem highly influenced by man. This ecosystem is somewhat similar to the “farmed parklands” of West African Sahel, described by Gijsbers et al. (1994). In the farmed parkland, big trees grow scattered, often in a regular pattern, in the agricultural landscape. The tree species are valuable to man, often multipurpose species, and they may either be planted, or retained from the natural vegetation. In the "farmed parklands" of West African Sahel the tree populations are decreasing due to long-term drought, overgrazing and increasing human populations.

Growth and age distribution

There were some practical problems in counting the growth rings. Even though the rings actually are annual (Wickens 1982), it is not easy to delimit them and assign them to a certain year. The core samples from the individuals cored all the way through showed that the number of year rings differed with 1-5 years between both sides of the trunk. The dead individual found in the study (tree no. 105), was cut to the middle so that a quarter of the circumference of the rings could be seen. Some (very few) of the rings split into two in part of the circumference. This feature of the annual rings is probably the reason why no significant correlation could be found between year rings and rainfall. If the core sample contains such a split ring, all the rings inside will be assigned to the wrong year.

In this study, I have shown that the growth rate, the annual radius increase, is significantly higher in a certain phase early in the Baobab's life, referred to as the Cone phase. This corresponds with the results of Breitenbach (1985) and Guy (1982). The year ring diagrams in Appendix 4, show that trees no. 20 and 23, both being cones, had wider rings in their Cone phase than in their Sapling phase. Trees no. 80 and 171 had big mean ring widths, both had a very cone-like shape even if they were classified as Bottles due to their big girths. In the graph for tree no. 51, there is a tendency for bigger rings in the innermost 15 centimetres, which represent the outermost part of its Cone phase. Real growth rate, the total biomass accumulation, is of course bigger for bigger trees, as they have more leaves to photosynthesise with. A one mm wide year ring in a tree with a big radius contains more biomass than one in a smaller tree. It is not surprising that the year rings at breast height are bigger in the Cone phase, since the trunk swells at the base. For the Bottles, the year rings are probably wider higher up the trunk, when the tree starts to adopt a more cylindrical shape. Also, bigger trees have more fruits, which decreases the annual biomass accumulation in the trunk.

The total size distribution for the Baobab trees in this study is shown in Fig. 6. There seem to be fewer individuals in the smaller girth classes, with extra low frequencies for girths around 4-5 meters. This does not necessarily mean that regeneration has decreased, if Cones (GBH 0.5-6 m) have a bigger growth rate than Bottles this could be the normal size distribution of a healthy population. I tried to convert the size distribution into an age distribution, using the mean growth rates for Cones and Bottles obtained from the core samples. This is very difficult to do since the variation in growth rates between individuals is so big. In the age distribution in Fig. 7, there is a drop in frequency for age classes 60-110 years (corresponding to GBH 2.6-5 m). This could imply a lower regeneration between the 1890's and 1930's, or a recent destruction or higher mortality in these classes, which is not very likely. It could also be an effect of some individuals in these size classes growing faster than the 7.7 mm per annum used in the transformation from the size distribution. Most of the bigger Cones cored actually had a mean growth rate bigger than 7.7 mm per annum.

The observed mortality in 1997 for Bottles and Old is one out of 257, ca. 0.4 % per year. The number of dead trees recorded in the interviews can not be used, since the Baobab densities in those areas are not known. Nevertheless, it seems as if the observed mortality is a bit too low. Assuming constant regeneration in the past, Barnes (1994) calculates an annual mortality rate for his population from the regression slope of the age distribution. This can not be done for the age distribution in Fig. 5, since the bars for the age classes vary too much and constant regeneration in the past can not be assumed. I believe that mortality is high for small individuals under a certain size-limit. When the trunk has reached a girth that can save enough water and that can stand fire, and the branches are at a height out of reach of browsing animals, the mortality probably decreases drastically. This limit may lie at a GBH less than 0.5 m, i.e. at an age less than ca. 15 years.

If the low frequencies of individuals 60-110 years old do originate from a situation with lower regeneration, the reason may be found in history. The beginning of the period coincides with the rinderpest and famine of the 1890's, which reduced cattle and human populations, and thereby probably increased vegetation cover, which would probably reduce Baobab regeneration. The latter part coincides with the bush-clearings in the 30's and 40's to combat the tse-tse fly, and with the soil conservation schemes introduced at the same time. Both of these actions could perhaps promote Baobab regeneration, but Baobab regeneration does not rise until the 1940's. The biggest age class is the one originating from the seventies, when Kondoa was virtually without vegetation cover and erosion was accelerating. This seems a bit puzzling, that Baobab regeneration should be at its best when erosion is at its worst, but perhaps many Baobabs germinated in abandoned fields left in the Ujamaa reform. Even if mortality rates are very low for adult individuals, the overall regeneration during the last 60 years seems to be insufficient to keep the population from declining. But even in the older age classes, there is a big variation between the 10-year periods. Since the old individuals live for so long, it is not necessary for the Baobab to have an exponentially declining age distribution as Barnes (1994) claims, regeneration may also be a pulsed event. It may be enough if the population regenerates successfully once every 50-100 years to assure continuation of the species (Owen 1974).

To learn more about the Baobab tree and to be able to predict the future of a Baobab population, more information is needed about the present age structure and mortality. There is a serious problem using GBH measurements to estimate age in Baobab populations, since the trunk exhibits girth variation depending on hydrostatic conditions within the tree besides the cambial growth. The variation in growth rates between individuals is so big that the age distribution should be adjusted for it. Fast growing individuals should be separated from slower growing ones, by distinguishing factors of growth. Growth should be monitored during a long period of time and be compared with annual rings. Mortality in different size classes, especially in the Sapling class, has to be observed in marked individuals during a long period of time. Nothing is known about seed germination in the field. Long-term studies are needed to find out how seed germination takes place in nature, how often it takes place and what factors influence germination and seedling survival. If regeneration takes place in pulses, the study has to coincide with such an event.

Seed germination tests

The seeds are quite difficult to germinate artificially. Seed dormancy can be broken quite easily just by soaking in cold water, but the seedlings had a hard time breaking the seed coat. It seemed as if the seedlings developed quicker at 30^o and had more strength to break the seed coat. The seedlings that did not manage to break the seed coat rotted inside it. Germination time ranged between 1 day to 30 days. The treatment of boiling seeds with the pulp gave only 10 % germination. It was meant to simulate the local practice of making Baobab beer, which I believe stimulates a lot of germination in reality. Many authors have suggested that Baobab seed may be adapted to elephant digestion or fire to break seed dormancy, since very low germination rates have been reported from plant nurseries. The HCl treatment was meant to simulate digestion, but perhaps the duration of the treatment was too short since most seeds did not even swell. The heat treatments were meant to simulate fire, but 250^o C dry heat killed all seeds. When lowering the temperature to 100 °C in test no. 3, the seeds survived and some of them swelled but none managed to germinate properly.

The germination percentages were higher for the treatment of soaking in cold water than for boiling the seeds, in contrast to the results of Essenwo (1990) and Danthu (1994), but the tests are not really comparable since they tested treatments for achieving high germination rates for commercial use. From my germination tests, the conclusion can be reached that the Baobab seed does not need any special treatment to germinate. Perhaps the seed is adapted to germinate at very different times, some the first year after they were produced, and others after 2 years, 3 years, up to maybe 10-20 years or more, as a risk-spreading strategy in an unpredictable environment.

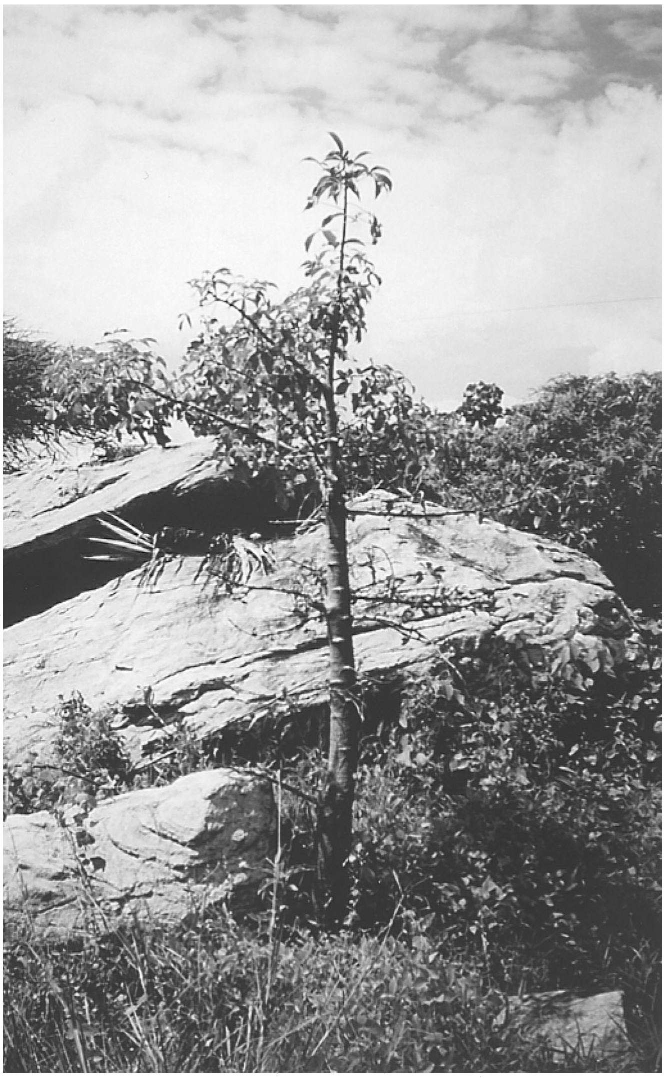


Fig. 9. A young Baobab tree. The girth at breast height is 19 cm and the height ca 2m.

Fig. 10. A Baobab tree classified as a Bottle. The girth at breast height is ca 13.65 m.

Fig. 11. The big Baobab at Kondoa bus station. The girth at breast height is ca 20 m.

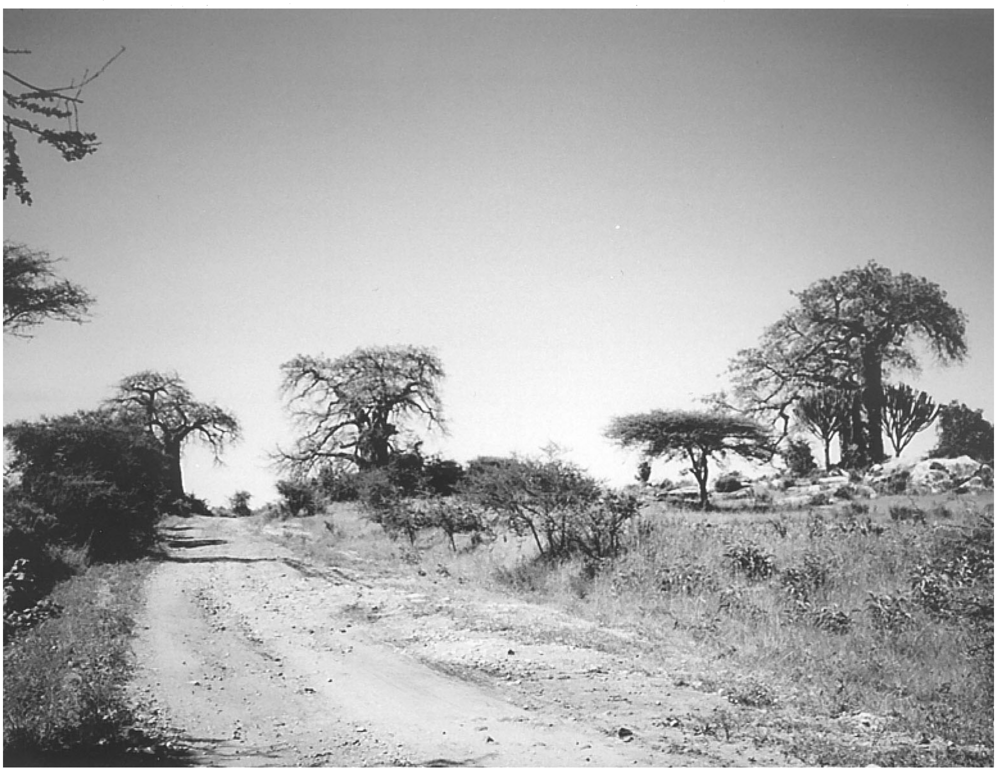
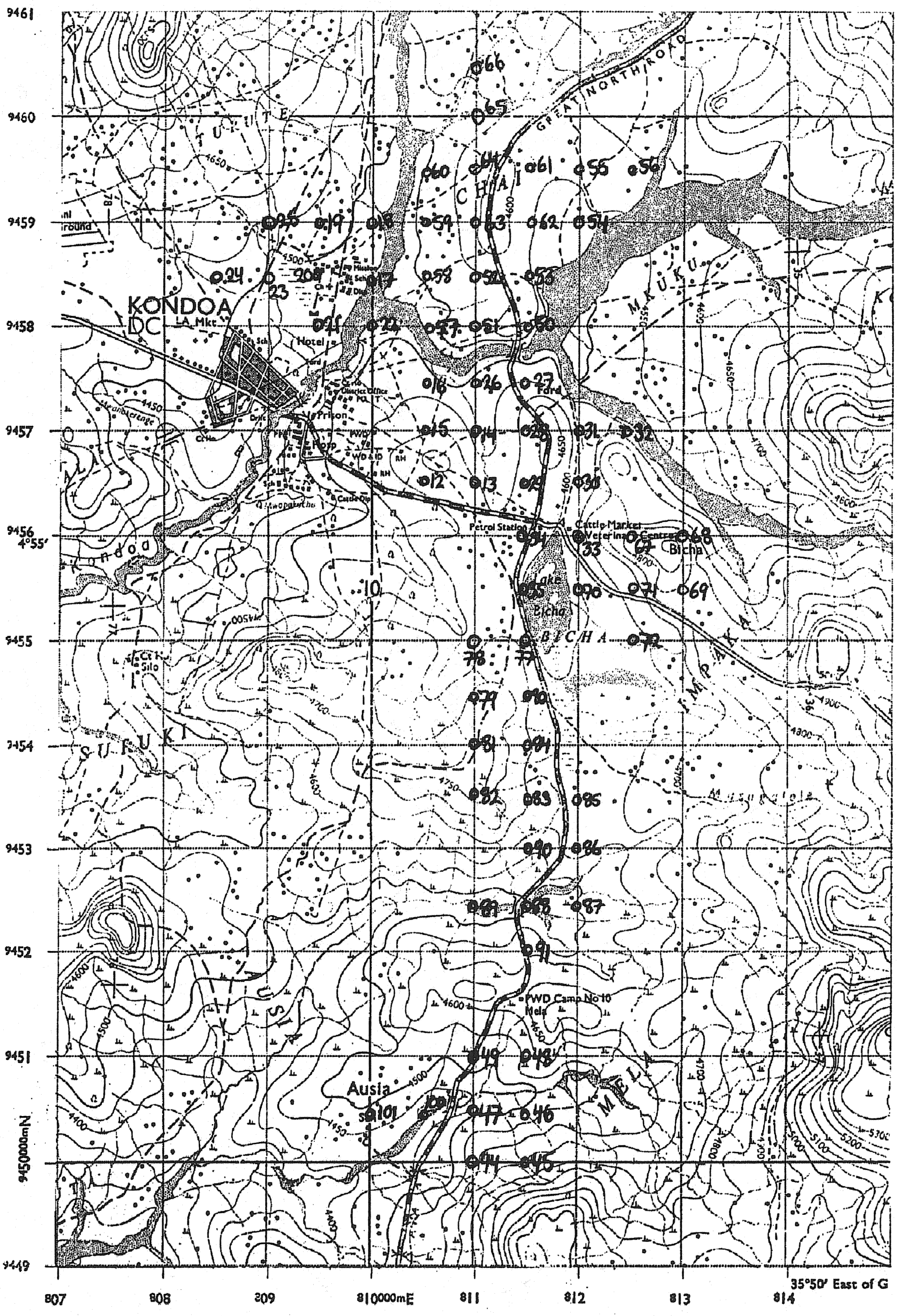


