JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) | No. 2

MINISTRY OF ENVIRONMENT AND NATURAL RESOURCES (MENR)

THE REPUBLIC OF ZAMBIA

THE FOREST RESOURCES MANAGEMENT STUDY FOR ZAMBIA TEAK FORESTS IN SOUTH-WESTERN ZAMBIA

FINAL REPORT

Volume 2

(Main Section)

March, 1996

JAPAN FOREST CIVIL ENGINEERING CONSULTANTS FOUNDATION

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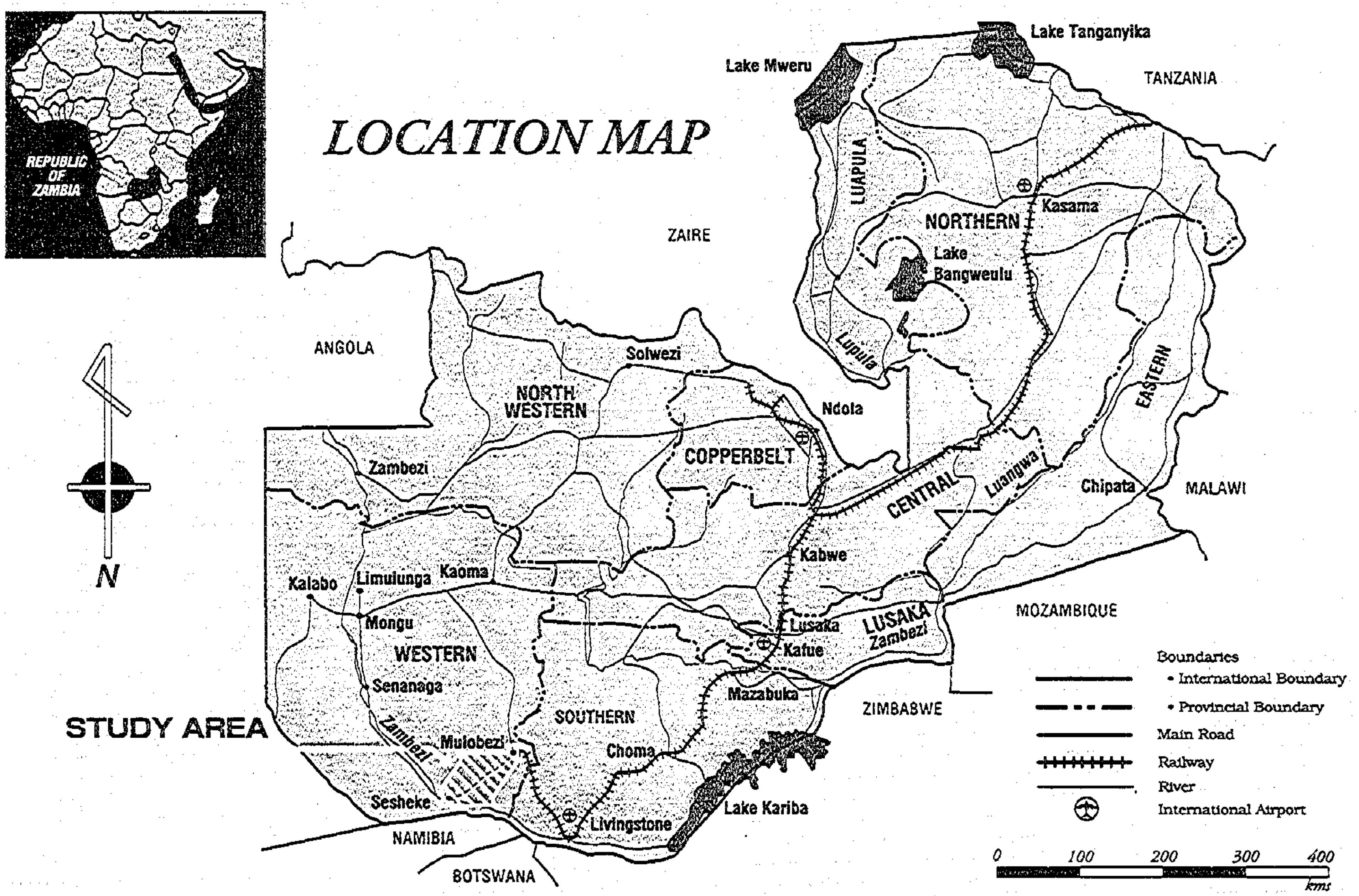
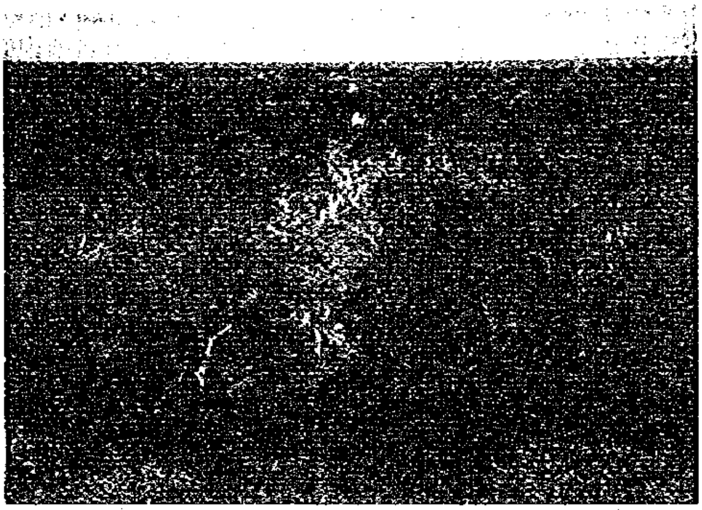
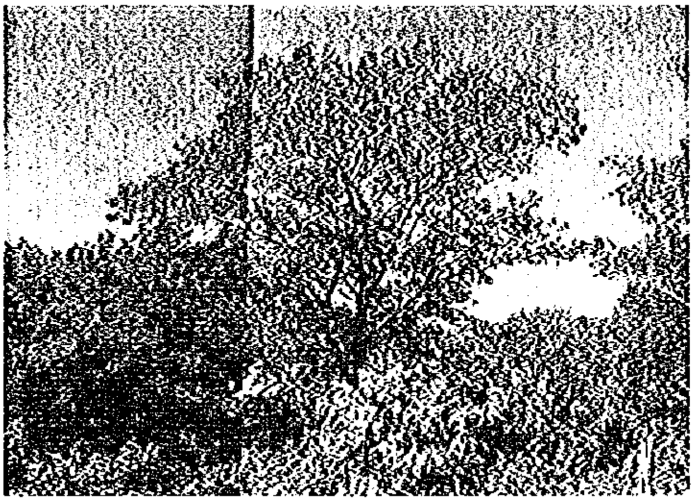
LOCATION MAP

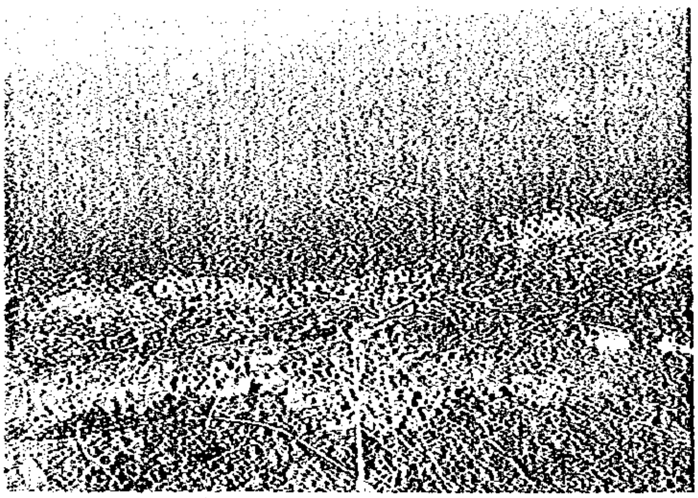




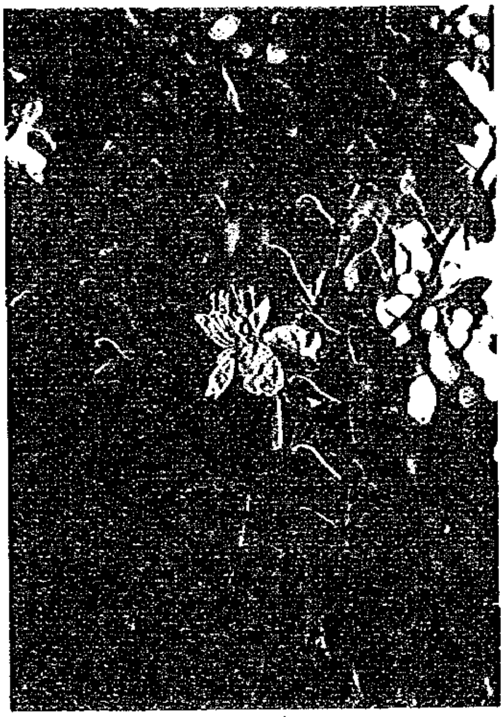
A Zambia teak forest (Shimungoma West Forest)



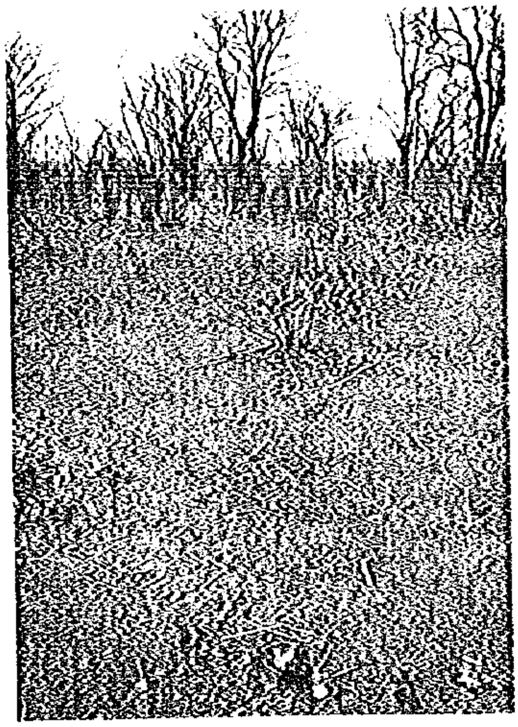
Zambian teak (*Baikiaea plurijuga*: "Mukusi" in Lozi name)



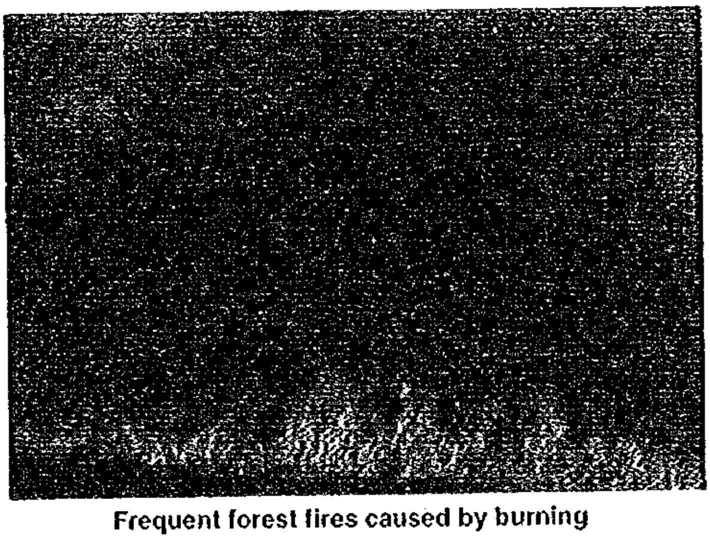
Aerial view of Situmpa Forest in dry season



Mukusi branches, leaves, and flowers



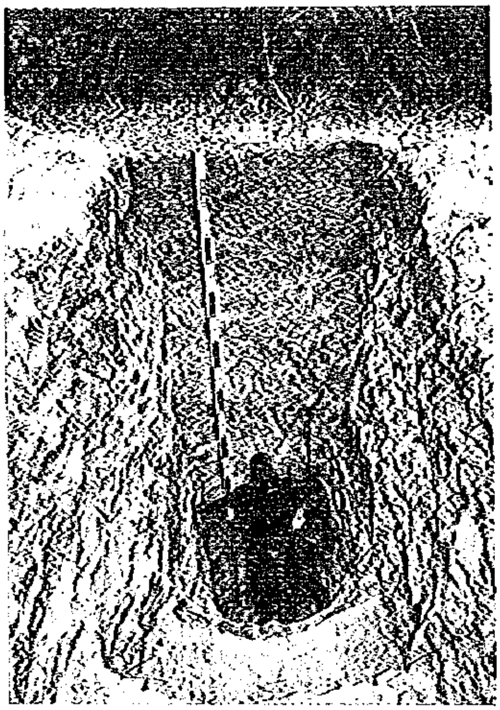
Forest destruction by repeated fires



Frequent forest fires caused by burning

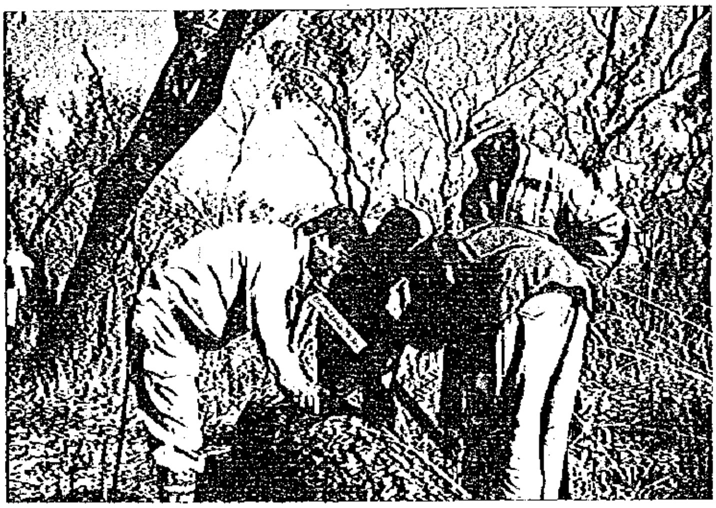
Mukusi coppices

Survey on root systems in an artificial forest in Sisisi Forest:
Thick bar-shaped tap roots

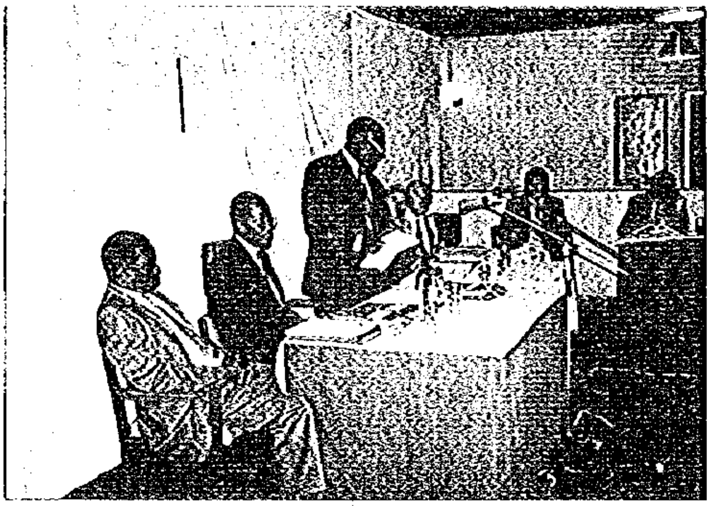


Soil profile survey in Malauwe Forest:
Classified as Ferralic Arenosols (orange type) soil

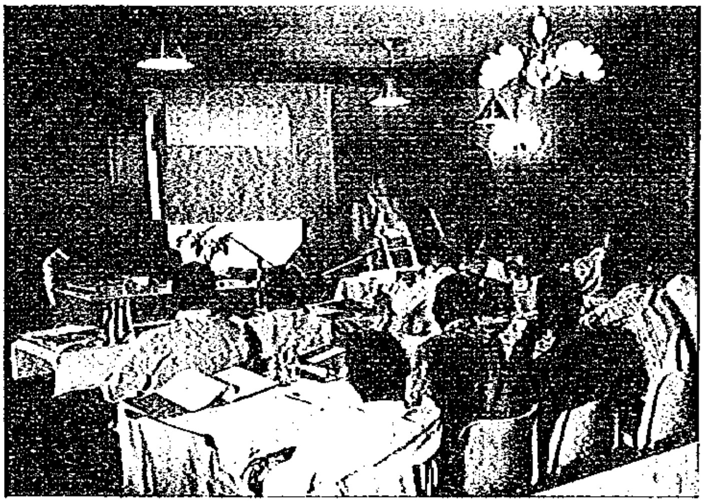

Farm household survey in Mahare village


An example of technology transfer in the field


Technology transfer taking place in a meeting



Holding a technology transfer seminar



The technology transfer seminar from another angle

Exchange of Minutes of Meeting

THE FOREST RESOURCES MANAGEMENT STUDY
FOR ZAMBIA TEAK FORESTS
IN SOUTH-WESTERN ZAMBIA

FINAL REPORT Volume 1 (Summary Section)

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INTRODUCTION

1. Background and Brief History of the Study

According to the forest resources assessment compiled by the Food and Agriculture Organization of the United Nations (FAO) in 1990, the forest areas of the Republic of Zambia (hereinafter referred to as "Zambia") totaled 32,300,000 ha. During the ten-year period preceding 1981, this forest area decreased by 3,630,000 ha, or at a rate of 1.1% per year.