Fig. 12. Baobab trees in the agricultural landscape in Kwantisi.

Map of plot locations

Appendix 1a

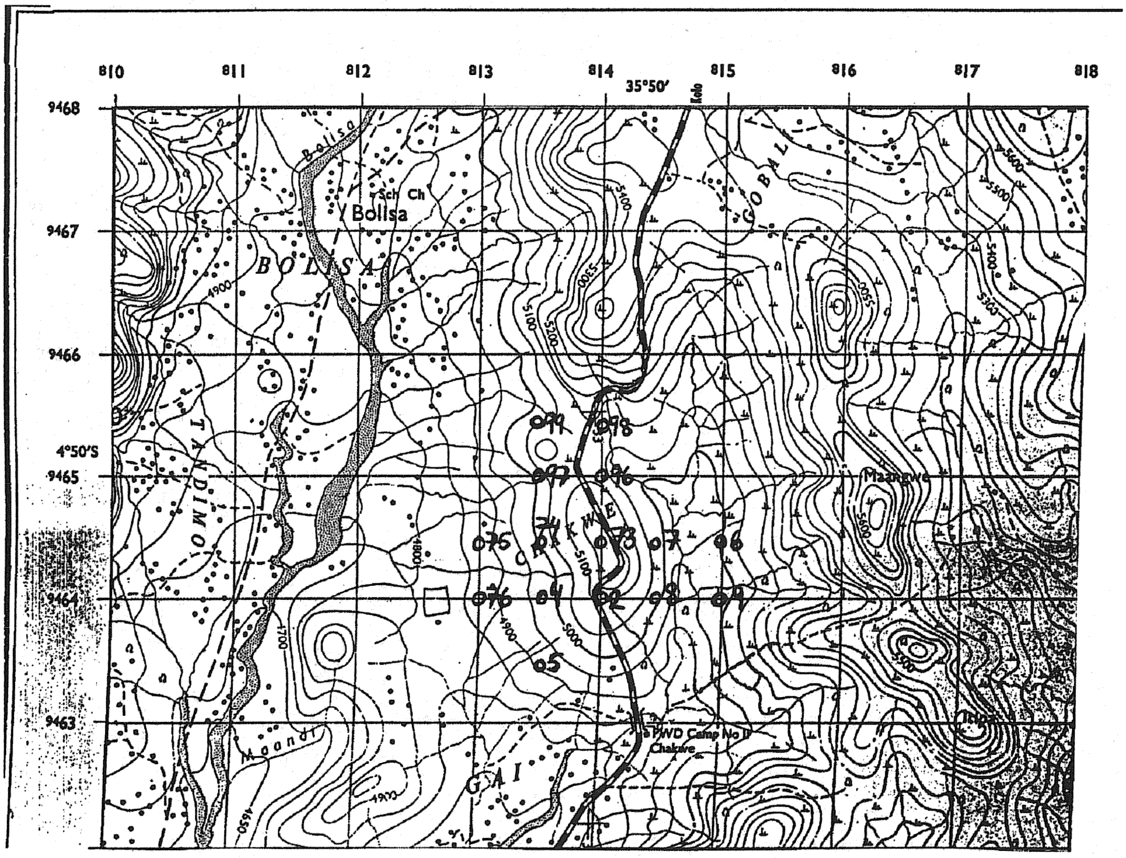
showing following study areas: Kwantisi (plots 50-66), Mission (plots 17-25), Kondoa (plots 12-16 and 26-32), Bicha (plots 33-35, 67-72 and 77-91) and Ausia (plots 44-49 and 100-101).

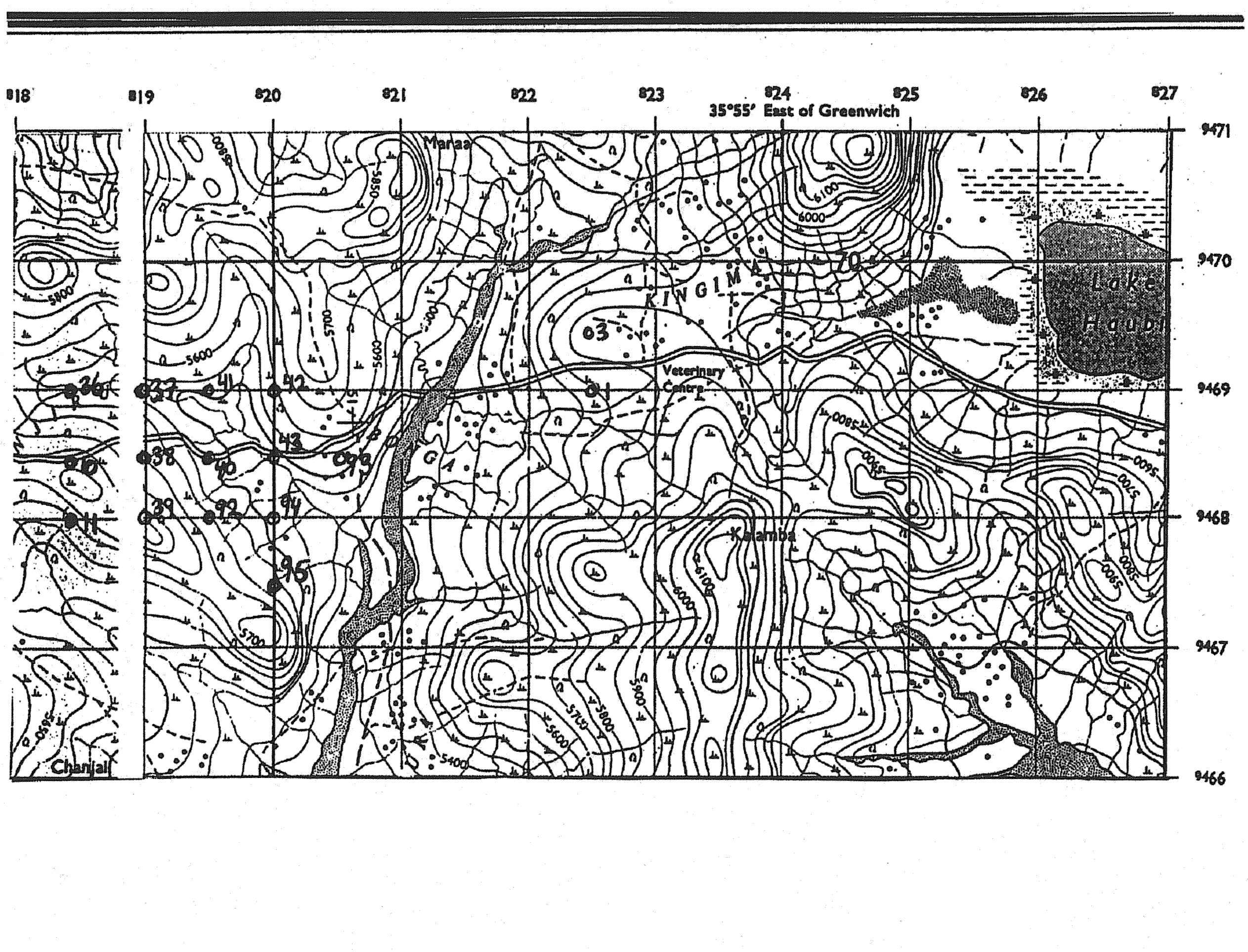


Map of plot locations

Appendix 1b

showing following study areas: Chakwe (plots 2, 4-9, 73-76 and 96-99) and Gongo (plots 1, 3, 10-11, 36-43 and 92-95).

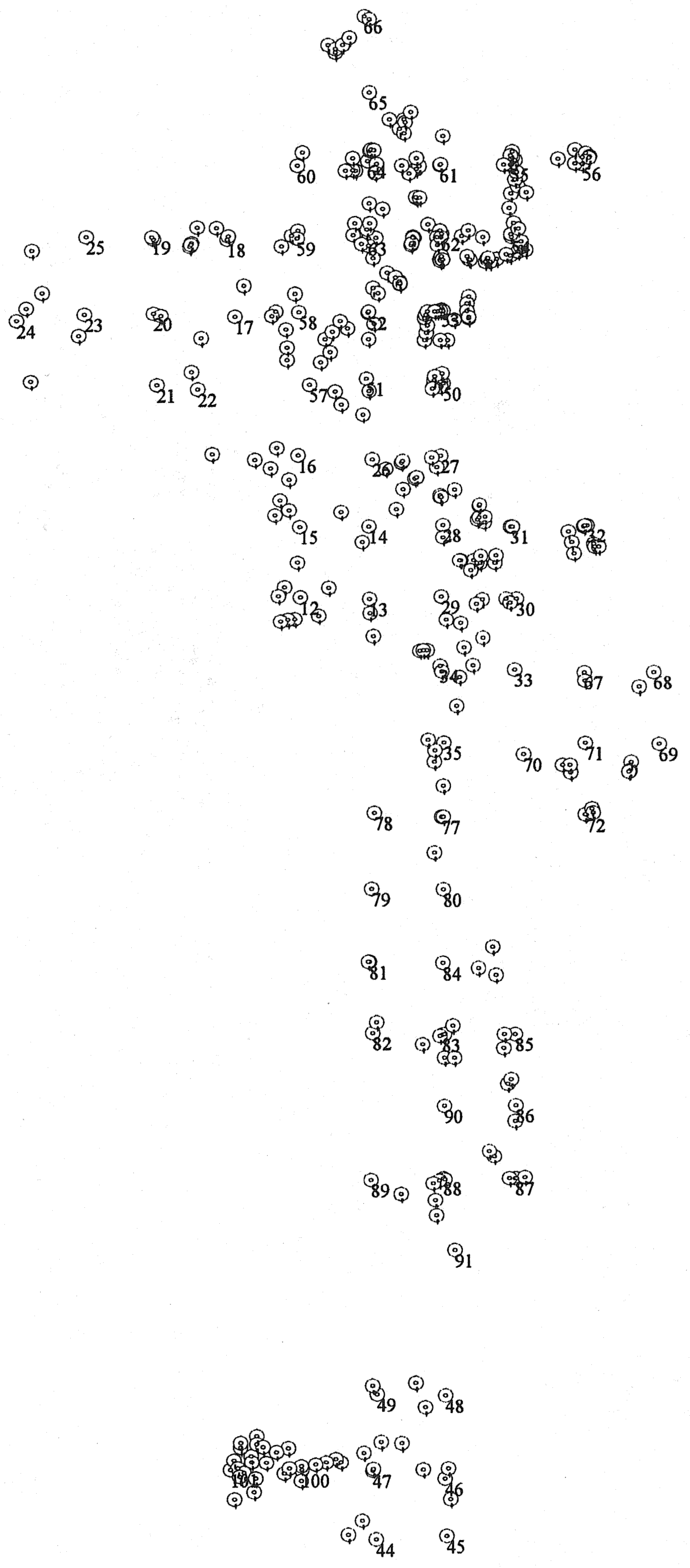




Map of Baobab individuals and plots

Appendix 2a

Numbered circles show the location of plots, empty circles show the positions of Baobab individuals. Areas: Kwantisi, Mission, Kondoa, Bicha and Ausia.



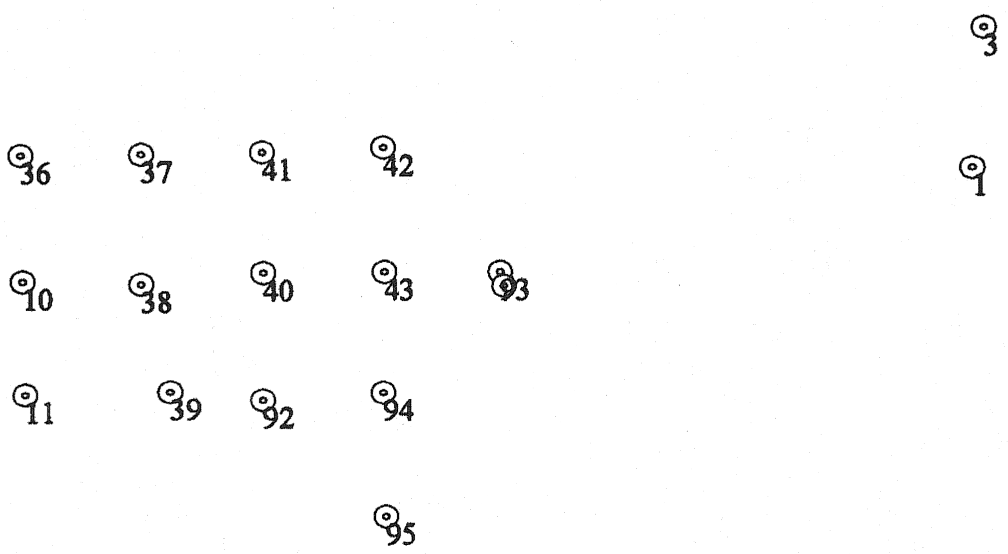
Map of Baobab individuals and plots

Appendix 2b

Numbered circles show the location of plots, empty circles show the positions of Baobab individuals. Areas: Chakwe and Gongo

Chakwe

Gongo



Plot data

Number of Baobab trees in different GBH size classes in the different areas, and other plot data.
GBH size classes: S = Sapling 0-49 cm, C = Cone 50-599 cm, B = Bottle 600-1599 cm, O = Old >1600 cm.
Landuse type is indicated by. C = cultivation, G = grazing land. Percentage cover of tree-, shrub-, and field-layer species is indicated by: 1 = 0-25%, 2 = 25-50%, 3 = 50-75%, 4 = 75-100%. The soils are classified according to dominating soil fractions: s = sand, l = loam, h = humus. The position along the catena is indicated by: t = top, e = erosion, d = deposition.

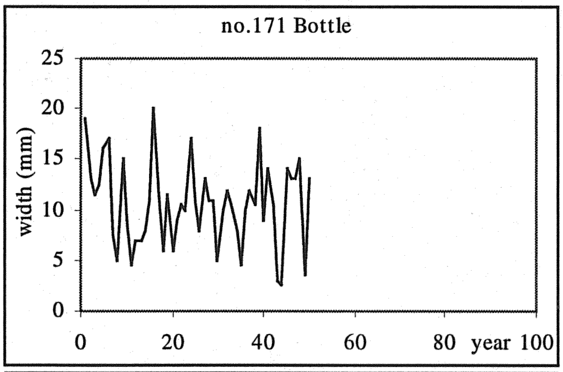
plot	size class				area	landuse		tree l.	shrub l.	field l.	elev.	slope	stone	soil	catena	fire
	S	C	B	O		present	< 1975				m a.s.l.	deg.	%			year
44			2		Ausia E	G	C	1	2	2	1400	7 N	5	s	e	1997
45			1		Ausia E	G	C	1	1	1	1420	3.5 NW	15	s	e	1997
46			2		Ausia E	G	C	1	2	2	1370	4 N	30	s	e	1997
47			5		Ausia E	G	C	1	1	4	1360	5 SW	3	slh	e	1997
48			1		Ausia E	G	C	1	1	2	1390	3 NW	50	s	t	1997
49		2			Ausia E	G	C	1	1	4	1380	2 SW	0	sh	e	1997
100		3	12		Ausia W	C	C	2	2		1350	3 SE	0	sh	e	
101		2	13		Ausia W	C	C	1	1		1360	2 SE	0	s	t	
34		1	4		Bicha	C	C	1	1		1400	0	0	sl	d	
35		1	2		Bicha	C (fallow)	C	2	2	2	1400	2 SE	0	sl	d	1997
70					Bicha	C (lake)	C				1400	0				1997
72		2	1		Bicha	C (fallow)	C	1	1	3	1420	1.5 W	0	s	d	1997
77	1				Bicha	C (fallow)	C	1	2	2	1410	3 E	40	s	d	1997
83		1	3	2	Bicha	C (fallow)	C	1	1	3	1420	4 E	5	sh	e	1997
84		1	2		Bicha	C (fallow)	C	1	1	4	1420	4.5 E	0	s	e	1997
85			2		Bicha	C	C	1	1		1400	0.5 W	0	s	d	
87		3	2		Bicha	C	C	1	1		1390	0	0	s	d	
33			1		Bicha	G	?	1	1	3	1400	2 SW	0	sl	d	1996
67			1		Bicha	G	G	1	1	2	1460	18.5 N	60	ls	t	1997
68			1		Bicha	G	G	1	1	3	1470	17.5 N	60	sh	t	1997
69		2	1		Bicha	G	G	1	1	4	1460	4 E	0	s	e	1997
71			3		Bicha	G	?	1	2	3	1430	2.5 W	0	sl	d	1997
78					Bicha	G	?	1	2	3	1410	?	40	s	e	1997
79					Bicha	G	?	1	1	3	1430	2.5 W	10	sh	e	1997
80	1		1		Bicha	G	?	1	1	3	1420	4 E	40	sl	e	1997
81			1		Bicha	G	C	2	1	3	1450	5 NW	10	sh	e	1997
82			1		Bicha	G	C	1	1	2	1450	4 SW	40	sh	e	1997
86			3		Bicha	G	?	1	1	4	1420	2 S	0	s	d	1997
88	1		4		Bicha	G	?	2	2	4	1390	0.5 SW	0	shl	d	1997
89			1		Bicha	G	?	1	2	3	1390	7 S	0	sl	e	1997
90					Bicha	G (lion)					1420					
91					Bicha	G (lion)					1420					
2					Chakwe E	G	G	1	1	3	1550	4.5 SW	5	s	e	1996
4					Chakwe E	G	G	1	1	2	1520	7 NW	20	s	e	1996
5					Chakwe E	G	G	1	2	3	1490	3.5 SW	0	sl	d	1996
6		1			Chakwe E	G	G	1	2	4	1520	7 E	0	sl	e	1996
7					Chakwe E	G	G	1	1	2	1520	7 E	5	s	e	1996
8			2		Chakwe E	G	G	1	1	3	1520	7 E	5	s	e	1996
9		1	1		Chakwe E	G	G	1	2	2	1520	3 E	0	sh	e	1996
73					Chakwe E	G	G	1	1	2	1570	5 NE	2	sh	t	1997
74					Chakwe E	G	G	1	1	2	1530	7 SW	25	s	e	1997
96					Chakwe E	G	G	1	1	1	1540	4.5 NE	0	s	t	1997
97					Chakwe E	G	G	1	2	2	1540	6 W	5	s	e	1997
98					Chakwe E	G	G	1	1	2	1550	3 S	0	s	e	1997
99					Chakwe E	G	G	1	1	1	1540	4 N	60	s	e	1997
75		1			ChakweW	C	?	1	1		1490	3 W	0	s	d	
76		4			ChakweW	C	?	1	1		1490	1 W	0	s	d	
102	2	10	1		Goima	C	C	1	1		1400	1.5 W	0	s	e	
103			2		Goima	C	?				1400					

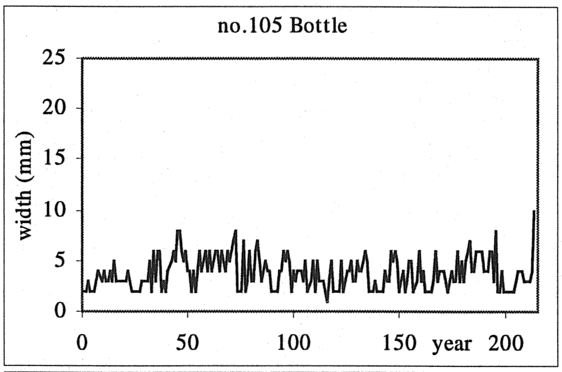
plot	size class				area	landuse		tree l.	shrub l.	field l.	elev.	slope	stone	soil	catena	fire
	S	C	B	O		present	< 1975				m a.s.l.	deg.	%			year
104			1		Goima	C	?				1400					
17		1		1	Mission	C	C	1	1		1370	0	0	s	d	
18		3	3		Mission	C	C	1	1		1370	0	0	sl	d	
19			2		Mission	C	C	1	1		1380	0	0	s	d	
20			1		Mission	C	C	1	1		1370	0	0	s	d	
21			1		Mission	C	C	1	1		1370	0	0	s	d	
22					Mission	C (river)					1370	0				
23		1			Mission	C	C	1	1		1370	0	0	s	d	
24		1	1		Mission	C	C	1	1		1390	0	0	s	d	
25	1				Mission	C	C	1	1		1390	0	0	s	d	
12			7		Kondoa	C	G	1	1		1410	5 S	0	sl	e	
13			2		Kondoa	C	G	1	1		1400	2.5 N	0	s	e	
14			3		Kondoa	C	G	1	1		1390	5 E	0	s	e	
15	1		3		Kondoa	C	G	1	1		1400	2 N	0	sl	e	
16		1	2		Kondoa	C	G	1	1		1370	3 N	0	sl	d	
26	1	1	3	1	Kondoa	C	G	1	1		1370	3 NW	0	s	e	
27		1	1		Kondoa	G	G	1	1	2	1390	3 NE	5	s	e	1997
28	1		4		Kondoa	C	G	1	1		1410	5.5 W	1	sl	e	
29		1	7		Kondoa	C (house)	C	1	1		1400	3 W	0	s	d	
30	1	1	7	1	Kondoa	C	?	1	1		1400	2 NE	0	s	d	
31			7		Kondoa	C	?	1	1		1400	2 E	0	s	d	
32	2	3	4		Kondoa	C	?	1	1		1400	2 N	0	sl	d	1996
50			6		Kwantisi	C	C	1	1		1390	2 S	0	s	e	
51	2	2			Kwantisi	C	C	1	1		1380	1 W	0	s	e	
52		2	13	1	Kwantisi	C	C	1	1		1390	2.5 S	0	s	e	
53			16		Kwantisi	C	C	1	1		1390	3 SE	0	s	e	
54		2	15		Kwantisi	C	C	1	1		1380	0	0	s	d	
55		4	9		Kwantisi	C	C	1	1		1390	0	0	s	d	
56		1	7		Kwantisi	C	C	1	1		1390	0	0	s	d	
57		2	3		Kwantisi	C (river)					1370	0				
58		1	4		Kwantisi	C	C	1	1		1370	2 W	0	sl	d	
59		2	2		Kwantisi	C	C	1	1		1370	2 W	0	sl	d	
60			1		Kwantisi	C	C	1	1		1370	1 W	0	sl	d	
61		1	10		Kwantisi	C	C	1	1		1390	5 E	0	sl	e	
62	1	8	9		Kwantisi	C	C	1	1		1390	2 E	0	slh	e	
63		1	13	1	Kwantisi	C	C	1	1		1400	2 W	0	slh	e	
64		5	5		Kwantisi	C	C	1	1		1400	2 W	0	s	e	
65		2			Kwantisi	G	C	1	1	2	1390	1 S	0	s	d	1997
66	1	3	1		Kwantisi	C	C	1	1		1390	1 S	0	l	d	
1					Gongo	G	G	1	2	2	1720	8 S	1	sl	e	1997
3					Gongo	G	G	1	2	3	1740	4.5 NW	0	sl	t	1997
10					Gongo	G	G	1	2	2	1770	5.5 N	10	sl	e	1995?
11					Gongo	G	G	1	1	2	1770	10 SW	0	s	e	1995?
36					Gongo	G	G	1	2	2	1700	1.5 SE	5	s	e	1995?
37					Gongo	G	G	1	1	2	1680	0.5 E	5	s	e	1995?
38					Gongo	G	G	1	1	1	1720	5 E	0	sl	e	1995?
39					Gongo	G	G	2	3	2	1770	5.5 NE	20	lh	e	1995?
40					Gongo	G	G	1	3	2	1680	3 E	5	sl	e	1995?
41					Gongo	G	G	1	1	2	1680	5 S	2	s	e	1997
42					Gongo	G	G	1	2	2	1710	6 W	1	s	e	1997
43					Gongo	G	G	2	3	2	1680	3.5 SW	10	sl	e	1997
92					Gongo	G	G	1	2	2	1710	5.5 N	0	s	e	1997
93			1		Gongo	C	?	1	1		1690	3 S	0	sh	e	
94					Gongo	G	G	1	2	1	1670	?	60	s	e	1997
95					Gongo	G	G	1	3	2	1700	9 E	12	s	t	1997

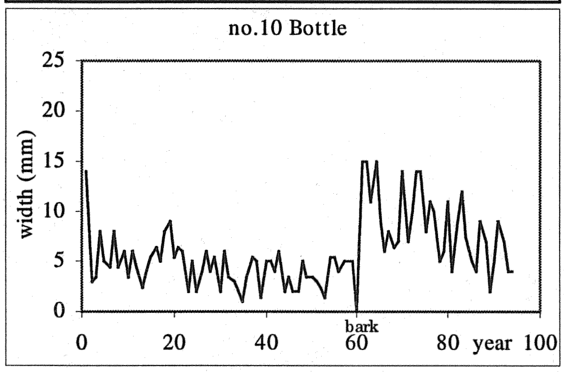
Annual rings

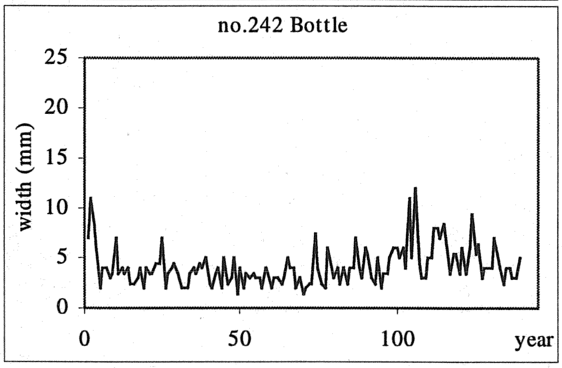
Appendix 4

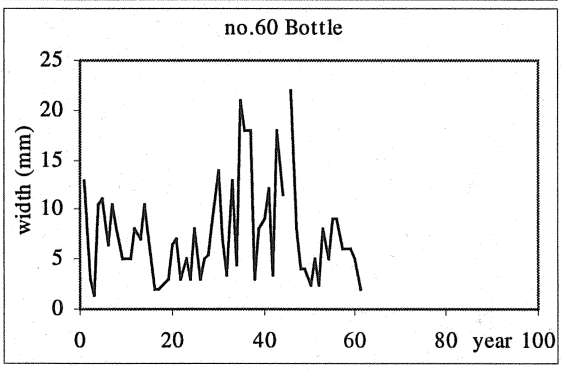
Ring width, mm, at number of years from cambium for cored Baobab trees, marked with individual number and size class.