Zambian teak (baikiaea plurijuga), which grows in the south-western part of Zambia, shall hereinafter be referred to as "Mukusi." The names of trees given in this report are Lozi names, in view of the fact that the report is centered in the south-western region of Zambia, an area populated by the Lozi tribe. Mukusi forests are distributed throughout the area, but their reduction in recent years has been remarkable.

Mukusi wood is widely used for railroad sleepers, building materials and furniture, in addition to being an export product. These activities have created employment opportunities for local residents, and have been a source of income. Moreover, the Mukusi has played an important role in preserving the natural environment of the area, as the Mukusi grew despite the harsh conditions imposed on the area by drifting Kalahari sands. Although a qualitative study of Mukusi forests was carried out in the 1960s, a quantitative study was not, with the result that the volume of forest resources and Mukusi resources has not been grasped. Accordingly, basic data with respect to the forest stand structure, as well as the volume tables and yield tables required for the management of forest resources, are non-existent. If these data are not purposed, it will be difficult to grasp the resources volume.

The custom of forests being burned by villagers and the numerous forest fires in national and local forests (126,000 ha), in which large areas are covered by Mukusi forests, have led to considerable destruction.

During a 20- to 30-year period, the Mukusi forests dwindled by more than 40%. Even in forest that were spared, fires have raged, with most of the succeeding trees being destroyed. The occurrence of forest fires has been especially pronounced in recent years, thus interfering with the regeneration of forests and causing great problems for the preservation of resources. In addition to this, the relationship between the Forest Estates and the villagers has not been close, so that interest in forest preservation has not been especially great. Thus, the relation between forests, land and people needs to be restructured and the problem faced.

Recently, the climate in the south-western part of Zambia has tended to become dry, resulting in reduced agricultural harvests. Along with this, the chronic problem of fires is hastening the expansion of desert land where vegetation will not grow.

To cope with the above problem, it is necessary to quantitatively grasp the forest condition by collecting the latest data. Along with this, a forest management plan that includes environment protection is needed. This is an emergency situation facing Zambia.

It was against this background that, in September 1992, the Government of Zambia requested the Government of Japan to undertake a study to determine the amount of Zambian resources and to formulate a management plan. In response to this request, on 21 October, 1993, the Government of Japan decided to undertake this study after making preliminary surveys in May and October 1993. As a result, a period in which a study is to be undertaken for 20 months, from August 1994 to March 1996, was initiated.

Among the teak forests where the Mukusi tree is dominant, we will refer to these forests as Mukusi forests.

2. Purpose of Study

The purpose of this study is to survey the resources of the Mukusi forests found in the south-western region of Zambia, to prepare land-use and vegetation maps, and to draw up a forestry inventory book and

* *In this report, the National Forests and Local Forests in the Zambia Forest Law are referred to as Forest Estates.*

soil maps. A forest management plan integrating the survey and study results will be formulated. Necessary technology will be transferred to our counterparts in Zambia through this study.

3. Study Area

The *study area is composed of about 500,000 ha in the south-western part of Zambia, including Mulobezi and* Sesheke (see Figure 1).

4. Study Team

The study team members listed below have made survey trips to Zambia on the following occasions:

Phase II	*(A)*	*7 August to 5 September, 1994*	*(30 days)*
Phase II	*(B)*	*6 September to 9 October, 1994*	*(34 days)*
Phase II	*(C)*	*17 January to 18 March, 1995*	*(60 days)*
Phase III	*(A)*	*9 July to 6 August, 1995*	*(29 days)*
Phase III	*(B)*	*20 October to 8 November, 1995*	*(19 days)*
Phase III	*(C)*	*28 January to 9 February, 1996*	*(13 days)*

Name	Responsibility	Dispatch periods
1 Keiji TAKESHITA	Leader	Phase II (A), part II (C), III (A), III (B) and III (C)
2 Masahisa ARAKAWA	Deputy leader Forest management plan	Phase II (A), II (B), II (C), III (A), III (B) and III (C)
3 Juemon ITO	Land use, vegetation	Phase II (A), II (B), II (C), III (A), III (B) and III (C)
4 Mitsuru NAITO	Resources study (1)	Phase II (A), II (B), II (C), III (A), , III (B) and III (C)
5 Hideki IMAI	Resources study (2)	Phase II (A), II (B), II (C) and III(A)
6 Hiroshi TAKATOH	Soil study	Phase II (A), II (B) and II (C)
7 Yoshihide SAWANOBORI	Socio economy Forestry industry Social forestry	Phase II (A), III (A), III (B) and III (C)
8 Masayuki TOJO	Forestry	Phase II (A) and III (A)
9 Akiyosi KATO	Environment influence	Phase II (A) and III(A)

5. Progress to Date

In Phase I, aerial photographs of the study area were taken and 1/50,000 topographic maps were prepared for implementing this study.

In Phase II (A), reconnaissance of the entire study area, a preliminary study of the method to measure forests, and interviews with villagers were conducted.

In Phase II (B and C), the following studies were performed to determine the present status of the forests:

<u>Land-use and vegetation study:</u> Classification of land-use modes and vegetation types, measurement of structural composition for each vegetation type and preparation of a tentative interpretation standard for aerial photographs.

<u>Forest resources study:</u> Data on stand volume was collected.

<u>Soil survey:</u> A soil profile survey was conducted and soil types were classified.

<u>Draft land-use and vegetation maps, a forest inventory book and soil maps</u> were prepared and submitted to Zambia.

In Phase III (A), the following studies and surveys were conducted for formulating a forest management plan.

<u>Resources management plan:</u> Determining the fluctuating elements of resources, including measurement of forest growth.

Utilisation system: Interviews with villagers and farm households were conducted. Utilisation of Mukusi and Mukwa lumber was studied.

Operation systems: The conditions for growth in existing experimental plots, the conditions for work, and conditions for regeneration and elements related to forestry management were studied.

Land-use management: Site conditions were surveyed and their relation with land-use and vegetation distribution was studied.

Environmental conservation: The relation between burning and forest devastation was studied.

The results of the Phase III (A) survey are given in the Interim Report.

In Phase III (B), a supplementary survey of the verification inquiry and insufficient matters as regards the content of the Interim Report was carried out, and is included in the draft final report.

A seminar was held on Phase III (C). Subsequently, Zambian comments on the Draft Final Report were examined and, as a result, supplementary explanations were added and the necessary corrections were made. Then, this Final Report was produced.

6. Characteristics of Study

The basic requirement for examining what is appropriate forest management is the availability of quantitative data and information concerning the forest environment, ecological conditions, and the volume of resources in existence. The great problem encountered was the lack of such quantitative data for South-western Zambia. Therefore, emphasis of the present Study was placed on the clarification of basic data through quantification, and satisfactory data were obtained as a consequence.

(1) Ecological Environment

Covered by thick sandy layers belonging to a former desert, South-western Zambia constitutes a special environment in which the possibilities of forest growth are still little known. In the present Study, topographical characteristics (including buried topography) and the water-retaining condition inside the sandy layers were theoretically estimated, and the ecological environment mechanism allowing forests to exist in sandy layers was clarified from the observation of the different root systems of plant species existing in various environments.

(2) Estimation of Forest Resources by Aerial Photography

Aerial photography is the most useful means of surveying resources over an extensive area. It is possible to retrieve data on crown shapes and distribution patterns, canopy closures, canopy height and other conditions from aerial photography. In the present Study, using a theoretical ecology model, an all-inclusive survey was conducted on aerial photographs, and the volume and distribution of resources were estimated for each location.

(3) Volume Table and Yield Table

The standing tree volume table and the yield table provide the basic data that are indispensable for examining the methods of forest resources management through quantification. However, quantified data were practically non-existent when the present Study was started. (In fact, there are very few quantified yield tables for broad-leaved forests in the world.) Consequently, in the present Study emphasis was placed on the quantitative grasping of the ecological structure of the forest. As a result, the Study was able to realise a standing tree volume table and a yield table for natural broad-leaved forests containing Mukusi.

(4) State of Forest Denudation

In the process of investigating and analyzing the ecological constitution of forests, the state of destruction of forests and grasslands by forest fires and grazing was grasped, and the destruction mechanism was clarified.

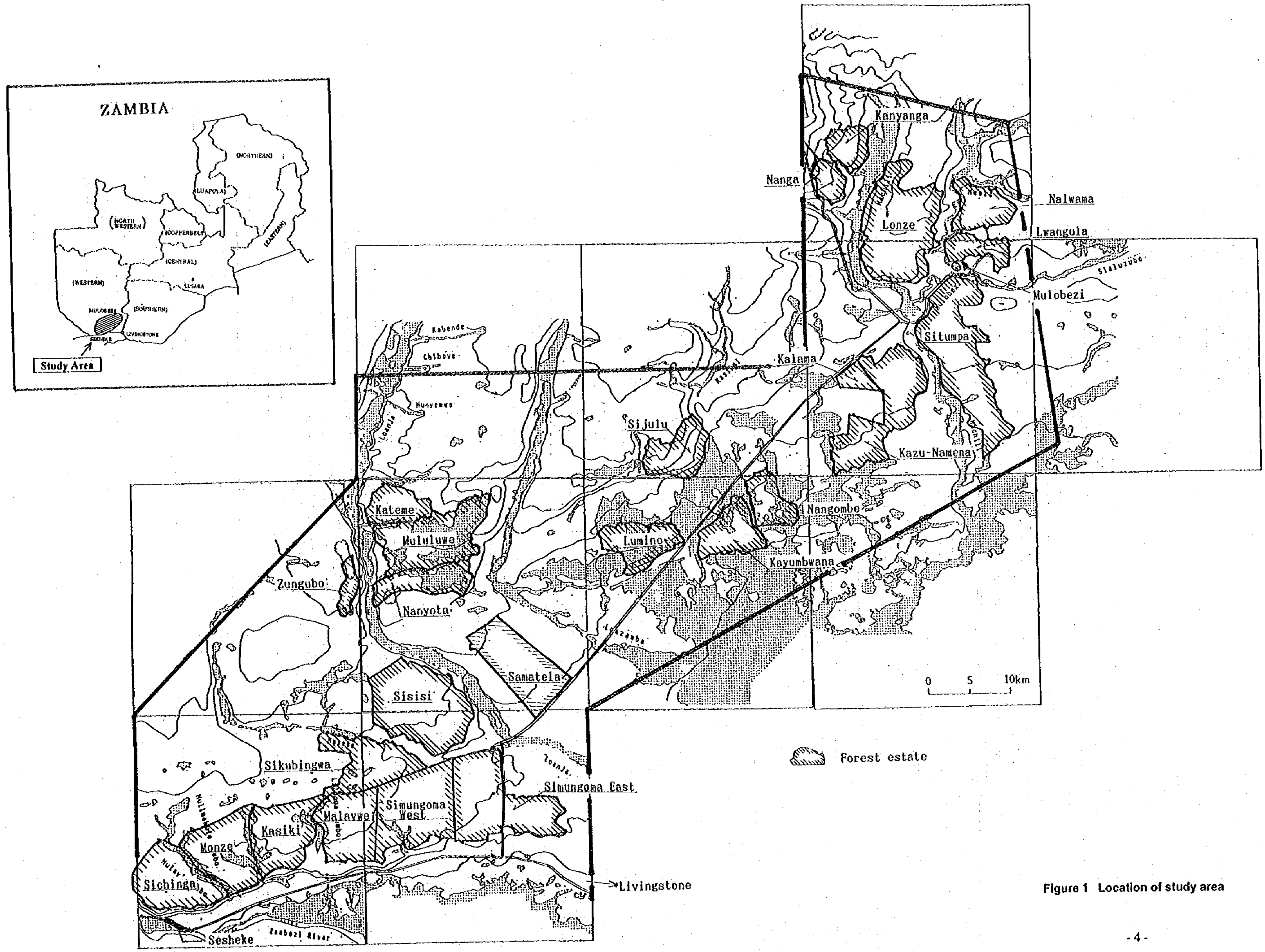


Figure 1 Location of study area

I. SOCIOECONOMIC AND NATURAL ENVIRONMENT OF ZAMBIA

1.1. Socioeconomic Environment

1.1.1. Socioeconomic environment of Zambia

(1) Area and population

The land area of Zambia totals 753,000 km^2 and is about twice the area of Japan. Western province, in which the study area is located, is 126,000 km^2 in area, accounting for 17% of the land in Zambia.

The population of Zambia in 1990 was 7,818,000, with a population density of about 10 persons/km^2. Between 1969 and 1990, the population doubled. In the past 20 years, the population of Lusaka province, where the capital is located, has increased more than three times.

The population of the western province was 607,000 in 1990, and was only 8% of the entire population of Zambia. The population density of this province was 4.8 persons/km^2, which is far lower than the average population density of Zambia, and is the second lowest in population density (Table 1). Western province has six districts, one of which is Sesheke, where most of the study area is located. Sesheke District has an area of about 30,000 km^2, population of 65,000 and in population density of 2.22 persons/km^2, the lowest population density in western province (Table 2).

Table 1 Population, area and population density of each province

Province	Population (1,000person)			Area (1,000km^2)	Population density (person／km^2)
	1969	1980	1990		
Central	359	512	726	94	5.4
Cooperbelt	816	1,251	1,580	31	50.4
Eastern	510		974	69	14.1
Luapula	336	421	527	51	10.4
Lusaka	354	691	1,208	22	55.2
Northern	545	675	868	148	5.9
North Western	232	303	383	126	3.0
Southern	496	672	946	85	11.1
Western	410	486	607	126	4.8
TOTAL	4,057	5,662	7,818	753	10.4

Source: RZ "Monthly Digest of Statistics," July-October 1991

Table 2
Population, area and population density of each district in western province (1990)

District	Population (person)	Area (km^2)	Population density
Kalabo	101,410	17,526	5.79
Kaoma	112,747	23,315	4.84
Lukulu	51,016	16,291	3.13
Mongu	142,213	10,075	14.12
Senanga	135,210	29,907	4.52
Sesheke	64,901	29,272	2.22
TOTAL	607,497	126,386	4.81

Source: RZ "Monthly Digest of Statistics," July-October 1991

(2) Race and language

Most of the people are of Bantu ancestry. There are 73 tribes and more than 40 languages. There are four major tribes: the Tonga in the south, Nyanja in the east, Bemba in the north and Lozi in the west. The official language is English, but each of the major tribes routinely use Tonga, Nyanja, Bemba and Lozi languages in their specific areas.

(3) Transition and characteristics of politics and economy

The Zambian economy has evolved from the production of copper. Development in Zambia (formerly North Rhodesia) during the British colonial period began with mining. Since Zambian independence in 1964, copper has been at the center of Zambia's economy. There has been no change in this typical monoculture-type export structure. (Ogura, 1986)

Before 1975, Zambia went forward in building its infrastructure with foreign currency earnings from the export of copper, and was one of the wealthiest countries in Sub-Sahara Africa. This monoculture structure was built on the double structure of modern capital-intensive industry, with copper at the center, and traditional self-sufficiency agriculture. When the copper prices remained high, the weakness of this structure was not called into question. With the downturn in copper prices from 93 cents/pound in 1974 to 56 cents/pound in 1987, plus a decrease in export volume, the export receipts dwindled by 40% and the government's finances decreased by 80%, in comparison with the 1974 level.

As the outlook for copper prices darkened, the Zambian government attempted to change the industrial and export structures from the latter half of 1970s. A mining country is destined to deplete its resources. One mineral resource besides copper is cobalt, but cobalt resources are few. So the possibility of finding a substitute for copper is remote. Accordingly, the general idea arose that the future of Zambia would rest on an agricultural base. So the government began to take concrete steps to convert to an economy centered on agriculture from the mid 1980s, with the copper industry in decline. Specifically, as a stimulus to agricultural production, a raise in the producer's price of maize and wheat was announced in June of 1987, and the International Fund of Agriculture Development (IFAD) financed $27.5 million to the small farmers in the agriculture section in October of 1987. But there is no denying that these steps came too late.

As in the above-mentioned case, this Zambian predicament began with the decline in the price of copper, which was the major export item until the middle of the 1970s. In addition, Zambia did not develop a new mine that was required to increase production, and did not re-invest in the existing mines. Thus, production did not increase. (Ogura, 1986) With the depression of the copper industry and a lack of an alternative industry, the Kaunda administration attempted to maintain the standard of living of relatively privileged urban residents by strengthening regulations, by intervening in the economy and by tightening the control over farm villages. His policy was to the subsidise maize (staple food) and to set up a uniform producer's price for the entire country. This was an excessively heavy burden on the government, bringing about a budget deficit and a deepening of aid dependency.

A structural adjustment under the IMF and International Bank of Reconstruction and Development was aimed at decreasing such government regulations and interventions. But this policy would directly affect the life of the people through a worsening economy. The result was to increase the people's dissatisfaction. A strong power basis was needed to promote the structural adjustment. As a result of the national parliament election and the presidential election in 1991, there was a shift to a plural party system democracy. The United National Independence Party (UNIP) headed by president Kaunda had ruled Zambia since its independence. The Movement for Multiparty Democracy (MMD) won the election, with F. Chiluba becoming president. The election victory had a significant meaning for the Chiluba administration and investors in foreign countries, which were urging structural adjustments.

The Chiluba administration first sought a curtailment of subsidies to milli meal and an increase in the consumer selling price. In Zambia, where urban residents made up 40% of the population, an increase in the staple food was politically risky and caused two riots under the Kaunda administration. But the Chiluba administration resolutely carried out a nearly complete abolition of the subsidy within several months after the inauguration of his administration and freed consumer prices in general. Due to the fact that these steps demonstrated a firm will to wards reforms, the confidence of foreign investors in the Chiluba administration was heightened. (Takahashi, 1995)

Thus, Zambia chose to adapt to "order" in the international community that was established by advanced aid-giving nations, and has gone ahead with economic management that depended on it.

(4) Economic position of forestry and forest products industry

In considering the general economic condition of Zambia in terms of gross domestic product (GDP), forestry generated US$26,200,000 on average per year over five years between 1989 and 1993, representing 0.9% of GDP. The forestry product industry is included in the miscellaneous sector of manufacturing and figures are not available. The miscellaneous sector of manufacturing totaled US$395,700,000 in production, accounting for 13.5% of Zambia's GDP (Table 3).

(5) Land use

Forest land in the land-use area totaled 29,000,000 ha in 1988, accounting for 39% of the nation's land area. Since 1973, the forest land area has decreased 1,400,000 ha in 15 years, while farm land and other lands have increased. Farm land especially increased by 250,000 ha. Grassland accounted for 35,000,000 ha and has not changed (Table 4).

(6) Agricultural production

In the production of agricultural products, maize, which is the staple food of the Zambia, leads the list. 640,000 ha of farm land yielded 1,010,000 tons of maize 1991. Other agricultural products after maize were groundnuts, from 80,000 ha, cotton, millet, barnyard millet and sunflowers (Table 5).

The agricultural management system of Zambia is a two-tiered structure: traditional self-supporting farmers (traditional farmers) and large-scale commercial farmers. Traditional farmers have worked a reckless agricultural production method of slash-and-burn, shifting farming without the use of fertilizers and agrochemicals. This production was mainly for self-supporting foods such as maize, cassaba, sorghum and millet. Maize is put on the market if there is a surplus. With the exception if Lusaka, Middle, Southern and Eastern Provinces, most formers in five provinces resort to this traditional method of farming. The stratified double-tiered structure overlaps with a regional disparity. (Ogura, 1986) The commercial farmers managed by whites are divided into the following types:

- Farmers selling 150 or more bags of maize (90 kg/bag) to NAMBOARD and cooperatives.
- Tobacco-growing farmers registered with the Tabacco Board of Zambia.
- Farmers selling to the Dairy Produce Board.
- Livestock farmers selling to the Cold Storage Board of Zambia, Zambia Pork Board, butcher shops with licences and supermarkets.
- Crossbreed poultry farmers.

Table 3
Structure of Zambian economy as illustrated by 1989-1993 average GNP (US$ million)

Sector		1989~1993 Ave.	Share (%)
Agriculture		476.4	16.2
Forestry		26.2	0.9
Fishing		36.7	1.2
Mining & Quarrying		216.1	7.3
Manufacturing	Food,Beverages and Tobacco	389.2	13.2
	Others	395.7	13.5
Electricity,Gas and Water		74.5	2.5
Construction		81.3	2.8
Wholesale and Retail Trade		234.6	8.0
Restaurants and Hotels		81.3	2.8
Transport,Storage & Communications		134.4	4.6
Financial Institutions and Insurance		68.0	2.3
Real Estate and Business Service		228.6	7.8
Community,Social and Personal Service		496.9	16.9
Other		1.8	0.1
TOTAL		2,942.0	100.0

Source: MAFF Agricultural Sector Investment Programme

Table 4 Breakdown of areas in use

1,000 ha

	1973	1978	1983	1988
Cultivated land	4,973	5,050	5,150	5,230
Grassland	35,000	35,000	35,000	35,000
Forests	30,490	30,040	29,590	29,090
Other	3,876	4,249	4,599	5,019
TOTAL	75,261	75,216	75,261	75,261

Source: FAO Yearbook, Vol. 43, 1989

Table 5 Planted area (1,000 ha) and production (1,000 tons) of main crops in Zambia

1,000 ha, 1,000 tons

		1986	1987	1988	1989	1990	1991	1992
Maize	Area	588.50	609.50	723.10	1,020.60	763.30	639.39	641.84
	Production	1,230.60	1,063.40	1,943.20	1,845.00	1,092.70	1,096.00	463.80
Sunflower	Area	57.20	31.60	44.60	45.00	44.30	36.49	22.31
	Production	30.60	17.00	15.80	15.00	20.00	10.65	4.56
Soy beans	Area	13.90	16.90	20.30	21.30	29.80	29.20	26.82
	Production	15.90	13.50	21.20	20.60	26.80	27.71	19.75
Groundnuts	Area	34.40	149.00	81.80	62.90	80.40	80.47	68.71
	Production	18.20	47.40	33.40	30.10	25.10	28.20	20.78
Rice	Area	10.40	8.70	10.40	12.80	9.50	13.45	14.15
	Production	11.20	8.20	9.40	11.70	9.20	14.60	8.48
M.Beans	Area	19.70	23.60	17.60	18.70	26.40	28.94	27.62
	Production	10.20	15.50	10.90	24.30	14.30	14.12	15.02
Sorghum	Area	59.60	47.50	47.40	52.00	48.50	31.79	42.16
	Production	45.00	26.20	36.10	33.80	19.60	14.12	15.02
Cotton	Area	52.00	28.20	77.90	106.40	64.00	74.02	64.20
	Production	33.40	20.20	58.50	34.80	30.70	48.72	35.89
Tabacco	Area	3.48	2.46	4.89	5.04	5.07	3.09	5.50
	Production	3.90	3.55	4.35	3.60	4.65	1.68	5.42
Millet	Area	18.50	43.60	44.10	47.40	58.90	45.27	53.00
	Production	11.70	30.60	28.60	27.30	31.50	25.57	25.95
Wheat	Area	-	7.45	6.93	0.20	0.36	12.50	14.90
	Production	-	27.46	31.55	0.17	0.33	69.26	97.23

Source : Official Crop Production and Sales Data for 1986-1992

Note : The 1992 harvests are estimated values. The production of wheat in 1987 and 1988 depended on irrigation.

1.1.2. Socio-economic environment of western province

(1) Area, population and number of households

Table 6 shows the areas and population according to sex in the districts in western province. Sesheke District, which is included in the study area, had 31,000 males and 34,000 females. It had 12,000 households, or 5.3 persons per household on average. Sesheke District does not have a relatively large-scale manufacturing industry, except for sawmills. Most of the households are traditional self-supporting households.

Table 6 Population, area and household per district in western province (1990)

District	Area (km^2)	Population (persons)			Number of households	persons / household
		man	woman	total		
Kalabo	17,526	45,854	55,556	101,410	19,419	5.0
Kaoma	23,315	53,969	58,773	112,742	20,292	5.5
Lukulu	16,291	23,704	27,312	51,016	10,152	5.1
Mongu	10,075	66,100	76,113	142,213	26,387	5.4
Senanga	29,907	62,383	72,827	135,210	24,426	5.6
Sesheke	29,272	31,194	33,707	64,901	12,206	5.3
TOTAL	126,386	283,204	324,288	607,492	112,882	5.4

Source: Zambia "Monthly Digest of Statistics," July-October 1991.

Republic of Zambia "Census of Population, Housing & Agriculture 1990, Descriptive Tables Volume 9 WESTERN PROVINCE."

(2) **Agriculture management system**

Most of the farmers in western province are traditional self-supporting farmers, while commercial farmers are almost non-existent. According to the 1980 statistics, commercial farming households numbered 5,450 and traditional households 85,400. Thus traditional households made up 94% of the total number of households. Commercial farms is small-scale farming on less than 10 ha of farm land.

(3) **Structure of agricultural production**

The self-supporting ratio of staple-food agricultural products, combining crops and cassaba in the entire western province, is estimated at 50 to 60%. According to recent statistics, western province imports 40,000 to 50,000 tons of maize per year from other provinces and exports 200 to 250 tons of rice and 12,000 to 15,000 head of cattle.

Farm-land area and the production quantity of principal agricultural products in the districts of western province in 1992 were as follows: Sesheke District: maize 7,600 ha and 12,000 tons; sorghum 2,000 ha and 1,000 tons; millet 1,600 ha and 1,500 tons; rice 81 ha and 76 tons; cassaba 1,900 ha and 260 tons and groundnuts 1,000 ha and 286 tons. The agricultural production of Sesheke District is characterized by the production of 1.5 tons of maize, compared with the production quantity per ha for the entire western province of 1.2 tons, indicating that land productivity was relatively high, production of rice limited and a relatively large amount of groundnuts cultivated locally (Table 7).

With respect to livestock, 4,350 households in Sesheke District owned livestock, raising 37,000 head of cattle, 679 pigs, 7,000 goats, 258 sheep and 34,000 poultry. One characteristic of Sesheke District is that many goats are raised (Table 8).

Table 9 shows the number of farmers according to the scale of the farm land area in various districts of western province. Compared with the other districts, Sesheke District has many farmers whose scale of owned farm land is large. A total of 683 farmers, or 16% of the total, had farm land areas of 5 ha or more. The farmers in Sesheke District have larger farm land compared with the other districts, but farmers owning less than 5 ha are many, or 3,667 farmers, representing 84% of the total.

App. Table 1 shows the number of farm households in various districts of western province according to agricultural type. Sesheke District also has the same agricultural composition as that of western province and the rest of Zambia. Among the agricultural types, crops + livestock + poultry prevail in Sesheke District with 1,800 households, which accounts for 42% of the total and is the highest proportion in western province. Crops + poultry follows with 1,252 households, accounting for 29% the crops—only with 740 households, accounting for 17% of the total.

(4) **Social peculiarities of western province**

In Zambia, the chief system is still the custom. This is one peculiarity, which is formed before a pre-modern social strata system.

Particularly in western province, the chief system is especially strongly entrenched and the stratified system of the Lozi remains as the social system. Although the chief system will be described later, this stratified social system severely affects the everyday life of its regional residents, as a land-owning system or a forest-protection system, and has a stronger binding force than any administrative institution. For this reason, the region has been a stronghold of the Lozi royalty, and a struggle for independence was almost realized. On the other hand, the region remains as the most economically underdeveloped.

Table 7 Planted area and production of main crops per district in western province (1992)

District	Maize		Sorgham		Millet		Rice		Cassava		Groundnuts	
	ha	t	ha	t	ha	t	ha	t	ha	t	ha	t
Kalabo	5,402	5,095.7	1,184	586.0	3,965	3,588.0	1,532	1,408.2	6,220	2,074.8	145	50.2
Kaoma	9,346	14,515.9	588	386.5	1,343	1,255.1	368	337.2	4,807	2,054.2	894	363.8
Lukulu	1,564	1,750.7	210	122.6	416	372.6	236	230.6	1,991	788.5	109	37.6
Mongu	4,103	4,015.4	425	235.9	1,035	9,637.2	2,595	2,521.3	6,375	2,793.3	123	34.0
Senanga	12,781	12,390.8	5,102	2,463.3	5,513	5,096.5	1,113	967.6	5,807	1,084.8	472	124.2
Sesheke	7,608	11,853.9	2,041	1,105.6	1,621	1,513.6	81	76.5	1,895	259.9	1,092	286.6
TOTAL	40,806	49,652.5	9,550	4,899.8	13,893	12,789.5	5,926	5,541.4	27,095	9,055.4	2,835	896.3

Source: Republic of Zambia "National Census of Agriculture (1990/92)," January 1994

Table 8 Number of livestock and poultry per district in western province (1992)

District	Holders	Number of Livestock and Poultry				
		Cattle	Pigs	Goats	Sheep	Chickens
Kalabo	10,679	83,656	1,430	737	24	64,666
Kaoma	9,471	20,762	7,160	5,195	12	291,138
Lukulu	3,341	27,561	373	319	0	25,451
Mongu	8,245	557,475	1,179	1,009	102	766,692
Senanga	11,865	122,220	2,629	5,536	61	89,215
Sesheke	4,350	37,073	679	6,946	59	33,861
TOTAL	47,951	848,747	13,450	19,742	258	1,271,023

Source: Republic of Zambia "National Census of Agriculture (1990/92)," January 1994

Table 9

Distribution of holdings according to district and farm size in western province (1992)

District	Total (persons)	Farm size category					
		< 5ha		< 5ha, but < 20ha		> 20ha	
		Persons	%	Persons	%	Persons	%
Kalabo	10,679	10,074	94.33	602	5.64	3	0.03
Kaoma	9,471	8,949	94.49	492	5.19	30	0.32
Lukulu	3,341	3,232	96.74	107	3.20	2	0.06
Mongu	8,245	7,664	92.95	563	6.83	18	0.22
Senanga	11,865	10,097	85.10	1,755	14.79	13	0.11
Sesheke	4,350	3,667	84.30	659	15.15	24	0.55
TOTAL	47,951	43,683	91.10	4,178	8.71	90	0.19

Source: Republic of Zambia "National Census of Agriculture (1990/92)," January 1994

1.2. Natural Environment

1.2.1. Climate

The area of study is located between 16.6 and 17.5 degrees south latitude and 24 and 25.5°C east longitude. Since the area is a highland 900 to 1,250 m above sea level, the air temperature is rather low (yearly average air temperature is 2 to 3°C lower than that of lowlands in the same latitude). The country has a tropical climate with an annual average air temperature of 20 to 22 degrees. The dry and rainy seasons are clearly distinguished. The dry season is long and annual precipitation is low (600 to 800 mm). However, trees do grow. The southern part of the country can be classified as having a semiarid tropical climate.

The northwestern part of Zambia (north of 13 Lat. S, west of 29 Long. E) has a long rainy season and has some areas resembling wet tropical regions with an annual precipitation of over 1,000 mm. However, most of Zambia is semi-dry with an annual precipitation of less than 1,000 mm. In particular, Zambia's south-western region, this is included in the present study, is a low-precipitation area whose annual precipitation has been less than 700 mm over the recent years.

Tables 10 and 11 show the monthly average air temperature and precipitation.

(1) Annual variations in climate

1) Air temperature

Located in the southern hemisphere, Zambia has high temperatures in October, November, December, January, February and March, when the sun approaches the tropic of Capricorn. Conversely, the air temperature in Zambia is low in June and July, when temperatures are high in the northern hemisphere. The temperature difference is large, especially in Sesheke, with high temperatures exceeding 36°C C in October and November, and low temperatures of 3 ~ 4°C and even zero may be recorded in June and July, which may damage plants.

App. Tables 2 to 4 and Figures 2 to 4 respectively show the variations per month over a one-year period of maximum, minimum and average air temperatures in Sesheke, Livingstone, Lusaka and Ndola (average or maximum values in the recent ten years).

2) Precipitation

The rainy season starts in October or November and ends in April. Rainfall is especially heavy during the four months beginning in mid-November and ending in mid-March. More than 90% of the annual precipitation is generally supplied during this period. App. Table 5 and Figure 5 show the monthly averages and transition of them in Sesheke, Livingstone and Lusaka.

The water level of the Zambezi River, one of the main rivers in Zambia, increases in December in proportion to precipitation. In January and February, the flood plain is flooded and water starts to recede in March. The level of underground water in small rivers with light flooding or in recessed areas in the highlands increases during this time frame and falls in March and April.

The level of underground water is relatively high for approximately one month (April) after the rainy season ends, and water storage (pF < 2.7) in the soil can be expected. However, from May or June to mid-October, moisture is depleted and a dry environment for plants, when plants depend only on soil moisture of pF2.7 to 4.2 (capillary water above the wilting point), will set in.

(2) Past variations in climate

Climate data could not be obtained within a short time so a study using direct-measurement values was not possible. However, the World Climatic Table, published by the Japan Meteorological Agency in 1967 and 1994, contains data for 1960 (average values from 1930 to 1960), 1980 (average values from 1961 to 1980) and 1990 (averages from 1961 to 1990). Averages from 1981 to 1990 were estimated by calculation).

This enabled a study of the average climatic values over the past ten years in Zambia and in surrounding areas.

Studies of the climatic values for Sesheke, Livingstone, Lusaka and Ndola were made, incorporating local data amassed over a ten-year period (between 1984 to 1993).

1) Air temperature

As mentioned in the section on precipitation, precipitation during the rainy season is decreasing in the south-western region. This is believed to be the reason for the high air temperatures between November and January. (See Livingstone example in Table 10.) However, this trend is not as prominent as the average observed values in other areas.

2) Precipitation

Figure 6 shows the average monthly values during different periods and a transition of them. As mentioned above, the north-western region of Zambia near the humid zones (Mongu and Ndola) and areas around it (Zaire and the northern region of Angola) continue to show much precipitation. However, in recent years, the areas south of these areas, which have little precipitation, are experiencing a condition which further accelerates the low precipitation trend. This trend is especially prominent in the south-western region.