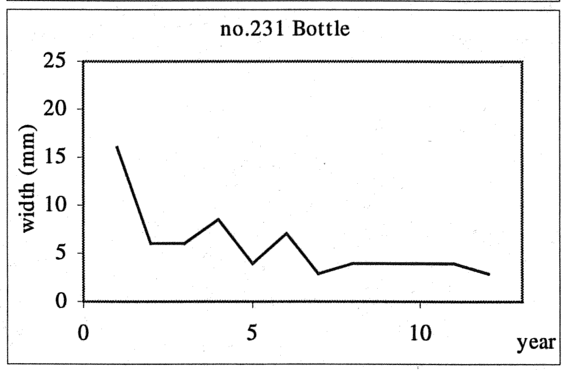


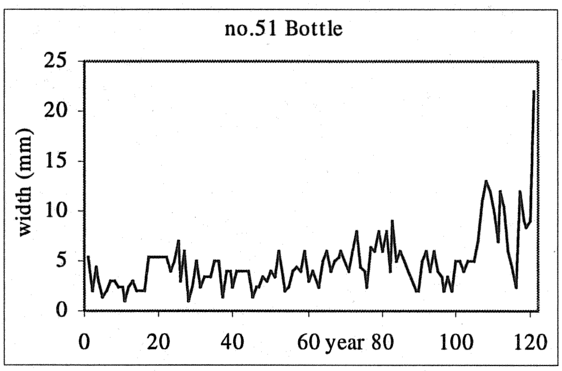


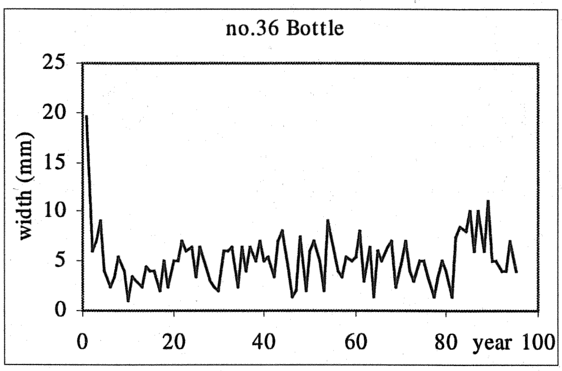


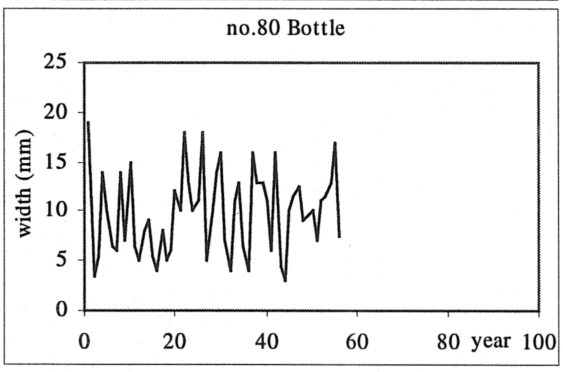


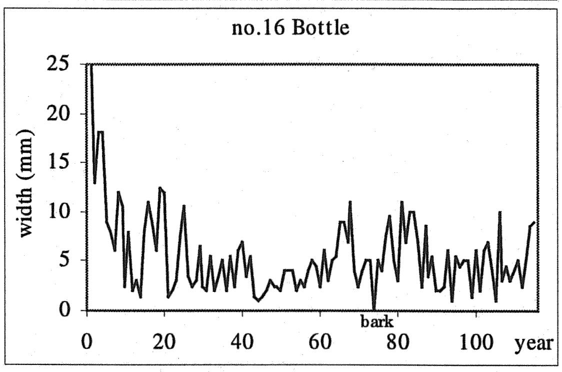






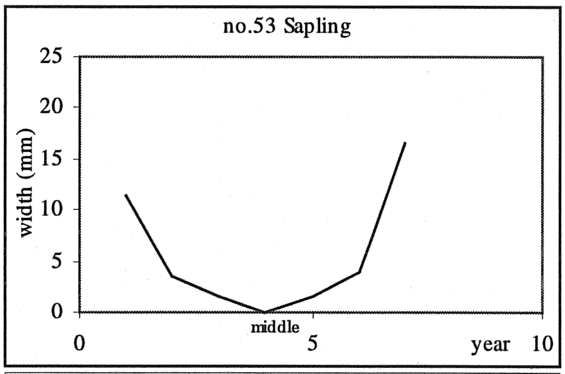


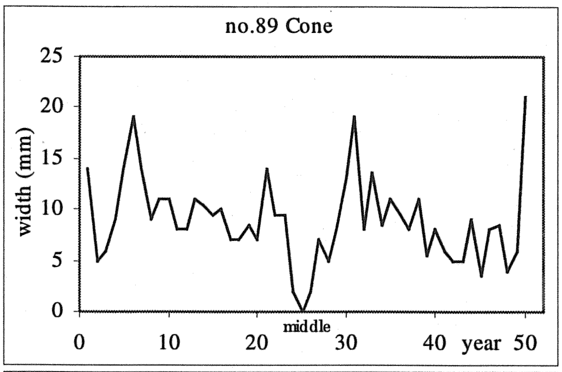


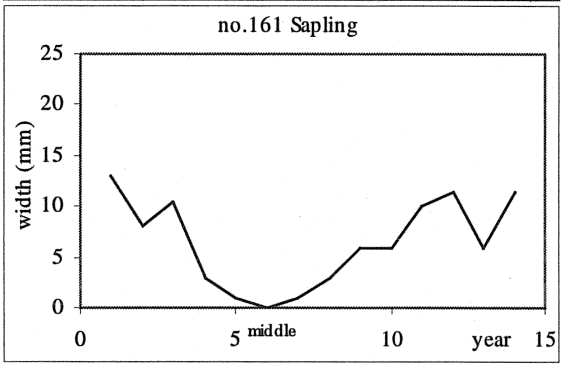


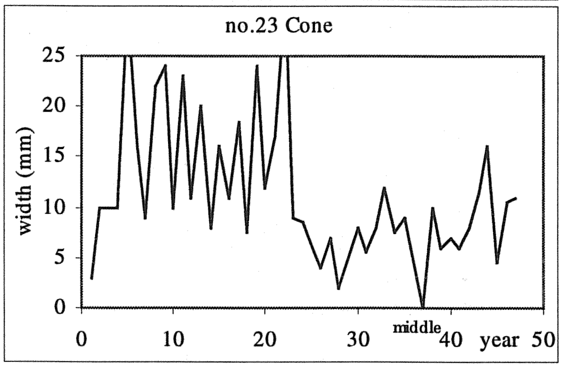
Annual rings

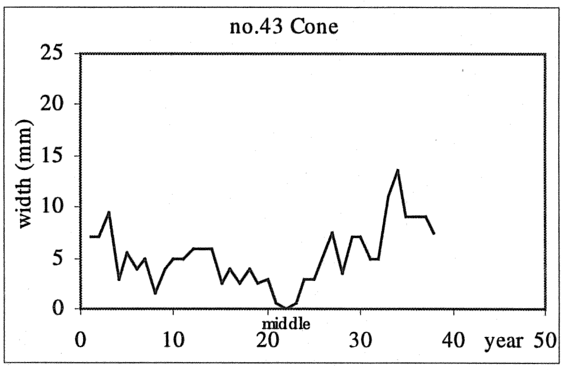
Ring width, mm, at number of years from cambium for cored Baobab trees, marked with individual number and size class.

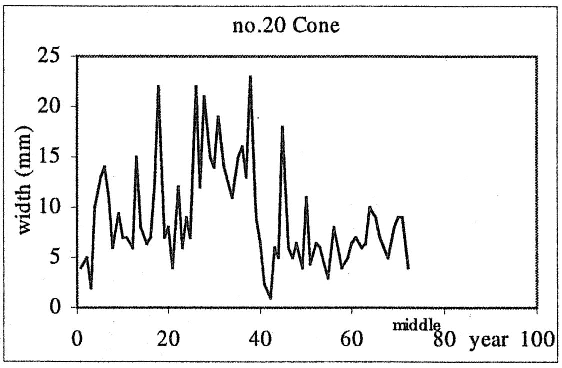


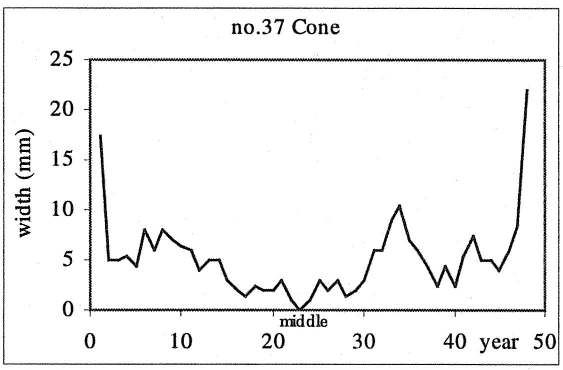


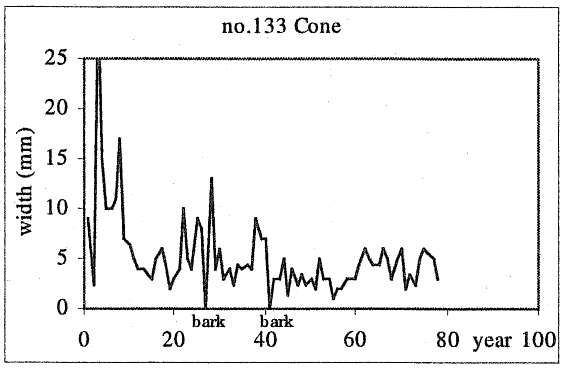


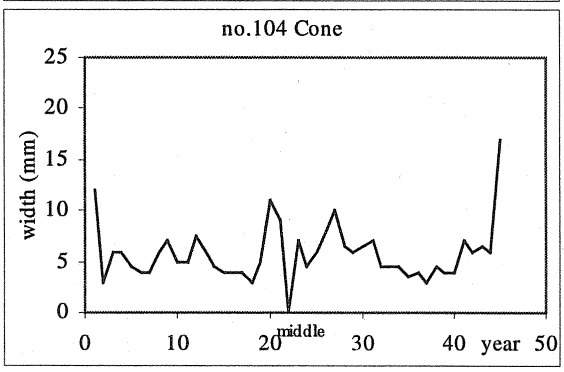


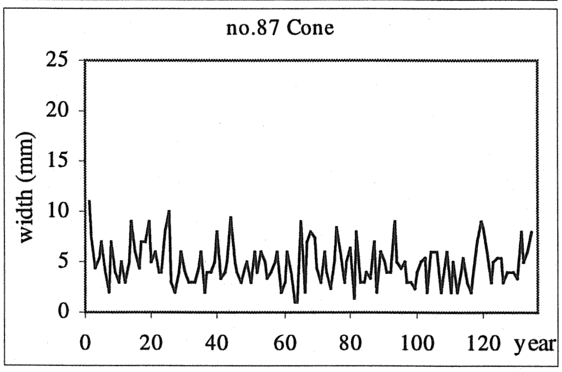








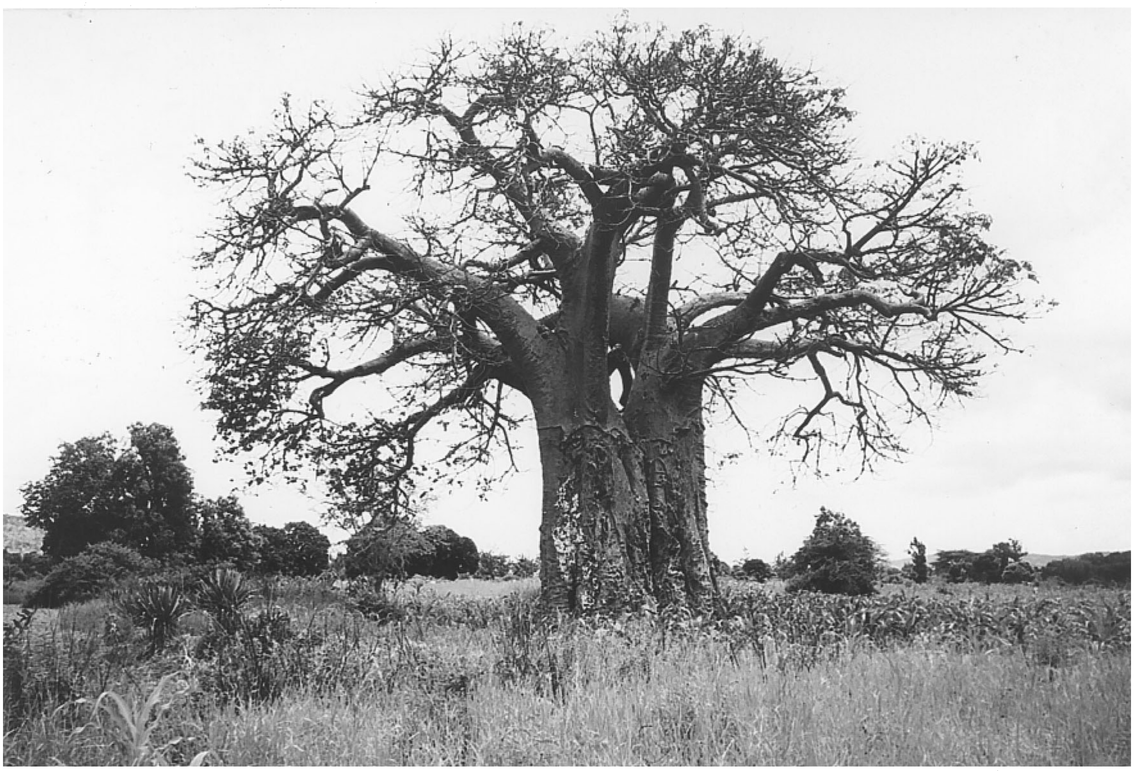




Part II: Literature study

Objective

This is a presentation of the background data on the Baobab tree, which I found in literature preparing for the field study. The information was too extensive to include in the field study (part I) so it is presented separately in this literature study (part II). Both parts can be read separately and some overlapping occurs. There are only a few population studies on the Baobab tree and most of them are on the Baobab in relation to elephants. I will discuss the differences in population parameters found in different studies, and compare them with my own findings. I also will discuss the theories presented in some of the studies. The presentation includes some interesting facts about the economic and cultural importance of the Baobab tree. The literature study also contains a presentation of background information about the study area, Kondoa Irangi Hills, and more specifically, Kondoa Eroded Area.



Kondoa Eroded Area and Kondoa Irangi Hills

Geology

Kondoa Eroded Area (KEA) is situated in the Irangi Hills in north central Tanzania (Lat. 4° 55´ S, Long. 35° 45´ E) (Fig. 1). The Irangi Hills were formed by a recent uplift of the bedrock from the Masai Plains, by a massive escarpment associated with the Central Rift Zone. The altitude ranges from 1000 m a.s.l at the foothills to 2190 m a.s.l. at Tomoko Hill at the edge of the escarpment in the northeast (Fig.2). The valley floors are typically situated at an altitude of 1300-1600 m a.s.l. The bedrock consists of deeply weathered precambrian gneisses and schists and is highly erodible. The hills are characterized by pediment slopes, from which inselbergs rise, and by ephemeral streams which cut into the erodible soils and form large gully systems. In the lower areas, the streams broaden out into wide sand rivers (Östberg 1986). The soils are deep, red or white, coarse loamy sands to sandy loams, low in nutrient content, organic content, base exchange capacity and water retention capacity. The more fertile soils in the valley floors are being buried by recent colluvial sand deposits (Payton et al. 1994).

Climate

The climate in the Irangi Hills ranges from semi-arid in the southwest, with about 600 mm rainfall per annum, to sub-humid in the Tomoko Hills with about 900 mm per annum. The 60-year median annual rainfall at the meteorological station in Kondoa town is 641 mm. Years with considerably less rainfall are common, resulting in crop failures and food shortage. The rainfall regime is highly erosive, falling as high intensity storms between November and May, with the heaviest rains falling between December and January. The long dry season lasts from May to October, with high temperatures reaching to above 23 °C in October. At the end of the rains, in May, the temperatures fall to as low as 16 °C. The yearly mean temperature for Kondoa town is 20.3 °C. The potential evapotranspiration is four times the rainfall (Mbegu et al. 1984). The only permanent water is in Lake Haubi, the Bubu River that forms KEA's border to the west, and a few permanent springs. The most important spring is Chem-Chem that provides water to more than 12 000 people in Kondoa town. Lake Bicha, 2 km east of Kondoa town, was formerly a permanent lake but today it is sedimented and ephemeral (Payton et al. 1994, Mbegu 1984, Ngana 1994, Eriksson 1998).

Vegetation

The vegetation of Kondoa Irangi Hills consists at the present of dense grassland, woodland and secondary forest. "Woodland" is defined as an open formation with a field layer dominated by grasses, while "forest" refers to a closed formation with a closed canopy and generally without dominance of grasses. The grassland vegetation is still mainly in early successional stages of poor grazing value, probably due to soil degradation. The succession of the grassland into wooded vegetation is also hindered by frequent dry-season fires. When ungrazed, the dense grass provides plenty of fuel that easily catches fire. Grasses and shrubs are also deliberately burnt before the rainy season to create a better pasture. Trees and shrubs are cut for fodder and charcoal burning. At altitudes between 1000-1600 m a.s.l. the valley floor is used for cultivation and the steeper slopes are used for grazing. The vegetation in the grazed slopes is wooded grassland, dominated by grass species like: *Brachiaria brizantha, Eragrostis cylindriflora, Heteropogon contorta, Hyparrhenia filipendula* and *Rhynchelythrum repens*. Scattered trees in the grassland are, among others: *Acacia tortilis, A. seyal, Commiphora africana, Euphorbia candelabrum* and *Senna singueana*. Secondary forests occur mainly at higher elevations, maybe because of less disturbance or a wetter climate. The woodlands dominated by *Brachystegia spiciformis* and *Julbernardia globiflora* at altitudes between 1600-1700 m a.s.l. probably originated during the period when KEA was heavily grazed and the field layer was reduced. At altitudes above 1700 m a.s.l. the forest is dominated by *Brachystegia microphylla* and at altitudes above 1800 m a.s.l. at Tomoko hill there is a small remnant of an evergreen humid forest, diminishing at an alarming speed (Backéus et al. 1994).

People

In Kondoa district, the population density was 25 persons per km^2 in 1985 but in the enclosed area of KEA it is considerably higher. Today, the Irangi Hills are dominated by the Rangi people, constituting about 85 % of the population. It is believed that the Rangi people colonized a limited area at Haubi in the 18th century, and from there expanded rapidly, today populating almost all of the Irangi Hills and still expanding into adjacent areas e.g. Burunge hills. The Rangi people were earlier agropastoralists but have become more dependent on pure agriculture as their major economic activity (Mung'ong'o 1991). The south-east of Kondoa is populated by the click-speaking Sandawe people. The Masaii and the Barabaig are nomadic pastoralists that for thousands of years have taken their animals to graze in the Irangi Hills in the rainy season. The Burunge Hills ca. 30 km south-east of Kondoa, where a small part of the field study was carried out, is populated by the Burunge people that are agriculturalists and beekeepers. In the Irangi Hills, Islam is the dominating religion but the Roman Catholic church is also of importance (Östberg 1986).

History

Kondoa town has for centuries been a resting-place for the caravans across the Masaii steppe. The permanent spring is probably the reason why Kondoa town is situated where it is. The very early history of Kondoa is not well documented. During the first half of the 19th century the human population density was still low in the Irangi Hills and the pressure on land was moderate. The vegetation of Kondoa probably consisted of woodlands and grass-covered plains. Soil erosion was reported from the area of Kondoa as early as in the 1850's (Östberg 1986). Erosion occurred in the form of gullies in certain places along the caravan route. The caravan trade had become more intense and came to have a greater impact on the fragile landscape. As the need of grain and cash crops increased, woodland was cleared up the hillsides and soil erosion followed. The Rangi people had already outgrown their original area in Haubi and had established themselves over the highlands. This state was temporarily changed by the turn of the century. The cattle suffered from epidemic diseases, including the rinderpest in the years 1890 to 1891, and this eased the grazing pressure on the land. These conditions were followed by droughts and locust invasions, which caused famine and reduced human population (Östberg 1986).

To get rid of the tse-tse nuisance, a clearing of woodlands was initiated by the British administration, in 1927 that continued through the 30's and 40's. With this deforestation, erosion accelerated and in 1930 the government came to consider soil conservation measures a matter of importance. People were discouraged from cultivating slopes, the agricultural department advocated contour ridges on cultivated land, schemes for rotational grazing were organized, and sisal was planted with the purpose to stop soil erosion (Mbegu et al. 1984). In the 1930's water facilities for the cattle were improved as an attempt to disperse the animals and thus reduce the erosion along the cattle tracks. Unfortunately, this also resulted in growing herds, which led to more pressure on the land, and despite all conservation efforts the situation grew increasingly serious. At this time the "Kondoa Eroded Area" in Irangi Hills became a concept that exemplified the enormous problems that soil erosion may cause in semi-arid environments (Östberg 1986).

After Tanzania's independence, the conservation measures of the colonial government were no longer upheld. Population grew fast and the double burden of need of more food and demands of cash crops laid pressure on the area and people began to clear even the steepest hillsides. This pressure was still not eased in the 70's. At this time the soil conservation concept was renewed and considered in new forms by the policy of President Julius Nyerere (Östberg 1986). In the early 1970's, large areas were virtually without any kind of vegetation cover (Backéus et al. 1994). Erosion had by then caused an acute shortage of arable land for the inhabitants of Irangi (Östberg 1986).

In 1973 the Tanzania government initiated the HADO-project (HADO stands for Hifadi Ardhi Dodoma which means, "soil conservation in Dodoma"). The main resources were concentrated to Kondoa Eroded Area (KEA), which covers 125 600 ha. Conventional land conservation methods proved ineffective in KEA and in cooperation with the District leadership it was decided to close the area to livestock. Some 90 000 domestic animals were moved out of the area, thereby transforming the predominantly agropastoral economy of the Rangi people in one drastic move. This destocking in combination with the Ujamaa reform (the Tanzanian villagisation reform in the early 1970's) was not acceptable to a big part of the population. Land conservation was viewed as colonial oppression and the relations between HADO and the Rangi people were hostile. Violation of the prohibitions of grazing and charcoal burning were common and even sabotage against HADO occurred. Today, the relation is more relaxed (Mung'ong'o 1991).

There has been a dramatic regeneration of vegetation since the destocking. The vegetation recovery seems to have eased the degree of erosion, the sediment transport in the streams has decreased, the sand rivers have been stabilized, there is water in the streams further into the dry season, and some wells have regained permanent water (Christiansson 1988). At present, no free grazing is allowed but in the rainy season small herds of freely grazing cows, sheep and goats, are a common sight. In the future, only a strictly regulated grazing would be sustainable (Backéus et al. 1994).

The Baobab tree

Classification

The Baobab tree, *Adansonia digitata* is a member of the pantropical family *Bombacaceae*, which constitutes about 29 genera and 225 species. *Bombacaceae* systematically stands close to the cocoa-, and cotton-families (*Sterculiaceae* and *Malvaceae*). Most members of the family are found in the tropical rainforest of South America, such as the Kapok tree and the Balsa tree. The genus *Adansonia* with its 9 species, occurs in tropical Africa (*A. digitata*), western Madagascar (7 species) and western Australia (*A. gregori*). This is a rather unusual pattern of species distribution, and could be a relic of the flora of Gondwanaland (Armstrong 1977).

Description

The Baobab is a massive deciduous tree, up to 23 m tall. The trunk is swollen and cylindrical or bottle-shaped, up to 8 m in diameter. The wood is soft and spongy, between each layer of xylem cells there is a layer of parenchyma cells that store water. Old trees are often hollow inside. The smooth bark is greyish-brown or purplish-grey. The crown is large and spreading, primary branches are short and twisted and either distributed along the trunk (young trees) or confined to the apex (older individuals). The leaves are digitate, with 5-7 leaflets, or simple (young trees), ca. 20 cm in diameter, alternate at the ends of branches. Petiole up to 16 cm long, pubescent, leaflets sessile or shortly petiolulate, elliptic with entire margins. Flowers pendulous, solitary or paired in the leaf axils, large and showy. Pedicles up to 20 cm long in eastern Africa. Sepals 3-5 pubescent, 5-9 cm long, petals 5 white 5-10 cm long. Plenty of nectar is secreted at the base of the sepals. Stamens numerous, white, joined into a staminal tube, producing large amounts of pollen. Ovary superior, 5-10 locular, style single, exerted beyond the anthers (Wickens 1982).

The fruit is a woody capsule with a very variable size and form, in East Africa ca. 7.5-25 cm, round to oval. Ripe fruits are filled with a dry mealy pulp, rich in sugars and ascorbic acid. The seeds are many, embedded in the pulp, reniform, dark brown, 0.8-1.3 cm long. The seed coat is very thick and hard. The seeds retain their viability for a long time, probably several years. The cotelydons are 4.2-6.4 x 3.3-5 cm, and square shaped. More than two cotelydons can occur. There is a great deal of variation in these features, and with a better knowledge of the species, it is perhaps possible to distinguish separate variants or subspecies. This is also supported by counts of chromosome numbers, which range from 2n=96 in South Africa to 2n=144 in West Africa (Wickens 1982).

Natural distribution

The Baobab is widely distributed throughout Africa south of the Sahara, but more particularly in the savanna regions. Under natural conditions it grows at altitudes between 0-1000 m a.s.l. with a rainfall regime between ca. 200-800 mm per annum (Wickens 1982). According to Wilson (1988), it occurs up to 1500 m a.s.l. in Tanzania as well as in Ethiopia. It is unclear if this is the natural distribution or not. The northern limit of the Baobab stretches from southern Mauritania (Lat. 16.5° N) eastwards along the 100 mm isohyet, through the Sahel to the western Sudan. To the south, the Baobab is limited by the occurrence of frost, the geographical limit stretching from southern Angola (15° S) to the tropic of Capricorn in the Transvaal, including the northern areas of the Kalahari desert and the Limpopo basin. Where the savanna extends to the coast, the Baobab grows interspersed with the coconut palm and its northern limit overlaps with the southern limit of the date palm (Owen 1974). Towards the interior of the continent, the distribution is limited by the rainforest. These are just the outer limits of distribution, and the Baobab may be absent from areas within, even where the environment is favourable to the species. Detailed knowledge of locations is fragmentary, and a Baobab map project at Kew Herbarium is attempting to collect information to plot the Baobab's distribution in half-degree squares of latitude and longitude. The Baobab prefers deep well-drained soils, but can tolerate shallow lateritic soils as well. It is a characteristic member of thorn woodlands and wooded grasslands. It grows solitarily or in small groups interspersed with other tree species such as *Acacia* spp. Its natural range has been extended by Man in all parts of Africa by clearing of forest for agricultural land (Wickens 1982).