In considering the Livingstone values, the annual precipitation over a 45-year period, from 1930 to around 1975, was approximately 800 mm and was relatively high, but the annual precipitation over the past 20 years, from 1975 to the present, decreased approximately 22% and is low at approximately 620 mm. This low trend is common in the western part of Zimbabwe, Botswana, the south-western part of Nambia and other areas. It is feared that this phenomenon might be an expansion of the so-called desert climate centering on the Kalahari desert. The precipitation during the 1994/1995 rainy season was very low.

By examining the recent precipitation trend by Martonne indexes, the south-western region of Zambia, which was not strictly a semi-arid climate zone in the past, is changing to a semi-arid area as follows:

Martonne's aridity index $I = P/(t + 10)$

I: Index, P: Annual Precipitation (mm), t: Annual average temperature

Livingstone	(1930 to 1975)	$I = 800/(21.8+10) = 25.1$
Livingstone	(1975 to 1993)	$I = 920/(22.6+10) = 19.0$
Sesheke	(1984 to 1993)	$I = 631/(22.1+10) = 19.7$

* $(5 < I < 10)$: Hyper arid, $(0 < I < 5)$: Arid. Both aridity indexes are desert zones.
$(10 < I < 20)$: Semi-arid
$(20 < I < 30)$: Light semi-arid

Recently, local residents in the south-western region told the consultants that the flow of rivers in the area, such as the Loanja, Loazamba and Machili Rivers, has been reduced. The decrease in precipitation observed in the region confirms this report. As far as the main stream of the Zambezi River is concerned, the precipitation in the upstream areas north of Mongu has not changed (decreased) over the past 10 to 20 years. It is assumed that the flow to nearby Senanga has not changed greatly compared with the past. However, in the mid-stream areas, the precipitation has decreased drastically and the trend seems to indicate that the flow has decreased in the lower areas, near Seshcke downstream from Senanga and Livingstone.

On a global scale, annual fluctuation ratios of statistical precipitation in desert areas are known to be high, or more than 30%, followed by the arid-climate zones around them with 20 to 30%. The south and south-western areas of Zambia can be classified as areas near a desert and were originally judged as areas with a high probability of abnormally high aridity. In the past 15 to 20 years, the scant-rain trend has continued and could lead to greater aggravation in the future. This is feared to be an abnormal fluctuation in excess of the variation rate. In the worst case, this may be a sign of an abnormal weather phenomenon caused by the recent warming of the earth. Thus, it can be surmised that the region has transformed itself to a reduced-rain-climate zone, where the aridity is higher than before, compared with that of 20 years ago.

1.2.2. Topography and geology

Topographical and geological features are generally characterised by the geological structure and changes in the structure. If one examines it in detail, one would find that it differs depending on the climatic variations and vegetation growth.

(1) Structure of bedrocks

Most of the landmass in the central and southern parts of the African continent is characterised by a high incline near the coast so that the entire highland topography rises one step higher. In the raised bedrocks, the central and southern parts of the continent (inland part nearer to the center than the seashore mountains on the Atlantic Coast), where the study area is located, have bedrocks which are greatly curved downward to form a large recessed basin-like shape, the Kalahari Basin (Jurrasic in Mesozoic Period).

Between the Mesozoic and mid-Tertiary Periods, land formed in the mountains and highlands near the basin was moved by rivers under humid conditions and by winds under arid conditions and is estimated to have been deposited continuously in the lowland. This was the formation of sedimentary rocks, which are generically called the Kalahari group (Figure 7).

At present, these strata are thickly covered by Kalahari sand layers, which are like a desert in nature. There are a very few places which allow us to directly confirm this condition by naked eye. However, the following condition can generally be estimated based on boring and other data (Thomas, Shaw 1992).

Sandstone, shale and other sedimentary rocks were the main bedrocks before the basin was formed.

During the Pliocene of the Mesozoic Period, granite intruded into the bedrocks and was metamorphosed. Partly due to this reason, the interleaved distribution of metamorphic rocks, such as mica schist, phyllite, gneiss, and plutonic, could be found. Gravel sedimentary rocks were found as a type of sedimentary rock after the basin was formed.

However, sandstone sedimentary rocks are most prominent, followed by mudstone sedimentary rocks. The sedimentary rocks were probably formed from the beginning of the Mesozoic Period until the mid-Tertiary Period. Historically, these rocks are old, but probably because the upper layers were not compacted, the solidification index of them is low and unsolidified gravel layers (red) and sandstone layers can be found.

Volcanic rocks of the basalt type (lava and tuffaceous breccia) erupted from the weak parts of the geological structure triggered by land, ascending or flexure descending, included in the lower parts of sedimentary rock layers or inside sedimentary layers. Places that are thickly covered by volcanic rocks appear on the edges (high places) of the region and in lowlands along the main stream of the Zambezi River.

Along the Zambezi River, these rocks are currently exposed in river beds of falls or rapids and on banks on both sides, allowing direct observation. (See Figure 8, Geological Map.)

Sedimentation of solidified or weakly solidified bedrocks ended during the first half (Miocene) of the New Tertiary Period. Between the Pliocene of the New Tertiary Period and the present through the Dilivium, non-solidified sand layers (desert sand layers) were deposited on a large scale. (A detailed history is not available as index fossils cannot be found.) Sand is believed to have been supplied in the following progression: Erosion of source rocks in nearby mountains → transportation → sedimentation in a fan shape. A large amount of rocks are deposited even in relatively high places.

It is believed that the large amount of aeolian layers were deposited by winds. In any event, sand layers were deposited as if to cover the existing topology, burying convex and concave parts of topography in the past so that variations appear to be flattened in a highland form as a characteristic.

These are the so-called Kalahari sand layers.

(2) Sedimentation mechanism of Kalahari sand layers

Judging from the sedimentary condition of sand layers, the weathering coloring conditions, and other conditions, the sedimentary process can be divided into the following stages.

During the second half of the New Tertiary Period and the Dilivium, the bedrocks of the entire south-western region, including the Kalahari Basin, ascended intermittently. It appears that ascension began during the Dilivium, when the present channel pattern was almost entirely large in scale. As a result, the Kalahari Basin, corresponding to mid-stream of the Zambezi River, became relatively high compared with the lowland in the eastern down-stream areas. The difference in the river bed between them must have increased.

To eliminate this height difference, the main stream of the Zambezi River made the downward erosion phenomenon go upstream with regard to the mid-stream, and for the downward erosion phenomenon to pass mid-stream, the erosion power of mid-stream which includes the tributaries must have increased. Describing it more specifically, after the New Tertiary Period, downward erosion seemed to have gone upstream from downstream to the Kalahari watershed in the midstream and upstream areas.

However, in the early stage, downward erosion of tributaries in the Kalahari Basin watersheds did not activate even though the main stream had downward erosion. It is assumed that the sedimentation of soil in the basin produced from nearby high places continued for some time and stratigraphy of sedimentary rocks increased. It is believed that the sedimentation activities in a fan shape continued for some time, even after the Zambezi River inside the basin started to show downward erosion. When the downward erosion trend reached the tributaries shortly thereafter, sedimentation activities of the fan shape was totally stopped. Conversely, it can be surmised that the activities started to shave the layers deposited so far. Thus, as a result, the hill-like topography rich in relief and uneven as an erosion topography, also seemed to have appeared in the Kalahari watershed.

At the end of the New Tertiary, or in the Dilivium, the climatic conditions changed and this area, including the upstream area of the Zambezi River, became a super dry zone, changing to the same condition, as the Kalahari desert in the south expanded. It is believed that this area was covered by thick sand layers after protruding sandstone and shale parts were shaved and transported by winds, with the soil flying from the center area of the Kalahari desert along with aeolian deposits. On the other hand, in this dry climate, the eroding power of rivers weakened so that soil deposited by winds was deposited in valleys, too, forming a gentle sand layer topography with less-sharp relief compared with the previous aeolian deposit.

The desert condition described above continued for some time. However, the climate again became humid and vegetation was believed to have recovered throughout the area. After the precipitation increased, the valleys too must have regained their eroding power. However, the slopes were covered with vegetation and strong erosion phenomena did not appear, with the result that valleys were dissected in a gentle condition.

Rapids that expose the local base bedrocks run in the main stream of the Zambezi River. However, in most of the river beds, deep dissection reaching the bedrocks has not occurred. And the tributaries in particular were not downward-eroded. The slopes became slightly more bumpy and dented in accordance with the surface unevenness of an underground basement. Geology seemed to have changed less radically, maintaining relatively thick sand layers. In other words, it can be assumed that even though the surface unevenness of the basement topography is reflected, a sand-layer-covered topography showing a surface unevenness gentler than that of the basement topography has appeared.

During this time, weathering progressed under a humid tropical climate condition and all of the sand layers became reddish. Inside the lower stratigraphy of sand layers, iron, aluminium and other metals moved by leaching of the upper layers have illuviated immediately above the low-permeable base rocks to form dark red consolidated layers (pans) called "curasses." Curasse layers are not formed in protruded topography whose basement topography drains water.

Partly because precipitation was accelerated on the basement layers, pans are distributed as if to cover almost all natural ground (basement topology) in the area, or in other flat or dented places. Some of the pans are as thick as 2 m, forming semi-permeable layers inside the sand layers.

The humid climate described above seems to have continued for some time. In the Pliocene of the Dilivium, the climate again became arid and desert-like, supplying a large amount of sand carried by winds. In places other than the main stream of the Zambezi River, soil deposited by winds was deposited as if to cover and hide the surface unevenness of the natural ground, resulting in the flat highland topography that can be viewed at present. These sand layers were deposited and exposed to new wear and are not reddish. In many cases, the residual B and C layers, which have been exposed to subsequent weathering, become a yellowish orange. In the post-glacial age, rainfall improved and the humid climate returned to the upstream areas of the Zambezi River, while the semiarid climate returned to the mid-stream area (the study area). The growth of forests, herbs and vegetation has been possible until today. Between Senanga and Sesheke, the river banks along the Zambezi River's main stream were once covered with healthy forests, but dissection became deep and the valley slopes relatively steep, so that over a period of many years most of newly deposited sand layers were washed away, resulting in an outcropping of the old red soil.

Reddish sand layers of former periods are now exposed. Sharp slopes of a residual hill shape are distributed in the upstream areas of the tributaries. Also in these areas, reddish sand layers of the former periods cover the surface layers. In many cases, the reddish sand layers underneath are exposed in areas which are made flat by new sand layers, provided buried topography is shallow (mostly on buried, convex slopes).

(3) Micro-topography on Kalahari sand layers

It appears that the main stream and tributaries of the Zambezi River slowly eroded downward, repeating large-scale meandering. Very large flood plains formed where the river bed gradient was small. New winding erosion was repeated as downward erosion progressed. As a result, old alluvia have remained as relatively high low terraces. Alluvial plains (high flood plains), flood plains during the rainy season (low flood plains, delta flood plains in downstream parts of tributaries) and other low topography are distributed over wide areas.

In summary, it can be surmised that lowlands below the low terraces were formed by alluvium and highlands higher than middle terraces were made up of sand layers which cover the natural ground. The underground water level in the case of the former tends to be strongly interlocked with the water levels of rivers. The underground water level in the case of the latter tends to be characterized locally by surface unevenness and inclination of buried topography.

In the case of medium plains and high terraces (highlands), draining in them becomes poor if the flat terrace areas are large, causing perhumid land and ponding basins during the rainy season. In many cases, these places are circular or oval. The causes of them can be explained by the past dune topography (semicircular dunes and dents inside them). However, in many cases, there are places such as dented parts of ground topography, places where sand layers are thin, and places where the "inlandness" characteristic is prominent.

Stagnation of underground water is mostly the reason for them. In these places where water stagnates, dents are formed by compaction of the natural ground, in addition to the nature of the natural ground which tends to form dents. A high content of silt and clay and a semi-permeable layer accelerate ponding.

The movement of some soil is generally observed on the top surfaces of terraces, highlands or flood plains even though they are flat. In this case, whether or not vegetation exists becomes a condition to regulate subsequent sedimentation (erosion). As a consequence, this causes a separation between relatively dry, high surfaces and perhumid bottom surfaces.

Vegetation does not grow on ponded surfaces, which have a large difference between perhumidness during the rainy season and aridity in the dry season, or in similar places. Compared with this, herbs usually grow in places where pond water is not available. In places where herbs grow, shifting soil, such as soil transported and deposited by winds, is caught to accelerate sedimentation. Furthermore, one characteristic is that subsequent sedimentary layers become stable. Under these conditions, compared with marshes, soil layers, in places where vegetation growth becomes thicker, increase environmental differences of relative height difference, aridity and humidity.

1.2.3. Vegetation

Large trees can grow in places where an underground water level is maintained at a suitable depth or in places where the soil layer is thick and some water is retained in the soil during the dry season, even though the dry season is long and the soil is prominently dry. Soil distributed in this area, which derives from the Kalahari sand layers, is made up of sand grains which are large in size. Therefore, soil in this area does not have many fine and small pores.

Common sense tells us that the sand soil is liable to be evaluated as having poor water retentivity. However, because the sand layers in this area have good porosity, the probability of retaining abundant underground water interlocked to water in rivers, lakes and marshes is high even if the distance to the said water sources is great. Compared with soil layers, sand layers are very thick, entire layers have a large amount of water retained in them, even though the water retentivity per cubic unit volume is low. Utilising this condition, it appears that large trees can be grown. The magnitude of difference in the level of underground water and of water, the amount of water retained in soil layers (sand layers) and the level of utilization factors of them, delicately differ in accordance with micro-topography, thickness of sand layer and other factors. This was found to have an impact on contributing factors on forests and woodlands and on the status of tree species composition in forests and woodlands. This research has clarified many questions regarding the relation between soil and moisture conditions and tree growth. These matters will be discussed in another chapter.

Perennial trees of almost all species do not grow in places which are flooded for a long time during the rainy season, probably because of decayed roots. Short-lived herbs, which can be regenerated or grow even during the early dry season, are found. The general vegetation landscape is greatly influenced by the water level environment, such as flooding, non-flooding, perhumidness or suitable humidity during the rainy season. Tree species and density are regulated by a fine match with water environment.

Thus viewed, regularity can be found in the natural distribution of plants. However, this regularity is disturbed by the expansion of farm land, by unattended farm land after expansion, by overgrazing and particularly by burning. What was once forests or woodlands is now grassland, bushes (shrub land) and bare land over a large area. Generally, dry areas in the tropics are considered as savannas where grassland areas are dominant or areas near a desert, where thorny shrub plants grow. Such a vegetation landscape is believed caused mostly by man-made impact, rather than by natural impact.

Table 10 Monthly average temperature (°C)

Place	Alt.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann	Term
PortFrancqui	485m	25.0	25.9	26.1	25.9	25.9	25.4	24.5	25.3	25.6	25.6	25.6	25.6	25.6	37-53
		25.9	25.9	26.1	26.9	26.9	25.0	24.8	25.3	25.6	25.6	25.6	25.6	25.6	51-55
Ilebo	420m	24.7	24.7	24.8	24.6	24.9	24.2	24.0	24.5	24.6	24.5	24.3	24.4	24.6	51-60
Elizabethvil	1276m	22.0	22.0	22.0	20.9	18.6	16.4	16.1	18.1	21.4	23.6	23.4	22.2	20.6	19-40
		22.0	22.2	22.0	20.9	18.6	16.4	16.1	18.1	21.4	23.6	23.4	22.2	20.6	41-55
Lubumbashi	1298m	20.5	20.4	20.7	20.7	19.1	17.0	16.9	19.4	22.3	23.1	21.6	20.5	20.3	51-60
Lusaka	1279m	21.4	21.7	21.1	20.6	18.6	16.4	16.1	18.3	22.0	24.5	23.4	22.0	20.6	38-54
Kabwe	1207m	21.0	20.7	20.7	19.8	17.5	16.0	15.8	18.2	21.8	24.0	22.6	21.0	20.0	61-76
		21.4	21.5	21.1	20.2	18.5	16.0	16.2	18,8	22.6	24.4	23.4	21.8	20.4	77-90
Lusaka	1270m	22.9	22.8	22.2	20.2	17.7	16.3	17.2	20.1	22.6	23.5	22.8	22.7	20.9	84-93
Mongu	1058m	22.5	22.4	22.7	22.3	19.8	17.2	17.5	20.4	24.4	26.1	24.4	22.4	21.8	41-60
		22.7	22.7	22.4	22.2	19.7	17.3	17.5	20.6	24.3	25.4	23.7	23.1	21.8	61-90
Livingstone	986m	23.1	22.0	22.8	22.2	19.1	16.2	16.5	19.4	23.9	26.9	25.1	23.7	21.8	41-66
		23.5	23.0	23.1	22.1	18.9	16.1	15.9	18.7	23.5	26.4	25.0	23.6	21.7	61-76
		23.5	23.0	23.3	21.8	19.1	16.1	16.2	19.6	24.3	26.1	25.7	24.1	21.9	77-90
		24.8	24.6	24.5	22.8	19.9	16.9	16.5	19.2	23.7	26.2	26.6	25.5	22.6	84-93
Salisbury	1478m	20.0	19.8	19.4	18.7	15.9	13.6	13.6	15.6	19.0	21.3	20.8	20.4	18.2	31-60
Harare	1472m	20.6	20.7	19.9	19.2	16.7	13.9	13.9	16.3	19.1	21.8	21.4	20.9	18.7	51-60
		20.4	20.0	19.4	18.1	15.5	13.1	13.1	15.2	18.6	20.6	20.7	20.3	17.9	61-90
Bulawayo	1344m	21.7	21.4	20.6	19.7	16.4	13.9	14.2	16.1	19.7	22.2	22.5	22.0	19.2	00-51
		21.3	21.0	20.3	18.7	16.1	13.5	13.7	16.3	19.7	22.0	21.6	21.2	18.8	51-80
		22.4	21.0	20.6	18.7	16.1	13.8	14.0	16.6	20.3	21.0	21.9	21.7	19.1	81-90
Windhoek	1700m	22.0	21.0	20.5	18.9	15.6	12.9	13.0	15.8	19.6	21.7	22.6	23.1	19.0	51-60
		22.8	21.5	20.6	18.8	15.6	12.9	13.1	15.8	19.7	21.7	22.6	23.6	19.1	51-80
		24.4	23.1	22.1	19.0	16.8	13.9	14.1	16.4	20.1	21.7	23.2	24.8	19.9	76-90

Table 11 Monthly precipitation (mm)

Place	Alt.	Lat.	Lngit.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann	Term
(Zaire)																	
PortFrancqui		04S20	20E35	152	163	211	180	74	13	20	48	170	178	249	218	1676	37-53
Ilebo		04S20	20E35	164	132	179	212	111	12	13	38	167	217	253	215	1709	51-60
Dundo(Angola)		07S24	20E49	213	163	227	196	36	10	3	39	108	156	281	215	1649	61-72
(Southern Zaire -- Northern Zambia)																	
Elizabethvill		11S36	27E32	248	263	204	57	4	0	0	1	3	27	164	258	1229	31-60
Lubumbashi		11S40	27E29	248	301	218	55	3	0	0	0	3	29	161	269	1301	31-60
Ndola	1270m	13S00	28E39	299	288	138	44	10	1	0	0	4	26	145	293	1244	61-69
				321	215	176	33	2	0	0	0	2	33	114	274	1168	84-93
(Zambia)																	
Lusaka	1279m	15S25	28E19	231	191	142	18	3	0	0	0	0	10	91	150	836	38-54
Kabwe	1207m	14S27	28E28	264	205	108	18	4	0	0	0	1	23	85	259	967	62-75
				221	167	107	57	6	0	0	0	1	39	117	210	915	76-90
Lusaka(1)	1270m	15S25	28E19	227	179	84	45	1	0	0	0	1	15	54	198	804	84-93
Lusaka(2)	1270m	15S25	28E19	241	180	81	30	1	0	0	0	1	13	57	192	797	84-93
Mongu	1053m	15S16	23E06	217	211	145	37	1	1	0	0	2	35	102	219	969	31-60
				209	183	143	57	6	1	0	1	6	54	114	193	966	61-90
Livingstone	986m	17S49	25E49	186	175	101	28	4	1	0	0	2	20	92	104	781	31-62
				190	177	84	28	3	1	0	0	2	29	86	217	805	61-76
				177	110	86	35	9	1	0	1	2	23	62	114	618	77-90
				159	135	88	24	0	0	1	0	1	21	55	149	625	84-93
Sesheke				130	160	81	23	0	0	0	0	3	28	73	133	631	84-93
Tsumeb(Namibia)1310m																	
1411m		19S14	17E43	117	119	81	38	5	0	0	0	0	18	56	84	521	21-60
Grootfontein		19S36	18E07	144	125	106	49	3	1	0	2	4	13	61	58	564	61-85
(Botswana)																	
Maun	945m	19S59	23E25	110	104	83	25	5	1	0	0	1	16	46	80	471	31-60
				127	114	66	34	6	1	1	2	6	21	53	80	510	61-89
(Zimbabwe)																	
Salisbury		17S55	31E06	216	172	99	36	11	4	1	3	5	30	100	186	863	31-60
Harare	1480m	17S50	31E01	236	167	68	45	13	8	0	2	8	37	94	201	897	51-60
				191	148	98	46	10	3	2	2	9	36	101	170	815	61-90
(Zimbabwe)																	
Bulawayo	1344m	20S01	28E37	142	169	84	18	10	3	0	0	5	20	81	122	594	00-51
				142	113	54	33	11	1	0	2	9	31	104	145	675	61-80
				91	83	42	40	2	3	1	1	4	51	64	74	456	81-90
(Namibia)																	
Windhoek	1728m	22S34	17E06	77	73	81	38	6	1	1	0	1	12	38	47	375	31-60
				73	105	80	32	6	2	1	1	5	14	33	36	388	61-80
				68	62	59	27	6	2	0	1	1	9	26	16	277	81-87

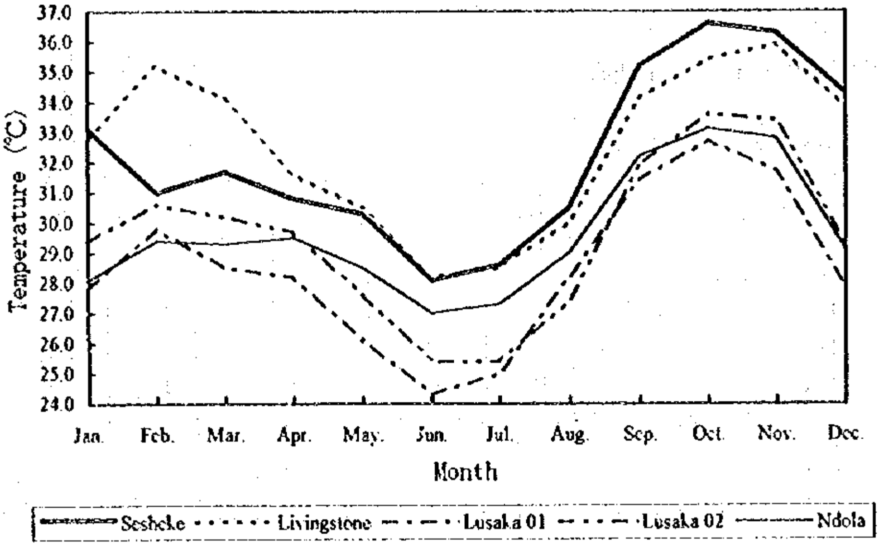


Figure 2 Monthly changes in maximum temperature (°C)

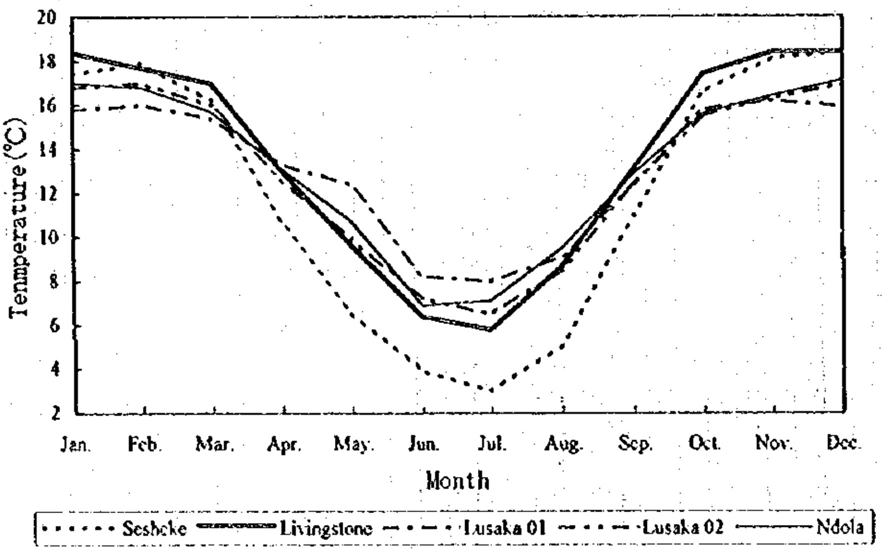


Figure 3 Monthly changes in minimum temperature (°C)

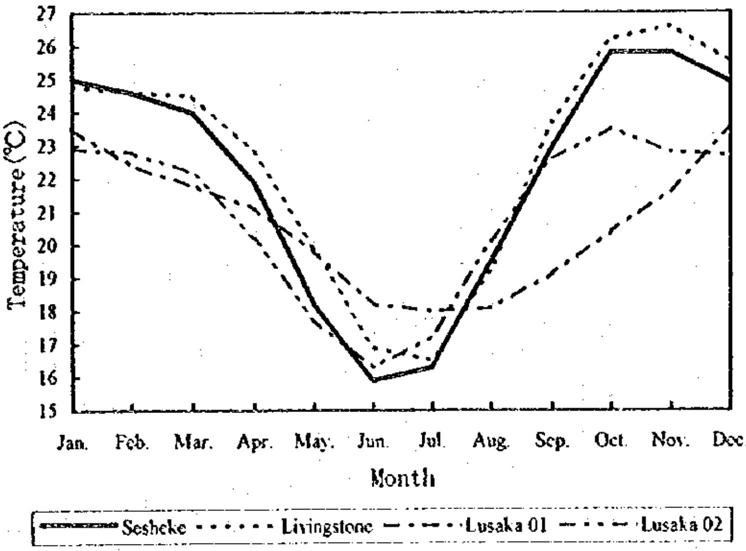


Figure 4 Monthly changes in temperature (°C) per annum

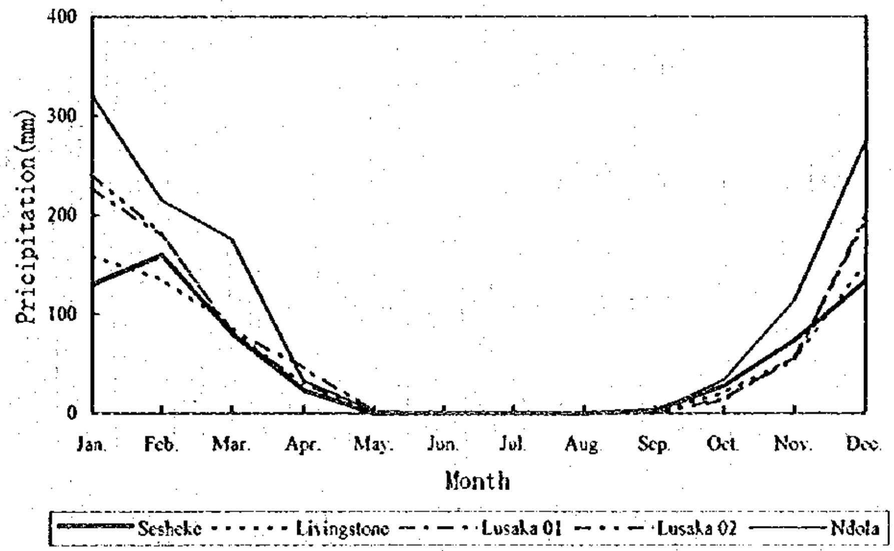


Figure 5 Monthly changes in precipitation (mm) per annum

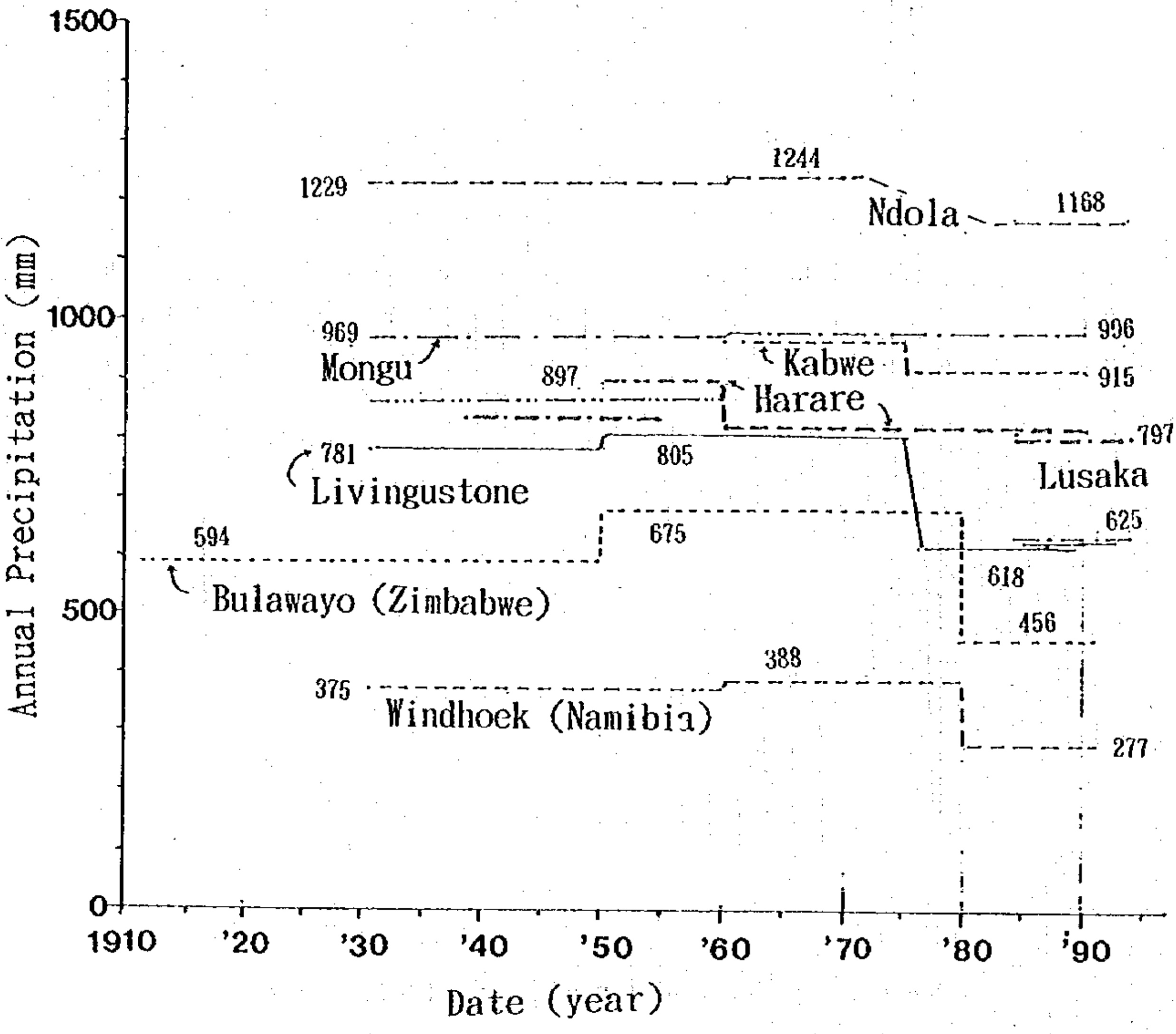
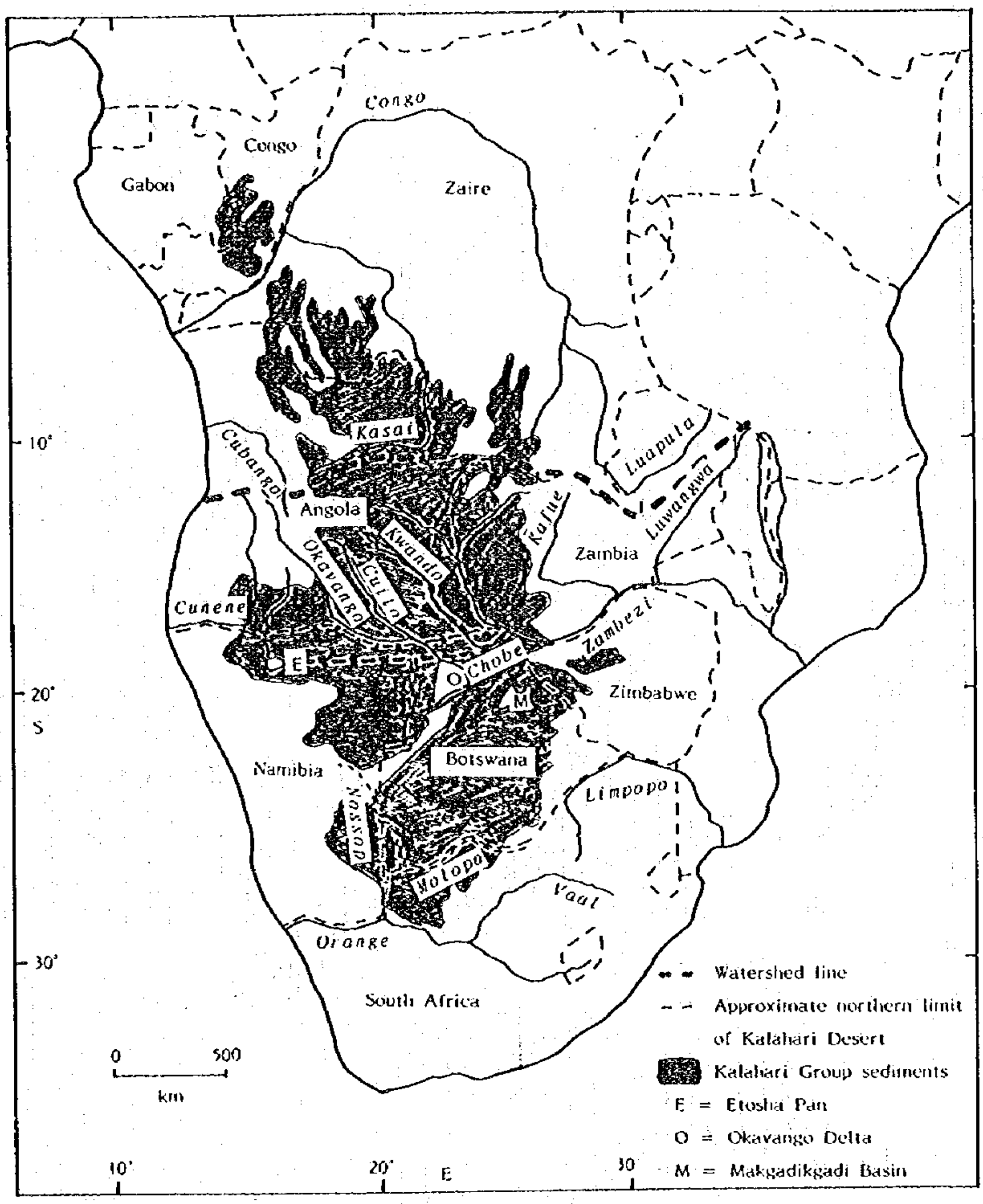
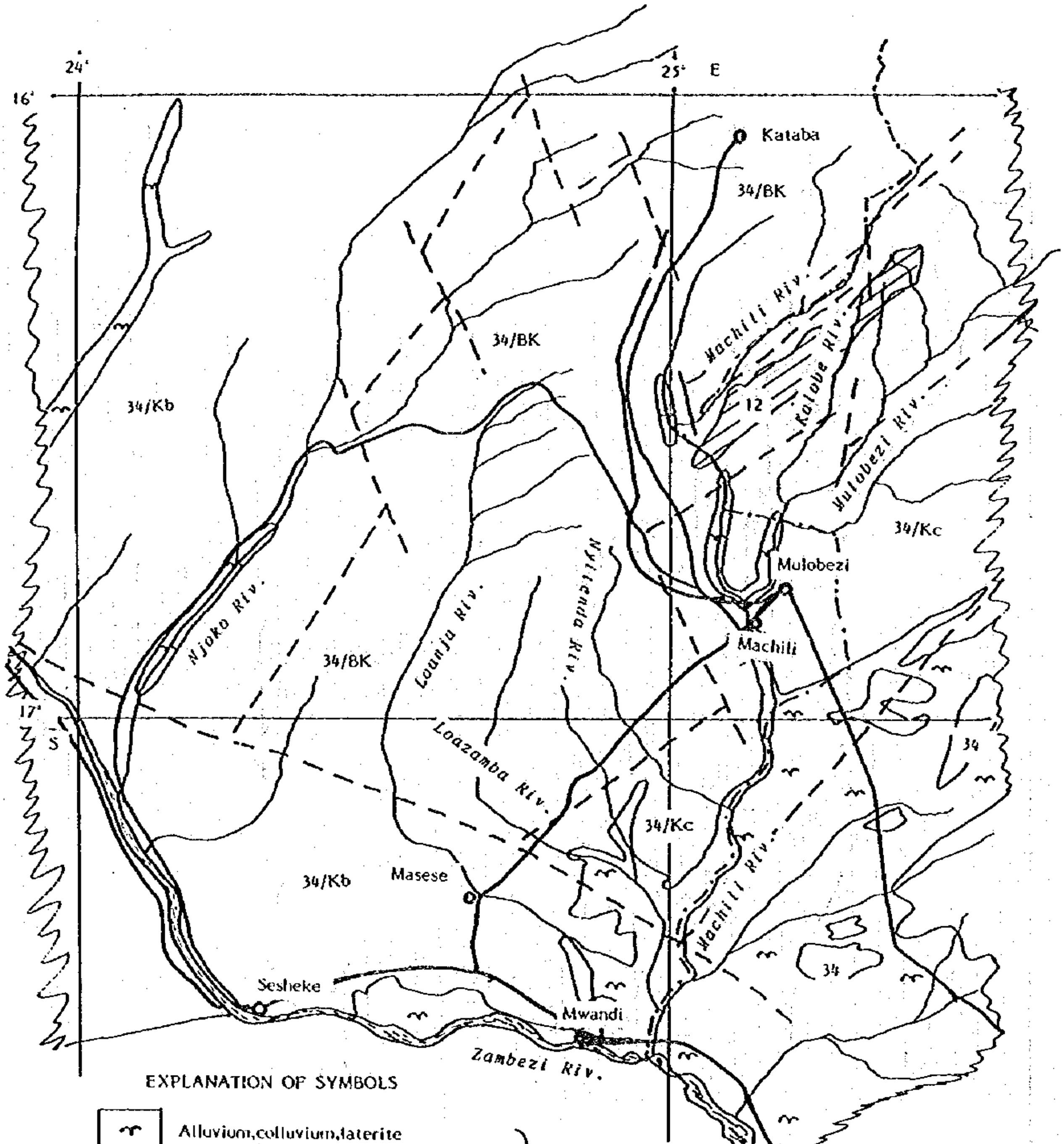