History and names

Baobab fruits have been reported from the ancient Egyptians' tombs, although the tree is not native in Egypt. The earliest record of the Baobab in literature is from an inscription near Aswan made by a caravan leader in ca. 2500 BC. The fruit was probably brought from Sudan to the Cairo market for its medicinal properties as a febrifuge. The name Baobab is perhaps a derivation of the Arabic *bu hibab* – "the fruit with many seeds" a name used by the Cairo merchants during the sixteenth century. The name *Adansonia* was given by Linnaeus in honour of the French botanist Michel Adanson (Wickens 1982). In Europe, the Baobab is also called "the monkey bread tree" because monkeys eat the fruit. In Swahili it is called "Mbuyu", in the Rangi language "mwiwi", in the Burunge language "dackau" and in the Barabaig language "gendergen" (Matari pers. comm.).

Economic importance

Throughout its distribution, the Baobab tree plays an important role in the local economies - practically all parts of the tree can be utilized. It provides food and forage, shelter, medicine, fibre and a suitable place to hang beehives. Many studies have been made on the chemical composition of the compounds used in traditional medicine.

Decoctions of the root can be used against malaria, to treat stomach-pains and to bathe babies in to give them smooth skin. A soluble red dye can be obtained from the roots and they can also be cooked and eaten in times of famine. The bark contains several alkaloids and has antiseptic properties. It tastes bitter and was exported to Europe to treat fevers as a substitute for *Chinchona*-bark. In East Africa it is used as an antidote to *Strophanthus*-poisoning and as a mouthwash against toothache. The flesh of animals killed by poisoned arrows can be restored by pouring the juice of the Baobab bark into the wound to neutralize the poison. Babies bathed in a decoction from the bark are believed to grow as big as the Baobab tree, but they must not get it on their head, as then the head will grow too big! In some countries the bark is used for tanning, it can also be used to make potash. The bark contains a white acidic gum which is used to clean wounds (Wickens 1982).

The most important use of the bark is to make fibre. The inner bark yields a particularly strong and durable fibre suitable for making ropes, baskets, nets, strings for musical instruments, etc. In Kondoa, the Rangi people make a special big grain storage container from the fibre, and filters for filtering the Baobab beer and beeswax (Nkana 1991). The bark is often completely stripped from the lower part of the trunk, but the Baobab tree survives and regenerate new bark within two years. Trees that have not yet been harvested for bark yield a fibre of higher quality, and the Rangi people prefer the younger trees (Matari pers. comm.).

The wood is soft and spongy and almost useless as timber (it can be used for making light canoes), but the trunk is used in other ways. Man usually learned where the old hollow trees were standing and collected water from the cavity within the tree. This is known from the Bushmen in South Africa and the Ethiopian slave traders crossing the driest parts of Kenya. In Mali and Sudan the trunks of Baobab trees have been hollowed out artificially for decades, storing up to 9000 liters of water, and keeping it sweet for several years if the hollow is kept well closed. In West Africa, the hollow trunks may be used as tombs, in Senegal members of the griot caste, poets and musicians, were buried in the hollow Baobab trees, so that their bodies were mummified and not polluting the earth (Wickens 1982).

Many people in Kondoa district are beekeepers, placing their beehives in Baobab trees, among other trees. The branches are strong enough to hold the heavy beehives, the flowers produce an abundance of high quality nectar, and the smooth bark prevents honey-stealing animals from reaching the beehives. The Burunge people in Goima are beekeepers, but do not plant Baobab trees, instead they nurse them and prune them to make them grow tall quickly, so that the "Njegere", the honey badger, (*Mellivora capensis*) can not destroy the beehives (Matari pers. comm.).

The young leaves are eaten as a green vegetable (mchalada in the Rangi language). They are rich in vitamin C, amino acids, sugars and calcium. In West Africa the leaves are used as fodder for the animals. The tree may be pollarded in order to produce more young leaves. The leaves are also used medicinally, to promote perspiration and treat kidney and bladder trouble, to treat inflammations, fever, asthma, dysentery genital-urinary disorders, guinea worm and insect bites. An infusion of leaves and flowers is used to cure respiratory and digestive disorders. Burnt leaves can be used as a fumigant. However, there is no record of any use of Baobab leaves as medicine in Kondoa district (Nkana 1991).

The fruit is used in several ways, the hard fruit shells can be used as vessels or fishing floats, they can be burnt as fuel and provide a potash suitable for soap-making. The seeds have a nutritional value similar to many leguminous seeds, but the very hard seed coat limits their use. They can be used as fodder or roasted and ground into an oil-rich paste used as a substitute for cooking oil or coffee. They can also be germinated and eaten as sprouts. The most important use of the Baobab fruit in Kondoa is the fruit pulp that covers the seeds. It is rich in sugars and has a vitamin C content four times that of an orange. It also contains pectin. The pulp tastes sweet and children eat it as sweets. From the pulp, the Sandawe people and others make an alcoholic brew. The pulp-covered seeds are boiled in water until all the pulp is removed. The white liquid is left to cool down and can be taken as an refreshment, plain or mixed with sugar or milk. This Baobab juice will soon start to ferment. The Sandawe people add yeast and malt flour to make the brew stronger. It seems as if this treatment makes the seeds germinate more easily, and we were told of a factory making Baobab beer which had a "forest" of young Baobab trees in their backyard. The pulp is also used as medicine, to curdle milk and to coagulate rubber latex (Nkana 1991).

Cultural importance

Maybe because of its divine appearance and its life-saving abilities as a medicine and oasis, there are religious beliefs and stories connected to the Baobab tree throughout Africa. It is widely believed that God planted the tree upside down. In Tanzania, people say that the Baobab was boasting in front of all the other savanna trees, that he was the biggest and most beautiful tree. Then God got angry and pulled him up and threw him back upside down, and said: "You may be the biggest, but not the most beautiful!" In West Africa, spirits are believed to live in the Baobab tree, so people worship and care for it. In Zimbabwe, the Baobab is believed to be bewitched and misfortune will fall on the countryside if it is killed. It is widely believed that there are no young Baobabs, they spring into being fully grown! (Wickens 1982).

Autecology

Very little is known of the ecology of the Baobab tree, not even more precise details of its habitat requirements. The habitats are different in different parts of Africa. Because of its widespread distribution, it is part of many different vegetation types, depending on geology, rainfall and the associated plant species. Population densities and structures are different in different areas, fecundity, mortality and survival depends very much on rainfall and interaction with other species in the area.

Age

The big size of the Baobab tree has led many authors to assume great age. In 1749, Adanson used the inscriptions made by European sailors in the fifteenth century, to calculate the age of two trees in the Cape Verde islands to 5150 years. In 1853, David Livingstone used growth rings and calculated an age of 4000 years for a tree in Botswana with a girth at breast height (GBH) of 25.9 m. Guy (1970) used the increase of diameter of a tree in Mozambique, measured by Livingstone in 1858. In 107 years it had increased from 23.04 m girth to 24.53 m, which gives an average radial increase of 1.68 mm per annum. Considering a declining growth rate, and the fact that there may be no girth increment at all, or even shrinking, for long periods of time, he estimates the age to more than 1700 years. In a later article Guy (1982) cautions against the use of girths to estimate Baobab age. Variations in girth caused by hydrostatic swelling and shrinking of the trunk may mask the actual cambial growth.

Swart (1963) was the first to use carbon-dating to calculate the age of a wild tree, with a girth of 14.4m (at 60 cm height) felled at Lake Kariba 1960. The heartwood gave an age of 1010 ±100 years, and a sample midway between the centre and cambium gave an age of 740 ±100 years. The calculated mean annual increase of radius the last 740 years is 1.5 mm, the actual measured growth rings were ca 1.1 mm, the outermost

20 centimeters. This tree was only 14.4 m in girth, and if it had been able to continue growing 1.5 mm per annum for 1000 more years it would have reached a girth of 23.8 m, almost the size of Guy's tree. But the size of a Baobab tree is not well correlated to its age, the annual increase, or decrease, in radius is highly dependent on the rainfall, and trees can not be compared between areas with different rainfall history. Wilson (1988) claims that in general, big Baobabs are younger than earlier believed, and only a very few trees are likely to achieve great age.

Germination

Although the Baobab is such a long-lived tree and the fact that a big tree may have thousands of fruits, each containing many seeds, the species is not particularly abundant. This seems to imply that natural regeneration is rather poor (Wickens 1982). There are no studies of germination in the field, but artificial germination tests give low germination rates, between 0-10 % for untreated seeds. The seeds seem to have a seed coat induced dormancy (Etejere et al. 1984). The seed coat can induce dormancy in two ways, by the hard and water-impermeable testa, or by inhibitors that prevent the seed from germinating at the wrong time (Essenwo 1990). In nature, this dormancy is believed to be broken by fire, a longer period of rain or perhaps digestion by an elephant. It is generally believed that the Baobab has long seed dormancy (Wickens 1982, Owen 1974).

Essenwo (1990) and Danthu et al. (1994) have tested different scarification methods for commercial use. Soaking the seeds in concentrated acid (HCl and H_2SO_4) for one hour can increase germination percentage (GP) to 41-98 %. Boiling the seeds in water for 5 s.-5 min., gave a GP of 21-57 %. Prolonged soaking in hot water (50-60 ^{o}C) gave a GP of 38-70 %. Manual partial decoating of the seed gave a GP of 65-85 %. Soaking in cold water for 30 minutes -10 days gave a GP of 7-13 %, not significantly different from the control. In all treatments, Essenwo had the higher germination percentages, except for untreated seeds, which did not germinate at all. The methods in the two tests are not directly comparable, but different results may also depend on the origin and age of the seeds. Essenwo concludes that the fruit pulp inhibited germination, since soaking for 3 days in distilled water stimulated 50 % germination. It was observed that seeds with the pulp still intact can not germinate. Reports on germination time suggests that they are very variable, some germinated after 12 days, others after 21 days, while some were found to germinate readily after the pulp was soaked off in water (Wickens 1982, Danthu et al. 1994).

Growth and development

The seedling's first leaves are simple, followed by digitate leaves with progressively more leaflets, up to the 5-7 leaflets of the adult tree. The simple leaf form may persist for years, or in combination with 2-3-foliolate leaves. Seedlings and young saplings lack the characteristic swollen trunk of the adults. The sapling develops a deep tap-root. In areas with a distinct dry season, the Baobab forms annual rings, ring counts from trees of known age have been within 2 % of the known age (Wickens 1982). As the trunk grows and thickens with increasing moisture content, four stages of growth can be recognized (Breitenbach 1985). First the sapling increases in height, up to ca 3-6 meters height, in this phase the increase in radius is quite moderate, annual rings may be between 1.3-6.5 mm depending on water supply. Then the tree starts to swell at the base and gets a cone-like shape, the faster a tree grows the bigger is the basal thickening. The branches are small and distributed along the trunk, the tree increases in height up to 5-15 meters, the girth up to 2.5-6.9 meters. In this phase the Baobab grows at its fastest rate, and annual rings up to 18.3 mm have been recorded. Some time during this phase the first flowering occurs.

When the tree has reached its mature height, 10-20 m, the increase in radius at breast height slows down to around 2-10 mm per annum. The trunk adopts a more bottle-like shape, with a uniform diameter except for a constriction just below the branches, which now are more confined to the top. Finally a widespread branching crown is produced, the trunk increases in radius but with a slower rate the older the tree is, 0.1-1.5 mm per annum is recorded. Even shrinking with up to 10 mm in one dry season has been recorded for big individuals. The mature Baobab produces an extensive root system of massive lateral roots, the taproot of the sapling has withered away. Old individuals often become hollow inside, and may consist of several trunks. If the main trunk dies or falls, new trunks can develop from vegetative shoots from the base (Wickens 1982).

There is only scattered evidence of different growth rates in different phases of the Baobab's life. Guy's, Livingstone's and Swart's estimated growth rates for old individuals were presented above. One famous tree at Bagamoyo Mission station in Tanzania is often cited. It was transplanted in 1869 when it was 2 m high, the age was estimated to 2-4 years. In 1913 it was 20-25 m high and had a girth at breast height of 542 cm. In 1927 the girth was 680 cm, and in 1956 it was 27-28 m high and the girth was 779 cm. This gives growth rates of about 18.3 mm per annum the first 44 years, 15.7 mm per annum next 14 years, and 5.4 mm per annum the last 29 years (Guy 1970).

Breitenbach (1985) has followed 40 planted specimens of known age, 12-92 years old, in Transvaal since the beginning of the seventies. He showed that the growth rate was moderate up to 10-15 years, then it accelerated and had its maximum at 60-70 years, before levelling out or declining in the case of his oldest individuals. He tried to delimit the different phases of the Baobab's life and called them: Sapling (up to 10-15 years), Cone (up to 60-70 years), Bottle (up to 200-300 years) and Old (up to 500-800 years). These phases are quite easily recognized in the field, and I have used them in my study, even if they are not easily delimited by girth at breast height (GBH). One tree may have the shape and growth-rate of a cone even if the GBH is bigger than for another tree behaving like a bottle. There are also intermediate individuals.

Adaptations

The Baobab is very well adapted to drought and fire, two major natural hazards in the savanna. The whole trunk is a water-storing organ, which can expand or shrink depending on the water status of the tree. The tree in Botswana measured by Livingstone in 1853 had shrunk from 25.9 m GBH to 24.5m in 113 years (Guy1974). De Villiers (1951) has recorded contractions of the trunks of several trees at the Messina sample plot in Transvaal during the dry period between 1931 and 1946. Fenner (1980) found both monthly and diurnal fluctuations of the girth of Baobab trees in Kenya.