Figure 6 Chronological changes of annual precipitation from 1930 to now



Note: The shaded area, defined on geological and structural grounds, is the Mega Kalahari.

Figure 7 Kalahari regions



EXPLANATION OF SYMBOLS

Alluvium,colluvium,laterite

34 Kalahari Group with fossil
Sub-outcrop of solid geology underlying these groups shown as follows:
Kb-Karroo Basalt, Kc-Karroo Clastics, BK-Basement and Katanga System.
} TERTIARY TO RESENT

12 Undifferentiated Basement Complex; mainly granitic gneisses and migmatites with some granite. Trends of banding shown where present
} PROBABLY LARGELY OLDER PRECAMBRIAN

– – – – Fault concealed

Figure 8 Geological map of survey area

2. LAND-USE, VEGETATION, FOREST RESOURCES AND SOIL

This section describes the state of vegetation, land-use, forest resources and soil in order to determine the present forest situation in the study area.

2.1. Conditions of Land-Use and Vegetation

2.1.1. Purpose of study

The purpose of this study is to grasp the state of land-use and vegetation so that land may be utilised in the intended forest management.

In general, forest vegetation in Zambia is roughly classified into forests and woodlands. The tree species making up each of these classes have been subdivided into different types. As a result of former vegetation analyses frequently conducted in the study area, vegetation maps have already been prepared showing the areas where subdivided vegetation types are distributed. It is reported that Mukusi forests, Munga woodlands, Kalahari woodlands, Mopane woodlands and (Dambo) grasslands are distributed in the study area. These analyses were intended to clarify the distribution range of vegetation from a botanical point of view, and a qualitative grasping of vegetation was enabled.

However, it was difficult to determine the contents and quantities of resources in specific regions. It was also difficult to grasp the state of land-use in the areas surrounding the plots where forest resources were distributed.

Consequently, the purpose of this study is to fulfill the above two requirements, which were not attempted in the vegetation analyses so far conducted, so that the results may be utilised in a quantitative and sustainable management of resources, especially Mukusi resources. It is also necessary to clarify the features of vegetation distributed in specific sites. This will be discussed later in the section related to the study of land-use management.

Further, in order to conduct planned forest management, it is essential to prepare drawings from which distribution of vegetation, status of land-use, as well as the quantitative distribution of forest resources are obtained. Consequently, we decided to prepare the drawings to satisfy the following requirements in a scale of 1/50,000.

- Grasping the distribution of Mukusi forests and other vegetation types
- Grasping the land-use status in the areas surrounding the forests
- Grasping the relation between forest resources and contents of the Forest Inventory Book, which describes the location and quantities of forest resources

Here, we decided to edit the drawing to determine the land-use status and distribution of vegetation types (land-use and vegetation maps) separately from the drawing to determine the quantitative distribution of forest resources (forest-resources distribution maps) in accordance with the respective purposes of their use. Therefore, the forest resources distribution maps would also have a role as drawings attached to the Forest Inventory Book, which will be discussed later in the section related to entries in this book.

2.1.2. Study methods

We employed a classification method to ensure a wide-ranging observation of the study area as a whole, and an on-the-spot determination of the characteristics of land-use forms and vegetation types. In order to clarify the characteristics of each vegetation type, we conducted a belt-transect survey to measure the forests and woodlands and a quadrat survey with regard to grassland. We also utilised the materials obtained through measurement of each plot. The method of preparing land-use and vegetation maps will be stated in the 2.1.6 section.

2.1.3. Divisions of land-use and vegetation

The divisions of land-use and vegetation are as follows:

a. Natural grasslands

b. Tree grasslands

 b1. Mupane tree grasslands
 b2. Natural tree grasslands
 b3. Artificially degraded tree grasslands

c. Woodlands

 c1. Open woodlands
 c2. Closed woodlands

d. Forests

e. Farm lands

Although the above divisions will be described in detail in the next section, in establishing the divisions, the following was taken into consideration:

Most of the conditions for distribution of vegetation types currently noted was mainly achieved through burning. It is not appropriate, therefore, to regard them as actual findings of natural vegetation. Notwithstanding this situation, we basically took the method of establishing the divisions of forests, woodlands, and grasslands since such divisions have been used for a long time and people are accustomed to them. However, in view of the fact that trees came to grow in grassland along with the recent dry weather and that the area of burned forests expanded to a large extent as a result of frequent burnings, the division of grasslands was subdivided into "natural grassland" and "artificially degraded tree grassland." Moreover, the division of "tree grassland" is used in some of the drawings already issued by the Survey Department of Zambia.

In distinguishing forests from artificially degraded tree grassland, a crown coverage of 20% was used as a standard; the land with a crown coverage of less than 20% was classified as artificially degraded tree grassland. Further, the fact that the land near villages with a crown coverage of less than 20%, in which trees were scattered and where land was frequently used for grazing, was also taken into consideration.

Open forests without any shrub layers called Mutemwa, whose surfaces could easily be interpreted in aerial photographs, were classified as woodlands.

In distinguishing closed woodlands from open woodlands, a volume of approximately 10 m^3 per ha was used as a standard. Land having a volume below this standard was classified as open woodland with no timber resources distributed.

Areas that flood during the rainy season, such as flood plains, river channel areas, and marshes, where herbs alone grow, were classified as natural grasslands.

Natural grasslands which were formerly flooded have become areas where trees have started to grow. These are called natural tree grasslands. Flood plain areas where Mupane now grow are called Mupane tree grasslands. Generally, pure Mupane forests are small-scale concretions, and are usually classified as Mupane woodlands. However, small-scale grasslands are mixed with the Mupane. And when a reduced scale of 1/50,000 is used, classification of these two becomes difficult. So the entire distribution area is referred to as Mupane tree grassland.

Areas which used to be forests but now have only scattered trees as a result of burning, farming and grazing, as well as the areas where shrubs less than 6 m in height and perennial herbs started to grow, were classified as artificially degraded tree grasslands.

Lands currently used for cultivation or lands having been used until recently were classified as farm lands, while lands formerly used as farm lands but whose cultivation has been abandoned were not classified as such.

Grazing is also a form of land-use. However, since fences were rarely used, the areas utilised for this purpose were apt to move constantly. Also, the areas for hunting and nut gathering also shifted. Such areas were not classified as any specific type of land

In classifying land, a minumum unit of 3 ha was used as the standard. However, taking into account the utilisation of maps, work units were integrated from time to time.

For an interpretation of the area studied, aerial photographs in scales of 1/25,000 and 1/50,000 taken in April and May of 1994 were utilised.

2.1.4. Vegetation types and land-use forms

(1) Vegetation types

As stated above, as a result of vegetation surveys conducted in the past, distributions in the study area of Mukusi forests, Munga woodlands, Kalahari woodlands, Mupane woodlands, and (Dambo) grasslands have been reported.

In classifying this study, while former Mukusi forests were included in the division of "forests," Munga woodlands and Kalahari woodlands were included in the division of "woodland." Further, former Mupane woodlands and (Dambo) grasslands were included in the division of "natural tree grassland" and "natural grassland," respectively.

The area of distribution and the area ratios of the following vegetation types represent data from a district of 500,904 ha for which land-use and vegetation maps were prepared.

a. Natural grassland (22,472 ha; 4.5%)

Natural grassland is distributed in flood plains, river channel areas, marshes, and dambo which flood during the rainy season, where perennial plants cannot grow but annual herbs alone grow.

b. Tree grassland (170,334 ha; 34.0%)

b1. Mupane tree grassland (30,824 ha; 6.2%)

This is tree grassland where Mupane is dominant and distributed mainly in flood plains in the midstream and downstream watersheds of the Machili River. Annual herbs grow in areas which are flooded during the rainy season. Pure forests of Mupane are distributed in concretion in areas that are 0.5 to 1.5 m higher than the flood water level do not flood even during the rainy season. Large growing stocks of Mupane sometimes reach 100 m^3/ha. Mupane grows in extremely hard soil and becomes the dominant species in overhumid or humid soil. Mupane is very active in its natural regeneration (seedling and coppice regenerations). However, natural regeneration is hindered in areas where burning takes place. Flood plains have become increasingly dry in general, and the range of Mupane distribution has been enlarged. Mukangala, Muhonono, Mukotokoto, Munga, etc. also grow, although their number and distribution areas are both limited.

b2. Natural tree grassland (33,548 ha; 6.7%)

In the Mulayi dambo, Mulimakule dambo, Lilonga dambo, etc. and river channel areas of tributaries, which are no longer flooded even during the rainy season, trees have started to grow in the areas which used to be natural grassland. Mubako, Musese, Muzauli, Muhoto, Muhonono, etc. are the pioneer tree species to grow first in natural grassland. Entire watersheds are increasingly dry and the areas which are not flooded any more even during the rainy season have expanded. Accompanying this trend, areas shifting from natural grassland to natural tree grassland have also been enlarged.

b3. Artificially degraded tree grassland (105,962 ha; 21.2%)

This type of tree grassland has come into being through human impact, and is distributed in the slashes of burned forest or land reclamation slashes for cultivation.

In the case of burned forests, if the multi-story structure of the forest comprising tree and bush layers is in good forest condition, fire tends to become a large-scale crown fire. On the other hand, in a woodland where lower-story trees and bushes grow under poor conditions, fire becomes a surface fire and the woodland itself is rarely burned down. In the burned slashes, trees which survived the fire are scattered and perennial herbs such as Nandundu, Sanko, etc. as well as bushes grow on the land surface.

Also in the slashes of cultivation, bushes and perennial herbs cover the land surface, while the remaining trees are scattered. Such places are prone to frequent burning even if no more cultivation is conducted.

Approximately 40% of the forests in the Forest Estates have been burned down, as fires have accompanied these burnings intended for cultivation, grazing, hunting, and honey collection, including fires that were left unattended. Thus the division of artificially degraded tree grassland came into being, which is still on the increase.

c. Woodlands (196,535 ha; 39.2%)

According to a botanical research conducted in the past, the Kalahari woodlands were formulated as a result of retrogressive succession from Mukusi forests to woodlands affected by fires, cultivation and the existence of elephants.

With a crown coverage that is smaller than that of forests, woodlands are an open forest, possibly having been formed because competition for water has priority over competition for light among trees constituting the woodlands. This will be discussed in detail in the section related to land-use management.

c.1 Open woodlands (43,383 ha; 8.7%)

Open woodlands represent a transition zone to natural tree grassland with very few trees. As a wood resource, its quantity is small, with its scale being approximately 10 m^3/ha at most where Musese, Muzauli, Mukwa, Muhonono, Mulya, Kapapati, etc. grow.

As an example, the results of a belt-transect method in the Buhunda open woodlands are provided below. Compared with that of closed woodlands, the number of tree species and of live trees was much smaller, and both the height and diameter at breast height of the trees were also smaller. Tree species appearing there were three in number, i.e., Mubako, Musese and Kapapati, whose stand density is 300 trees/ha with a small crown coverage of 16% (Figure 9 and Table 12).

c2. Closed woodlands (153,152 ha; 30.5%)

Although the woodlands are an open forest, they are relatively closed. The shrub layers and herbs are in poor condition. Mukwa, Muzauli, Mungongo, Muhonono, Mubako, and

Mukusi are growing.

As an example, the results of the belt-transect method in the Buhunda closed woodland are provided below. The closed woodland of Buhunda is formed on a continuous topography together with the Sikubingwa forest, which will be discussed later. The number of Mukusi in existence is small. With a diameter of 20 cm at breast height, the height of the Mukusi barely reaches the medium and high layers. The number of Muzauli is the greatest of those in existence, with a tree height of 16 m reaching a high layer, and a maximum diameter at breast height of 46 cm. The dominant species are Muzauli, mixed with Musese, Mububu, Mulya, Muhamani, Mukwa and Muwawa. Its stand density is 860 trees/ha, and crown coverage, 66%. The crown coverage for Mukusi alone is only 3% (Figure 10 and Table 13).

d. Forest (86,021 ha; 17.2%—including 61,670 ha and 71.6% of the forest existing within the Forest Estate)

In the conventional classification of forests, the division of "Mukusi forests" is employed. However, since one of the purposes of this survey was to clarify the amount of Mukusi resources, a collective division of "forest" was used including the forests where the Mukusi is not dominant. The mixing ratios of Mukusi contents indicated in the Forest Inventory Book will be discussed in the section related to forest resources surveys.

In a typical Mukusi forest, Mukusi and Mwangla are dominant in the upper layer while a shrub layer consists of trees called Mutemwa. The forests with growing stocks of 200 m^3/ha or more are included, and they are distributed mainly on medium and high terraces where Kalahari sand layers are thickly deposited.

In the areas where thick sand layers exist, shallow-rooting species grow only in small quantities, and Mukusi is dominant there, demonstrating its characteristic of being deep-rooted. Mukusi can grow even in low and red terraces. Although Mwangla is shallow-rooting, it is dominant, having been mixed with Mukusi due surface water. In those areas where sand layers are thick. The mixing ratios of Mukusi and Mwangla vary depending on where they exist.

The composition of tree species for the plots surveyed in 57 areas established in the entire range surveyed are provided below. The breakdown of 1,925 trees with diameters of 6 cm or more were: 841 Mukusi trees (44%) and 351 Mwangla trees (18%). The total of the two species accounted for 60% or more of the entire composition. The number of species next to the above two were 180 Isunde trees and 114 Kangolo trees. The two species were shrubs constituting a lower Mutemwa layer. Other species in ascending order of their number were: Mukololo, Mulombelombe, Mububu, Muhonono, Mulalabainga, Muhoto, Mwalachi, Mukena, Musheleshele, and Mulyanzove.

As an example of the stand structure of Mukusi forests, the results obtained through a belt-transect survey performed in the Sikubinga forest are described below. Mukusi, the dominant species in this forest with its tree height of 3 to 13 m, was distributed in shrub to high tree layers, and trees with diameters exceeding 40 cm at breast height were included. The species next in quantity to Mukusi was Muzauli, whose tree height and diameter at breast height both indicated the highest values of 14 m and 64 cm respectively. The crown diameters of Mukusi and Muzauli reached 8.5 m and 13.5 m respectively.

In addition to these two species, Sibobo, Isunde, and Mububu were mixed, its stand density becoming 770 trees/ha. The crown coverage of the stand as a whole and of Mukusi alone were 67% and 58%, respectively (Figures 11 (1) and 11 (2) and Table 14). In addition, the stands with Muhonono or Muhoto growing in a condition similar to that of pure forests as well as stands mixed with various other tree species constituting woodland were also noted. The characteristics of the location of these forests will be discussed in the section related to land-use management.

(2) Land-use mode

The study area is used for farming, grazing, timber production, hunting, as well as the collection of honey, fruits and nuts. The areas where land is used in the above manner are prone to rapid changes and, therefore, the land utilised in a relatively fixed condition was classified as farm land. Its areas and area ratio were 25,542 ha and 5.1%, respectively.

2.1.5. Actual state of land-use and vegetation

The actual state of land-use and vegetation obtained through measurement of land-use and vegetation maps are indicated in Table 15. In this table, the amount of forest resources determined through a resource survey are also indicated.

The range of distribution of artificially degraded tree grassland represents the area of burned forests, with 53,800 ha accounting for 42.4% of the total area of Forest Estates, 125,900 ha. In particular, 70% or more of the Forest Estates of Mululuve, Zungubo, and Sichinga were burned down, whereas 60% or more of the Forest Estates of Kasiki, Nanyonta, Zungubo, Nangombe, etc. were burned down. These data indicate the seriousness of forest fires.

The area of natural tree grassland was measured, and the result was 33,500 ha. This result also indicates that flood plains, marshes, and river channel areas in tributaries are becoming dry, which may possibly be associated with the weather of the area studied, which is getting increasingly dry.

The area of forest distribution is 86,000 ha, accounting for 17.2% of the total area of 500,900 ha. 71.6% of the total area of forests are distributed in the Forest Estates. Although the Forest Estates incurred serious losses owing to forest fires, the stand volume per ha in the Forest Estates is 1.9 times the stand volume of other areas. The forests in the Forest Estates constitute valuable forest resources in this district. In particular, since 79.6% of the Mukusi resources exist in the Forest Estates, the Forest Estates are positioned as a base to supply Mukusi resources.

Mupane tree grassland was measured and an area of 30,800 ha was obtained. However, since it is also distributed outside of the area studied, it might be necessary in the future to grasp an accurate range of its distribution together with the amount of Mupane resources.

Although woodland occupies an area of 196,500 ha, the area of closed woodland with timber resources was 153,200 ha, accounting for 78.2% of the total woodland area. Most of the closed woodland is distributed outside of the Forest Estates.

The farm land area was 22,500 ha.

2.1.6. Procedures for preparing the land-use and vegetation maps

The land-use and vegetation maps covering 500,904 ha were prepared by following the procedures stated below.

- On-the-spot grasping of the characteristics of aerial photographs per land-use and vegetation type
- Preparation of interpretation standards for aerial photographs with contents similar to those stated in the section on land-use and vegetation.
- Interpretation of each land-use and vegetation type based on the above interpretation standard, and entry of the results obtained in aerial photographs.

- On-the-spot classification of the parts not interpreted by aerial photographs
- Preparation of mosaic photographs
- Entry of the results obtained through interpretation of aerial photographs on mosaic photographs
- Preparation of drafts of land-use and vegetation maps through transfer of the above entry onto topographical maps on a scale of 1/50,000
- Preparation of the land-use and vegetation maps by editing the above draft drawing.

Interpretation standards were decided based on the results of field surveys, the legends of maps recently employed by the Survey Department of Zambia and an exchange of views with the representative of the above Department.

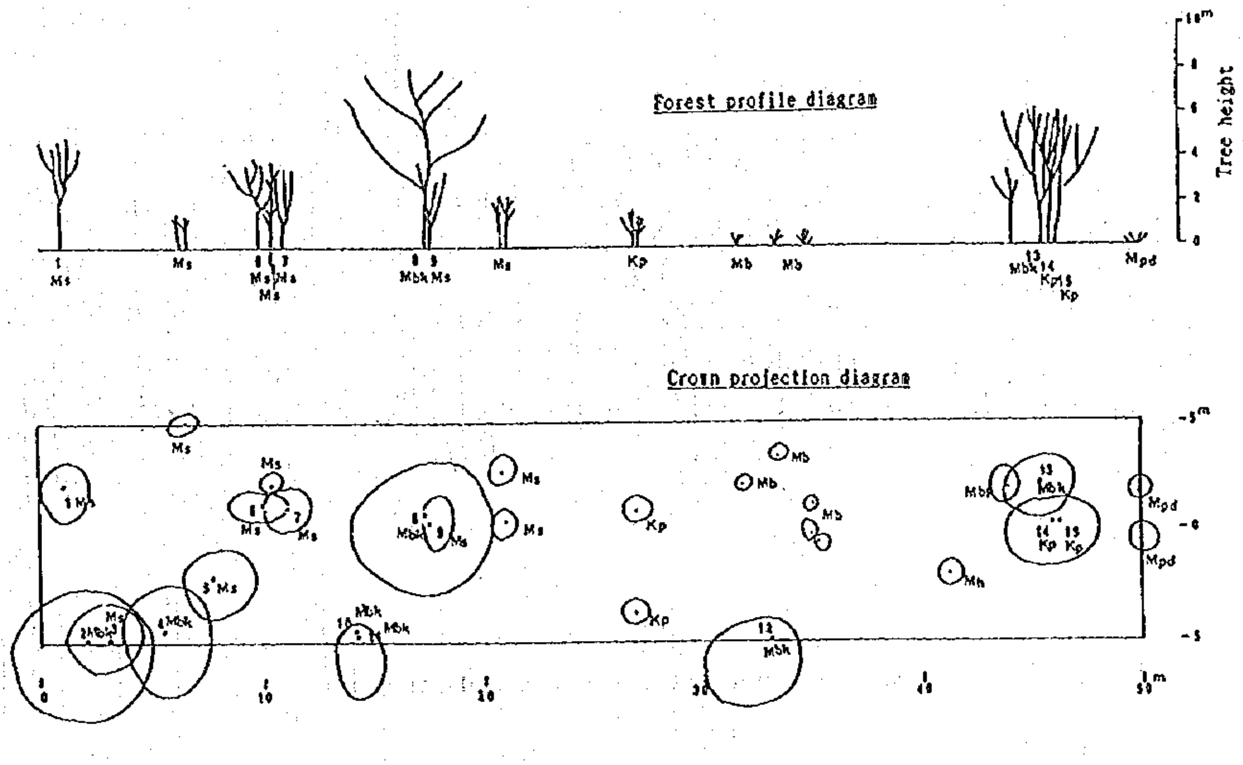


Figure 9 Belt-transect (Buhunde open woodland)

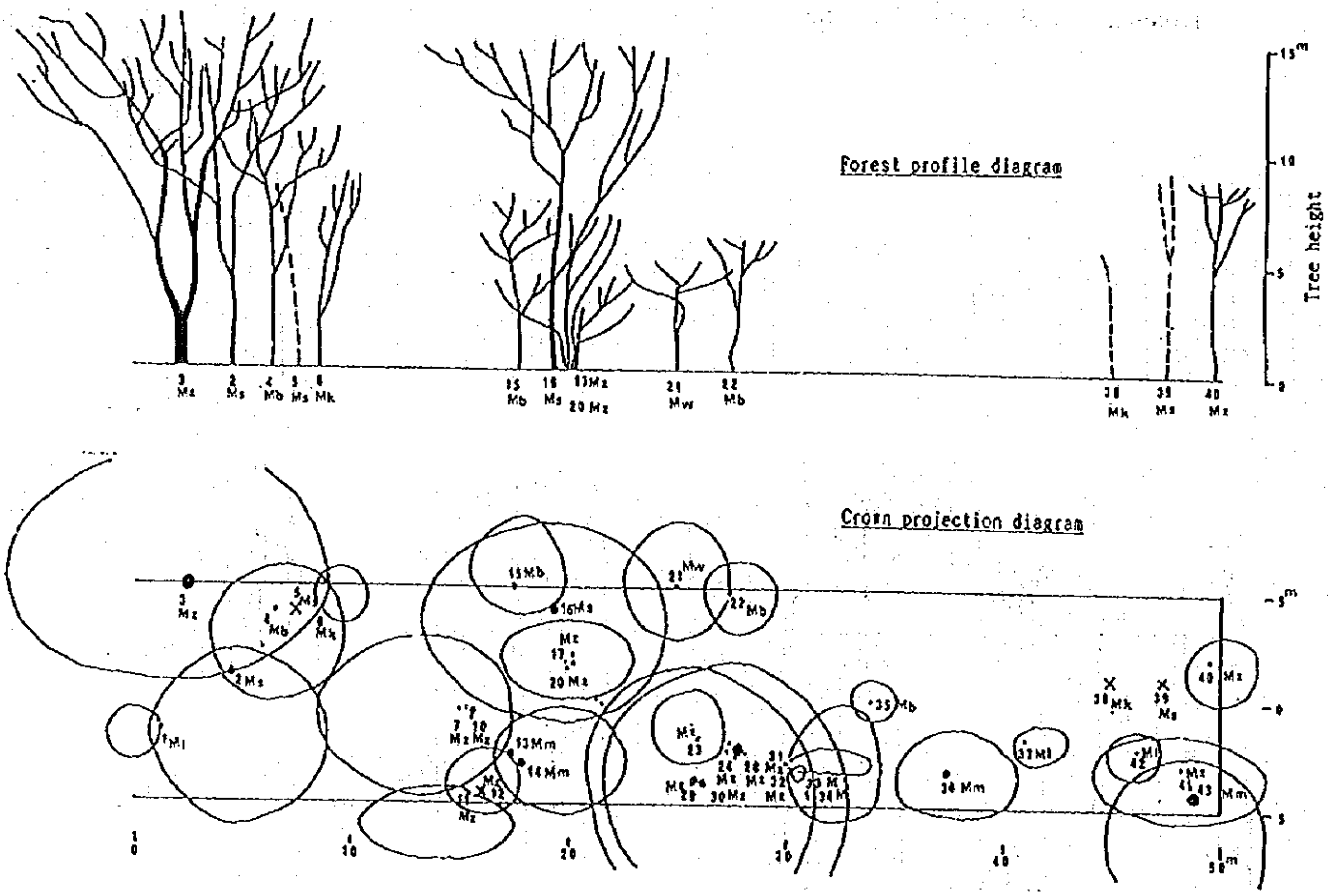


Figure 10 Belt-transect (Buhunda closed woodland)

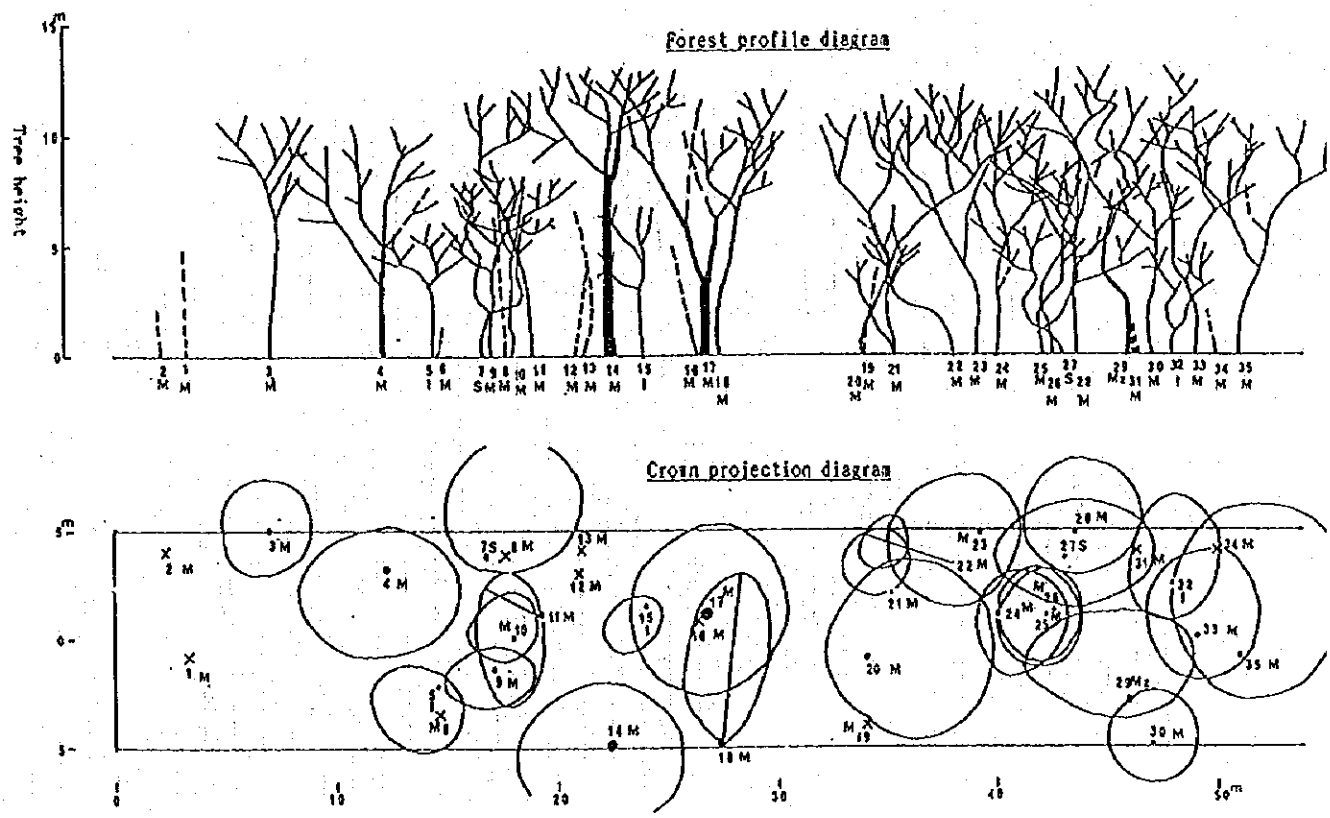


Figure 11 (1) Belt-transect (Sikubingwa forest)