One effective adaptation in an environment where rains are unpredictable, is the ability to survive without leaves. If the rainy season does not come, the tree does not set any leaves that year. It uses the water stored in the trunk, and a distinct green layer just below the waxy outer surface of the bark is used for photosynthesis and provides just enough carbohydrates to survive this hibernation (Owen 1974). The Baobab leaves are very water efficient, even though they lack typical water-saving features, like hairs, sunken stomata or thick cuticule. Compared with eight other species, the Baobab had the lowest rate of water loss per unit leaf area, its rate being less than half that of *Boscia coriacea*, a rather sclerophyllous species (Fenner 1980).

Adult Baobab trees have an outstanding ability to withstand the intense bush-fires that rage the savannas in the dry season. The thick bark is fire resistant and has amazing regenerative powers. Regrowth results in the thickened gnarled bark that resembles elephant skin, which serves as an added protection against fire. It is possible that seed germination is adapted to bush-fires, since heat treatment of seeds can enhance germination (Essenwo 1990, Danthu et al. 1995).

Phenology

In areas without a distinct dry-season the Baobab tree can retain its leaves throughout the year, but in Kondoa it sheds them during the dry-season. At the onset of the long rains in November the leaves develop and peak flowering occurs about a month later (Swanepoel 1993). The fruit ripens from late May and can remain on the trees until October (Nkana 1991). The leaves are shed when the dry-season starts around May. Leaf set seems to have a very high amount of plasticity. Sometimes half of the tree can be in leaf and half without in the middle of the rainy season.

Age at first flowering varies between 8-10 years in west Africa, 16-17 years (cultivated trees) in South Africa and 22-23 years in Zimbabwe. There are reports that flowering occurs just before the start of the rainy season, or even throughout the year except at the height of the dry season. Each flower follows a 24-hour lifecycle, where the buds begin to open from late afternoon and are fully open by the following morning, wilting during the next day (Wickens 1982). Mature trees do not always flower every year, Swanepoel (1993) recorded that 84% of the mature trees flowered every year. It is noteworthy that none of his 19 mature trees succeeded in producing any mature seeds during the four years the study continued. This was probably due to rain deficit, or elephant damage. All phenological features are very variable, both between populations and within them, which might be a risk-spreading strategy in an unpredictable environment.

Populations

Baobab trees are found in many different spatial arrangements, with single isolated trees along the roadside or in smaller or bigger groups. In higher rainfall areas, they may form almost a forest with a closed canopy. Population densities range between 3 to 723 individuals per km^2 in Ruaha National Park, Tanzania (Barnes 1980), and between 0.25 to 20 individuals per km^2 in Sudan. A mean density of 10.7 individuals per km^2 was reported from Mali (Wilson 1988). Many authors have noted a skewed size distribution in the populations, with very few individuals in the smaller size classes. Barnes (1994), Swanepoel (1993) and Weyerhaeuser (1985) have shown that in the national parks, this is mainly due to overpopulation of elephants who have the habit of destroying younger Baobabs in their search for water during the dry season. Guy (1970, 1982) and Wilson (1988) have presented a hypothesis that long-term changes in climate and land use have altered the size distributions towards fewer individuals in the smaller size-classes, which in the long term will result in declining populations.

Today, because of environmental change, many adult Baobabs are situated in inhospitable terrain where their offspring can not survive. Regeneration does not take place but the adults remain as relics for hundreds of years, the only threats to them being lightning, elephants and Man. Seedlings and saplings are much more vulnerable to environmental hazards like drought, fire and browsing animals. Reports on overall annual mortality rates range between 1.1 % to 3.7 % (Wilson 1988). Since regeneration is taking place in the higher rainfall areas, but not in the more arid regions, Wickens (1982) suggests a slowly contracting distribution of the Baobab tree due to a long-term change towards a drier climate in Africa.

Interaction with other species

The Baobab may be described as an umbrella species for all plant and animal species that live in, or visit the tree. It is often the only sizeable tree in the surrounding savanna, and big individuals considerably improve the local environment where it stands. One tree may be a whole small ecosystem. Under the tree the soil becomes more moist with a better texture and more organic matter, and provides a living space for plants and soil-living organisms. Epiphytic plants grow in the tree crown and weaver finches and birds of prey build their nests in the branches. The hollow trunk is utilized by birds, such as rollers, hornbills, parrots and kingfishers, reptiles such as several species of lizards and the boomslang, mammals like rodents and bats, and a great number of insect species. Among the insects, wild bees are important since their honey is eaten by the honey badger, the greater honey guide, and Man who learned to find the bees' nests with the help of the greater honey guide. Two other insects of importance to man are the "cotton stainer bug" and the mealybug. The cotton stainer bug spends one part of its lifecycle in the Baobab and the other part destroying cotton plantations by puncturing the seed capsule of the cotton plant. The mealybug acts as a vector for various virus diseases of cocoa. In the sixties and seventies a number of unsuccessful attempts to protect cotton and cocoa plantations led to large-scale Baobab eradication schemes, especially in West Africa, where the big trees were simply bulldozered down. This did not have any effect on the pests, which had many alternative hosts within the *Bombacaceae*, *Malvaceae* and *Steculiaceae*.

Pollination of the Baobab tree is carried out by three species of fruitbats, the bush baby and nocturnal moths. Wind pollination may also play a role. The flower seems to be well-adapted to bat pollination, since it opens during the night and it is big and robust with long pedicels. It has a white colour and a strong carrion smell and produces large amounts of high-energy nectar and pollen. These features also attract the bush baby and the moths, which locally may play an important role in pollination, but it is generally believed that the fruitbats are the main pollinators.

Many different animals that do not live in the Baobab tree feed on its fruits and leaves, e.g. fruit bats, domestic cattle and other grazing animals, particularly elephants. The feeding habits of the elephants have lately attracted considerable attention, since they also eat the trunk. They uproot the whole tree, strip the bark and chew the wood to obtain water during the dry season. The elephants may have played an important role in dispersing the seeds of the Baobab, since they eat the fruit and probably also swallow the seeds. The hard seed coat may be an adaptation to survive digestion by large mammals, and the animals' droppings are an ideal medium for seed germination. The fruit is also eaten by birds, squirrels, rats, antelopes, and monkeys, especially baboons. Seed transport by baboons may offer an explanation for the occasional presence of Baobabs on the summit of a hill or rock outcrop. To a great extent, Man has taken over the role of seed disperser in areas where elephants today are absent, by eating the fruit pulp and spitting out the seeds, or by the widespread practice of making an alcoholic brew from the seed pulp (Wickens 1982, Owen 1974).

Other population studies

An attempt to summarize these studies is made in Table 9 at the end of the chapter.

1. Barnes (1980, 1982 and 1994) has studied a Baobab population in the Msembe area in Ruaha National Park in Tanzania between the years 1976 and 1989. In the dry season of 1976 he measured the GBH of 328 live and nine dead Baobabs (in 15 transects 133 m wide and up to 2.5 km long). The mean density was 51 individuals per km^2 and the mortality in 1975 was 5.0 %. The size distribution of the population is found in Fig. 13 at the end of the chapter in the histogram for Tanzania. Core samples were taken from 71 Baobabs, all bigger than 1 m GBH. The last 10-20 growth rings could be measured, and a mean for each tree was calculated. The sampled trees were placed in seven size classes, and an analysis of variance showed no difference in growth rate between size classes. The mean annual increase in radius for all trees was 4.3 mm (s.d.= 0.77). By chance, he found a dead Baobab with a GBH less than 1 m, and from this he calculated the growth rate for the first 30 years of the Baobab's life. Years 0-10 it was 1.3 mm, years 10-15: 1.9 mm, years 15-20: 2.7 mm, years 20-25: 4.1 mm, years 25-30: 4.5 mm. These growth rates, plus the constant growth rate of 4.3 mm per annum for all size classes bigger than 1 m GBH, was used to convert the size distribution of the population into an age distribution.

In the age distribution only ten individuals were found in the 0-24 year age class, i.e., individuals less than 35 cm GBH. Fifty-five individuals were found in the 25-49 year age class, i.e. 36-102 cm GBH, then the number of individuals in each age class declined almost exponentially to one individual in the age class 475-500 years (GBH up to 13.2 m). The natural annual mortality rate, without the effect of the elephants, was estimated from the decline in number of individuals in each year class with the start from age class 100-124 (239-304 cm), where it is assumed that elephants had no effect, neither now nor in the past. The natural mortality rate was estimated to 1.1 % per annum. The very small size of age class 0-24 years, was considered by Barnes to be a result of higher mortality in this class due to the increased population pressure of the elephants. Even in the last 100 years there was a tendency of less regeneration or higher mortality in the smallest classes, assuming that the natural age distribution should be a declining exponential curve. A higher mortality in the younger classes was noted, and studies of the elephants' feeding behavior showed that they preferred forage on younger trees.

Barnes tried to model the future decline of the Baobab population with two different kinds of mortality patterns. In the first, a constant number of trees are killed by elephants each year, in the second a constant percentage of the trees are killed each year. In the first case, with a natural mortality rate of 1 % per annum, plus a constant number of trees equal to 3 % of the initial population killed by elephants, the Baobab would disappear from Msembe in ca. 30 years. In the second case, with a natural annual mortality rate of 1 % plus 3 % killed by elephants each year, the population would decrease by ca. 85 % in 50 years. His conclusion is that if nothing is done to ease the population pressure of elephants, the Baobab will almost disappear from Msembe in a short time, as has already happened in the eastern part of Tsavo National Park.

In the dry season of 1982 Barnes made a new study of the Msembe area. He now found that the density of Baobab trees had fallen to 27.6 individuals per km^2, a 45% decrease in 6 years. Returning to 12 of the 15 transects used in 1976 he recorded 160 trees, of which 15 had died in the previous dry season. The mortality rate was 16.9 %. Comparing the size distribution between 1976 and 1982 (in the 12 transects covered in both surveys), the percentage individuals with a GBH less than 2 m had decreased from ca 43 % to ca 11 %.

In the 1989 study, the transects of previous studies could not be found, because the records unfortunately were lost, but new ones were set up in the same area. Now the number of elephants in the park had decreased with about 60 % due to heavy poaching between about 1977 and 1984. The mean density of Baobabs was 34.6 individuals per km^2, not significantly different from 1982. Neither was the size distribution in 1989 significantly different from the size distribution in 1982. The mortality rate in 1989 was 2.1 %, significantly lower than in 1982.

2. Weyerhaeuser (1985) made a survey of elephant damage to Baobabs in Lake Manyara National Park, Tanzania. Altogether 553 individuals were measured in the dry season of 1981 and compared with a similar survey carried out in the same area in 1969. He found a size distribution similar to that of Barnes', with many individuals in the smaller size classes, but with a reduction of size class 0-1 m GBH compared with 1969. One big difference between this population and Barnes' population at Ruaha is that the biggest tree here is between 22-23 m in girth (GBH) and more than 7 % of the individuals in this population are bigger than Barnes' biggest tree of 13.2 m GBH.
The density in 1981 was 49.2 and 72.8 Baobabs per km^2 in two different areas, the density in 1969 is not presented. In 1969, the mortality was 0 (they did not find any dead trees), in 1981 it was 1.1 % caused only by elephants. Weyerhaeuser uses Barnes' growth rate of 4.3 mm per annum to translate his size distribution into an age distribution. He assumes a constant regeneration over time and that the natural mortality rate is constant for all age classes. The natural mortality rate is calculated from the regression slope of the age distribution, giving 0.47 % per annum. Mortality and bark damage caused by elephants has increased since 1969, and the percentage of individuals in the smallest size class has decreased. The relative number of trees killed or debarked by elephants was higher in the smaller size classes, and it is likely that the elephants are responsible for the reduction in the smallest size class. But, as Weyerhaeuser comments, it might also be due to a lower rate of regeneration in the recent past.

3. Swanepoel (1993) studied elephant damage to a Baobab population in Mana Pools National Park in Zimbabwe between the years 1984 and 1988. A total of 124 Baobab trees near the Zambezi River were monitored monthly, except for individuals inaccessible during the rainy season. Elephant damage was restricted to the dry season and then concentrated to individuals situated near perennial water. Small trees had the ability to coppice after being felled; 33 % of the trees with a GWH (girth at waist height) less than 7.5 m showed regrowth. Many of the individuals with a girth less than 2.5 m were thought to have originated from regrowth from earlier felled individuals. This study found no indication that elephant-induced mortality was higher in any particular size class. The annual mortality caused by elephants was 7.3 %. The density of Baobabs decreased from 18.4 to 13.1 individuals per km^2 in four years. The size distribution in 1984 was similar to that of Barnes' in 1976, i.e. with most individuals in the smaller size classes and the biggest individuals having a girth less than 13.5 m. The basic size distribution of the population was not significantly different in 1988, even if the reduction of the size classes less than 3 m GWH was bigger than the reduction of the other classes.

4. Guy (1970 and 1982) studied 17 Baobab trees in Messina, South Africa, which have been monitored in periods since 1931 (De Villiers 1951). The biggest tree was 8.8 m in girth in 1931. Guy cautioned against using girth measurements as a method of assessing age of Baobab trees. Since the trunk is a water-storing organ, it exhibits diurnal, seasonal and annual variations in diameter. These variations may mask the actual radial increase brought about by cambial activity. Each of the 17 trees had its own individual growth rate which varied throughout the tree's life, and generally decreased with age. An analysis of variance showed significant ($P<0.001$) difference in growth rates between 5 girth classes (GBH<2, 2-3.99, 4-5.99, 6-7.99 and >8 m). The larger trees (>4 m GBH) decreased in girth between the dry season 1931 and the dry season 1966 while the smaller trees increased in girth. For the trees that decreased in girth, the mean annual decrease was 0.9 mm. For the ones that increased, the mean annual increase was 1.0 mm. Guy compared changes in girth over time for the 17 trees with rainfall data. Mean rainfall in Messina is 350 mm. per annum and Guy discussed that the climatic conditions were probably better before 1931 than they have ever been since. In the drought years, 1959-1966, hundreds of Baobabs have shrunk and died near Messina, South Africa. Guy concluded that it was probably changes in climate and land use, not elephants that have changed Baobab distribution in southern Africa.

5. Caughley (1976) measured 173 Baobabs in the Luangwa Valley in Zambia. Individuals younger than 40 years were aged directly by core samples, and since no individuals were as big as Swart's tree (GWH=14.4 m.), Caughely assumes a constant growth rate of 7.5 mm per annum for the rest of the individuals. His age distribution histogram peaks for an age around 140 years, and falls away on either side. The oldest age class ends at 350 years. The first half of the histogram he interprets as a progressive decline of recruitment of Boababs into the adult age classes over the last 140 years. This is because of high densities of elephants; the elephants attack young individuals, and only one below the age of 25 was found within the reserve. The second half he says, can be interpreted in two different ways: Either it indicates a constant recruitment between 140 and 350 years ago and a constant high rate of mortality, or it could imply failing recruitment over that period. He concludes that since we know that Baobabs can live for at least 1000 years, the second interpretation seems more

likely. Caughley states that elephants are responsible, at least in part, for declining Baobab recruitment and that this decline indicates that elephant populations have been increasing for the last 140 years. He suggests that elephants' relation to trees is one of a "stable limit cycle". The markedly lower frequency of Baobabs of a certain size is evidence of long-term cycles of utilization by elephants, i.e. size classes with a low frequency correspond to periods of high elephant pressure when they were small.

6. Wilson (1988) used data from five Baobab populations in Zambia, Sudan, Mali, Kenya and Tanzania to compare size distributions and age distributions of the populations. (The data from Tanzania is from Barnes' study in Ruaha 1976. The data from Zambia is from Caughley's study in Luangwa Valley.) The size distributions of the different populations are shown in Fig. 13. With the exception of the Tanzanian population, all populations show a similar size structure and indicate very little recruitment of young trees in recent years. The average spatial density is 11.2 individuals per km^2 for Sudan and 10.7 for Mali.

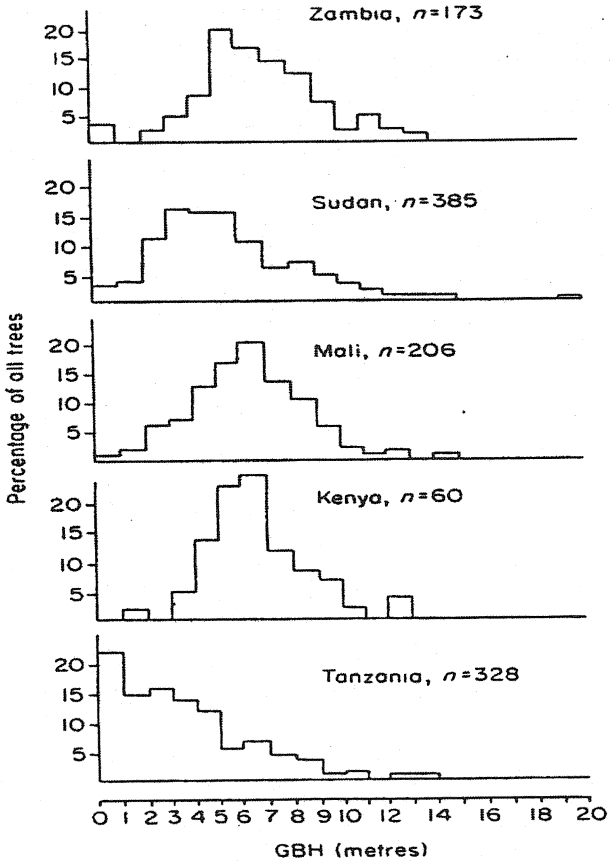


Fig. 13. Size distribution for five different populations of Baobab trees in different parts of Africa (from Wilson 1988).

Wilson uses growth rates calculated in different ways for the different populations. From Kenya a ring count from one tree gave a mean growth rate of 14.4 mm. annual radius increase. For the Sudanese population, a ring count from a mature tree gave a growth rate of 8.4 mm, and actual measured growth in three trees measured 1925, 1932 and 1977, gave a mean growth rate of 11.8 mm per annum. For Mali, estimates of age by owners of the trees gave a mean growth rate of 9.3 mm per annum, and measured growth of two trees over six years gave a growth rate of 10.0 mm. For

Zambia, 40 core samples gave a mean growth rate of 7.5 mm per annum. The Tanzanian population had a mean growth rate of 4.3 mm per annum, estimated from 71 core samples (see above). The size distributions of the populations were converted into age distributions using the above-mentioned growth rates. Since the growth rates are constants, the shape of the age distribution curve for each population is exactly the same as the size distribution curve. Compared with the other populations the age distribution curves are shifted along the x-axis (age) depending on the growth rate. Using these constant growth rates a tree with a girth at breast height of 10 m, has an age of 215 years in Zambia, 189 years in Sudan, 171 years in Mali, 111 years in Kenya, and 370 years in Tanzania. An analysis of variance showed significant differences in age distribution in the different populations. Wilson concludes that: - "none of the populations shows an age distribution that would be expected in a self-maintaining tree population, where a smooth decline in numbers from a maximum in the youngest age class would be normal." The annual mortality rates were estimated from the regression slope of the age distribution after the peak age class. Assuming constant regeneration and mortality rates in the past, and that the natural mortality rate is constant for all age classes. The annual mortality rates were estimated to; 1.4 % in Zambia, 1.9 % in Sudan, 3.4 % in Mali, 3.7 % in Kenya and 1.1 % in Tanzania.

Wilson claims, in contradiction to the slow growth rates for old individuals presented by Guy (1970, 1974 and 1982) and Swart (1963), that most evidence indicates a very rapid growth, and that Baobab populations appear to be much younger than generally believed. In the Zambian, Kenyan and Tanzanian populations, elephants are likely to be responsible for the recent lack of recruitment of young trees. (The histogram for Tanzania shows Barnes' population in 1976 and his studies from 1982 and 1989 showed a size distribution more similar to the other histograms.) In Sudan and Mali there has been no interference by elephants in the last forty or fifty years, and very little before that. The similarity in age structure of the Sudan and Mali populations would tend to support a hypothesis that climate and land use are major factors in the present demographic patterns of Baobabs. Both Sudan and Mali are suffering from long-term drought and increasing human populations, resulting in expanding cultivation and heavier grazing pressure from domestic livestock. The estimated "natural" mortality rates are higher for Sudan and Mali than for Zambia and Tanzania. Wilson presents a hypothesis of constant recruitment before the period at which the histogram peaks for the population, and with a recent extraordinarily high rate of mortality. He also mentions that Baobab populations may be subject to some pulsed effect, but the factors triggering such a pulse are not known from present evidence.

Table 9. Summary of the population parameters from different studies

Study	n	GBH range (m)	Mean density, (ind./km^2)	Growth rate (mm/year)	Natural mortality % / year	Elephant killed % / year	Size distr. peak, GBH (m)
Barnes 1976	337	0-13	51	>30 yrs, 4.3	1.1	5.0	0.36-1.0
Barnes 1982	160	0-13	27.6	-"-	-"-	16.9	2-3
Barnes 1989	159	1-13	34.6	-"-	-"-	2.1	3-4
Weyerhaeuser	553	0-23	49.2 and 72.8	-	0.47	1.1	0-3
Swanepoel 1984	124	0-13.5	18.4	-	-	7.3	0-1.5
1988			13.1				4.5-6
Guy	17	0-9	-	1.0 and -0.9	-	-	-
Caughley	173	0-16	-	>40 yrs, 7.5	-	-	6-7
Wilson							
Sudan	358	0-20	11.2	8.4	1.9	0	3-6
Mali	206	0-15	10.7	9.3-10.0	3.4	0	6-7
Kenya	60	1-13	-	14.4	3.7	0	5-7

Discussion

Comments on Barnes studies: It was unexpected that no difference in growth rates could be found between any size classes. A growth rate of 4.3 mm per annum, is slightly too high for the oldest individuals, but is of little consequence since a very small portion of the population is bigger than 8 m GBH. If individuals in the Cone-phase actually grow faster than the measured 4.3 mm per annum, as recorded in other studies, then their age is largely overestimated. According to Barnes, a Baobab with a GBH between 2 m and 3 m GBH is between 56-92 years old. According to my ring counts to the centre of the tree, in Kondoa they are approximately 30-40 years, the rainfall being almost the same (580 mm in Msembe and 640 mm in Kondoa). However, my measurements of GBH are slightly overestimated since they were measured in the rainy season. According to Breitenbach, (planted) trees in Messina, Transvaal, with a GBH of 2-3 m, are between 30-55 years old, rainfall in Messina being 350 mm per annum.

In Barnes' age distribution, the difference in number of individuals, between age class 0-24 and the two following, is too big. To the elephant it should not make any difference if the tree is 35, 102 or 169 cm GBH (the observed percentage of elephant- killed trees in these classes was 0 for the first one and 3.8 for the two following). As Weyerhaeuser (1985) points out, small individuals are often missed in surveys since the search image is quite different from that for a big tree. In none of the studies were any seedlings found, and since Barnes had problems in discovering all dead big Baobabs from the transect centre line, he probably missed some individuals with a girth less than 35 cm. From the 1982 study it would be interesting to know the actual difference in girth for every individual since 1976, in order to get another estimation of growth rates. The trees were enumerated, so possibly the same individuals could again be identified in 1982.

It could be possible that the high number of individuals less than 2 m GBH in 1976, is the result of a pulsed regeneration event at the turn of the century. But it is more likely that the regeneration in this area, without the effect of the elephants, is considerably better than for other areas. Barnes states that nothing is known about factors that influence regeneration; fruiting, seeding, germination, seedling mortality, etc., but he assumes constant regeneration and a higher mortality in the small size classes.

Comments on Caughley's article: I do not believe that Baobab populations are subjected to any cyclic relationship with elephant populations. When the elephant population decreases, Baobab populations will of course increase, if elephants kill young trees. But I do not think that elephant populations decrease as an effect of decreasing Baobab populations. The Baobab may be an important source of water that affects elephant survival in the dry season, but elephants do not depend on Baobabs alone.

Comments on both Barnes' and Wilson's articles: I think that it is wrong to convert size distributions into age distributions with a constant growth rate. Breitenbach (1985) has shown that the growth rate (annual increase in radius) increases up to 10-16 mm per annum during an early phase in the Baobabs life. This phase continues up to an age of 60-70 years and a GBH of 2.5-7 m. After this phase, the growth rate slows down and is quite moderate (2-10 mm) during most of the trees life-span. Guy (1970, 1974 and 1982) and Swart (1963) has shown that the growth rate of old trees declines gradually with the age of the tree; 0.1-1.5 mm per annum or no growth at all, or even shrinking has been recorded. Wilson's very high growth rate of 14.4 mm per annum is based on a ring count from one tree, and the size of that tree is not presented. He refers to Hobley (1922), and the earlier-mentioned Bagamoyo tree, who reported that growth rates are particularly high in areas with two distinct rainfall seasons. But the Bagamoyo tree only grew rapidly (18.3-15.7 mm per annum) during its first 60 years; when it reached 90 years the average growth rate had slowed down to 5.4 mm per annum. I think most of Wilson's growth rates are too high to apply to the whole population, and that they are based on too little data.

Barnes' 71 core samples give better data, but due to the infection risk he only cored trees already damaged by elephants, and the elephants prefered to damage smaller trees. Barnes' biggest tree is only 13-14 m GBH so the very slow growth rate of the oldest individuals perhaps cannot be seen in this population. He only had a short increment borer, and could only see 10-20 rings, and could not observe if the tree had had a different growth rate when younger, as I could see in some of my trees in Kondoa. But this still does not explain why he did not find any fast-growing Cones. Perhaps the Baobabs in this area do not have a Cone-phase. In my study in Kondoa, the growth rates were highest for individuals with a distinctive cone-shape, and those were individuals that seem to have had access to plenty of water, standing in a depression or close to a house.

The growth rates of the Baobab trees in Kondoa lie within the total range of growth rates presented in the literature (Breitenbach 1985, Guy 1970 and Swart 1963) and they correspond approximately to the growth rates in the population studies presented above. What I have shown, though, is that growth rates vary significantly between individuals and between size classes, and that one growth rate can not be assumed to be applicable to a whole population. Very slow growth rates, like the 1.1-1.5 mm per annum presented by Swart (1963) could not be found in the study in Kondoa. One tree in the same size bracket as Swart's tree, 14.4 m, had a growth rate of 8.6 mm per annum. This could be explained in many ways, perhaps it had access to more water, it was probably much younger, and it was measured in the rainy season.

Unfortunately, only one dead individual (that died in 1997), was found in Kondoa, and mortality rates could not be estimated with any certainty, but the estimated 0.4 % is almost the same as the 0.47 % presented by Weyerhaeuser. The size distribution of the Baobab population in Kondoa is quite similar to the ones presented in Fig. 13 except for the one from Tanzania. The environmental factors influencing the population in Kondoa are probably more similar to the populations in Mali and Sudan, where long-term drought, agriculture and domestic livestock, rather than elephants, are important factors influencing the populations.

Both Barnes and Wilson assume that a healthy self-maintaining Baobab population must have more individuals in the smaller/younger classes than in the bigger/older classes. This is not necessarily true for a long-lived tree. Assuming that growth rate slows down with age, and that the mortality is low for old individuals, a healthy population could have more big individuals than small ones, which is the population structure often seen in nature. There is an old African saying: "There are no young Baobab trees, they spring into being fully grown!" Even if only very few individuals reach great age, they stay in this phase for a very long time, giving enough time for the young faster-growing individuals to replace them. The regeneration does not have to be constant over the time. Pulsed regeneration events are quite probable, considered that the young saplings need perhaps 10-15 years of good conditions to reach a certain threshold size, above which their vulnerability to fire and grazing is drastically lowered. Such a long period of favourable conditions is not likely to happen very often.

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