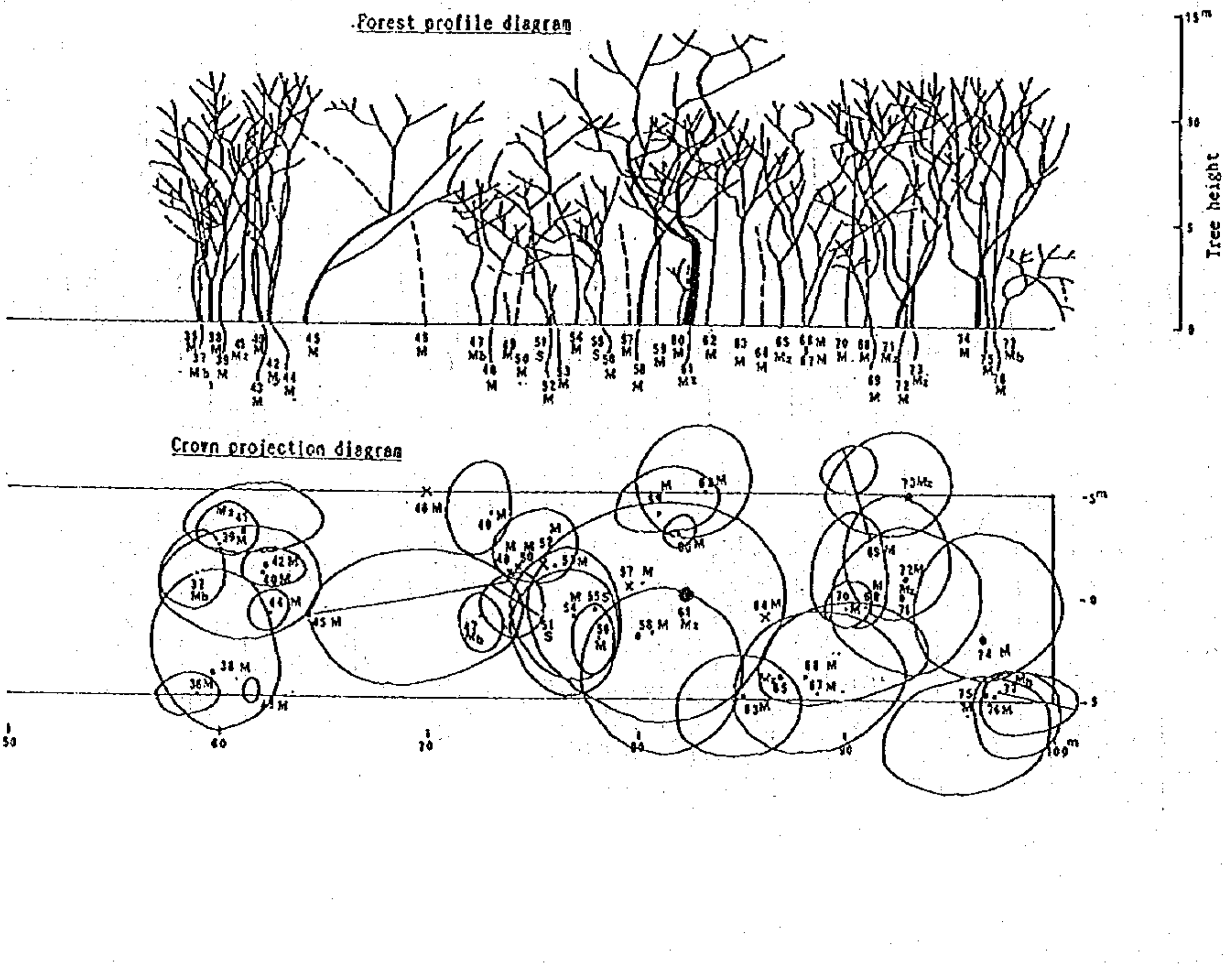


Figure 11 (2) Belt-transect (Sikubingwa forest)

Table 12 Belt-transect (Buhunda open woodland)

Species		Height cm	Diameter at breast height cm	Crown Diameter m	Number
Kubako	(Kbk)	5-8	6-16	2.5-6	7
Kusheshe	(Ks)	3-6	6-9	1.5-3	6
Kapapati	(Kp)	6	13-14	3.5	2
Total					15

Table 13 Belt-transect (Buhunda closed woodland)

Species		Height cm	Diameter at breast height cm	Crown Diameter m	Number
Kukusi	(K)	10	10-17	4.5	3
Kuzauli	(Kz)	3-16	6-46	1-13.5	23
Kusheshe	(Ks)	11-15	14-34	8-10.5	4
Kububu	(Kb)	5-11	8-17	2-6	4
Kulya	(Kl)	4-5	7-8	2	3
Kuhamani	(Km)	7-10	33-45	3-7	3
Kukwa	(Kk)	9	12	2.5	2
Kuwawa	(Kwa)	5	16	5	1
Total					43

Table 14 Belt-transect (Sikubingwa forest)

Species		Height cm	Diameter at breast height cm	Crown Diameter m	Number
Kukusi	(K)	3-13	7-43	1-8.5	61
Kuzauli	(Kz)	10-14	26-64	5-12	6
Sibobo	(S)	5-8	9-24	3-6	4
Isunde	(I)	5-6	9-10	2-4.5	3
Kububu	(Kb)	4-6	8-10	2.5-4	3
Total					77

Table 15 Present condition of vegetation and forest resources

No.	Forest estate	Total area(ha)	Area(ha) of each vegetation: Forest	Closed Woodland	Open Woodland	Mupane tree grassland	Natural tree grassland	Artificially degraded tree grassland	Natural grassland	Farm-land	Rate of "Forest" (%)	Remark	Total stand volume: Vol. per ha(m^3)	Stand volume(m^3)	Mukusi volume(m^3)
1	Masese group of forest	54,933	25,228	612	0		2,480	26,319	291	3	46	Total(a-h)	104	2,626,240	1,688,323
a	Sichinga	5,974	1,220	137			216	4,350	48	3	20		40	53,654	17,339
b	Monze	6,083	769				1,136	4,178			13		52	39,614	13,282
c	Kasiki	5,540	2,022				818	2,700			36		96	194,544	110,289
d	Malavwe	5,681	2,291				116	3,274			40		71	163,366	81,735
e	Simungoma west	7,990	5,734				194	2,062			72		125	717,222	435,337
f	Simungoma east	8,540	6,237					2,303			73		129	801,522	621,779
g	Sikubingwa	5,385	3,391	279				1,555	160		63		92	336,525	222,470
h	Sisisi	9,740	3,564	196				5,897	83		37		85	319,793	186,092
2	Zungubo	950	191	65				694			20		81	20,782	2,582
3	Kateme	2,560	1,043	132				1,343	42		41		97	114,496	31,386
4	Mululwe	7,276	899	127	505			5,588	108	49	12		58	59,476	12,246
5	Nanyota	3,432	763	212	222			2,211		24	22		68	66,492	31,641
6	Samatela	6,485	1,389	1,062	1,529			2,497		8	21		51	125,463	39,474
7	Lumino	4,000	1,742	32				2,168		58	44		115	203,596	85,369
8	Kayumbwana	3,575	1,919		120			1,536			54		109	208,394	81,000
9	Nangombe	2,380	855		84			1,441			36		111	94,768	13,959
10	Sijulu	2,770	1,731	77	385			452		125	62		124	224,627	76,888
11	Kalama	1,006	302		216			308		180	30		53	16,070	3,968
12	Kazu-Namena	7,860	5,287	23	944			1,582		24	67		100	529,917	134,436
13	Nanga	1,450	1,149					295		6	79		171	197,002	114,580
14	Kanyanga	1,980	1,337	57				542		44	68		98	136,190	58,792
15	Lonze	9,295	6,519					2,744		32	70		114	742,353	351,576
16	Nalwama	3,340	2,084					1,125		131	62		77	161,167	64,613
17	Lwangula	2,131	1,212		29			674		216	57		98	118,641	32,507
18	Situmpa	10,520	8,020		135			2,318	17	30	76		127	1,017,401	410,875
	Subtotal(Forest estate)	125,943	61,670	2,399	4,169		2,480	53,837	458	930	49		104	6,663,075	3,234,215
Sheet No. of Topographic map															
	1724A2	42,570	418	31,283	1,850	0	2,390	4,342	1,593	694			51	1,626,928	2,532
	1724A4	36,703	2,009	9,229	566	0	4,420	18,348	178	1,953			46	518,569	18,025
	1724B1	46,663	1,935	26,280	2,878	0	3,083	8,275	1,567	2,645			61	1,724,379	269,367
	1724B2	55,398	5,072	10,107	9,816	16,683	10,972	1,465	128	1,155			58	881,903	136,618
	1724B3	19,635	3,643	1,369	1,260	0	1,748	7,426	1,285	2,904			58	288,757	78,429
	1725A1	20,306	3,100	0	1,362	13,071	156	52	1,255	1,310			60	185,157	66,083
	1624D3	37,943	687	28,522	179	0	0	2,286	4,522	1,747			52	1,509,796	92,006
	1624D4	33,648	1,656	20,071	4,008	0	1,952	3,058	385	2,518			45	985,605	14,537
	1625C1	34,848	1,065	16,413	2,647	0	360	4,342	6,193	3,828			59	1,023,271	39,334
	1625C3	38,234	4,657	7,479	11,256	618	3,290	1,144	4,086	5,704			63	766,110	110,458
	1625C4	9,013	109	0	3,392	452	2,697	1,387	822	154			58	6,285	79
	Subtotal(Sheet)	374,961	24,351	150,753	39,214	30,824	31,068	52,125	22,014	24,612			54	9,516,760	827,468
	Total	500,904	86,021	153,152	43,383	30,824	33,548	105,962	22,472	25,542			68	16,179,835	4,061,683

2.2. Soil

2.2.1. Survey period and survey contents

The soil survey is directly related to the preparation of soil maps of areas containing Mukusi forests. In Phase II (A), a field reconnaissance to understand the general condition of the region was conducted between 7 August and 5 September, 1994 (30 days). In Phase II (B), a soil profile survey was conducted between 6 September and 9 October, 1994 (34 days) with emphasis on Mukusi forests in order to collect the data needed for soil classification in the preparation of maps. In Phase II (C), a soil profile survey and soil classification were carried out in succession between 17 January and 18 March, 1995 (60 days).

In Phase III, soil maps were prepared and an overall study was made on explanations to be given on soil maps and on the results of the soil survey.

2.2.2. Survey plots

Survey plots were selected using interpretations of aerial photographs 1/50,000 and 1/25,000 in scale that were taken in Phase I (April 1994). Also, the existing diagrams of the Rhodesian Teak Forest Area attached to the Rhodesian Teak Forest Working Plan (1964) and field reconnaissance in Phase II (A) were used as references.

Interpretation of micro-topography from the aerial photographs was attempted. However, the topography was generally flat and classification of topography was not possible. The field reconnaissance also confirmed that almost all Mukusi forests were located on nearly flat highland topography (plateaus). Therefore, the survey plots for the soil profile survey were selected from the existing "Zambia Teak Forest Area" data, focusing on Mukusi forests and woodlands.

The soil profile survey was conducted at one or two places for each Mukusi forest.

During the field reconnaissance in Phase II (A), a soil survey was conducted of Mukusi forests, woodlands, dambos and other places by simple pitting while roughly surveying the entire study area. In Phase II (B), 12 pits, Nos. 1 to 12, were drilled and 26 pits, Nos. 13 to 38, were drilled in Phase II (C) in forests, woodlands and other places to conduct the soil profile survey. Figure 12 shows the survey plots for the soil profile survey.

2.2.3. Survey method

In the field reconnaissance, soil color and texture were mainly surveyed by simple pitting. After arriving at survey plots, the plots to be used as typical survey plots were selected in this survey, judging from the surrounding environment, and pits were drilled for the soil profile survey. A vertical profile was set in a pit to observe soil. Generally, a standard profile for a soil survey requires 1 m in width and 1 to 1.5 m in depth. If bedrock is struck at a depth shallower than this depth, the pit depth is set at this depth. Several steps are provided on the opposite side of the soil profile for survey work. The depth of soil profiles was set at 1.5 to 2.0 m in this study because most of the soil in the area was sandy soil and it was difficult to decide the horizons and to discern variations in soil color. Furthermore, the roots of Mukusi were deep.

After roughly drilling a pit, scoop marks put inside a profile to be examined were shaved using a trowel, pruning shears and other tools for soil surveys, and plant roots were cut to make the profile to be examined smooth. After smoothing the soil profile, a scale was put on the left side of the profile and a tag written with the survey plot name, survey date and other information was put on the profile for photographing.

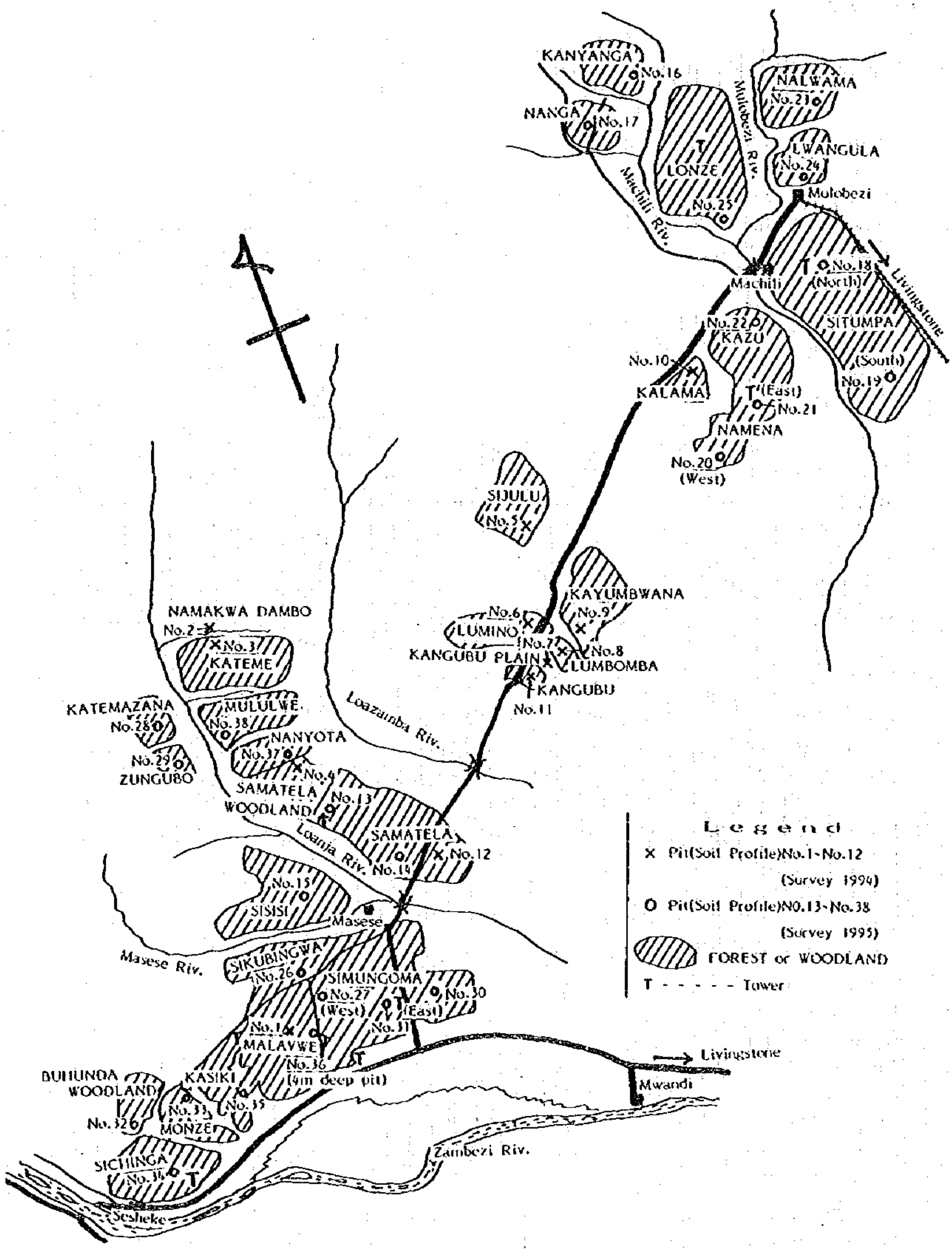


Figure 12 Zambia teak forest soil survey plots

Next, the profile sketch, horizon differentiation, texture, soil color, compactness, distribution status of gravel and roots, and other information was written on a soil profile chart. App. Figure 1 shows a sample of the soil profile chart. The items and descriptions in the soil profile survey conform to the "Guidelines for Soil Profile Description (2nd ed. 1977)" of the FAO. App. Table 6 (1),(2) lists the specific items and symbols used. Vegetation (tree name and other information), land-use status, and other information of the survey plots are also written on the soil profile chart. Survey plots were determined by the global positioning system (GPS) during the soil profile survey to identify the survey plots on the topographic map. A GPS of the same grid (UTM Zone 35) as that used in taking aerial photographs was used.

2.2.4. Results of soil survey and soil classification

Each soil profile was described as shown in the sample for descriptions of the soil profile chart shown in App. Figure 2 (1a), (1b), (2a), (2b), (3a), (3b). App. Table 7(1)-(4) lists the results of an individual soil profile survey. The soil at each survey plot was classified in accordance with the "Soil Map of the World, Revised Legend (1988)" of FAO/UNESCO based on the soil morphology.

The surface geology of the study area is Kalahari sand, which was aeolian sediment during the expansion period of the Kalahari desert from the Pliocene of the Tertiary Period to Pleistocene, forming a deep, sandy sedimentary layer. The soil of almost all layers is coarse-grained. Most of the soil types appearing in highland topography (plateaus) approximately 1,000 m in elevation, where Mukusi forests are distributed, are Arenosols (AR) [quartz sandy soil] in major classifications of the FAO/UNESCO soil classification.

The Soil Map of the World (1/5,000,000), Volume VI (Africa), compiled by the FAO/UNESCO in 1977, shows the soil type of the Kalahari sand area in south-western Zambia to be Qc29-1a. Qc29-1a is a compound mode of the following soil units:

Dominant Soil Unit	Qc	:	Cambic Arenosols
Associated Soils	Ge	:	Eutric Gleysols
	P	:	Podzols
Inclusions	V	:	Vertisols
	Sg	:	Gleyic Solonetz
Soil Texture	1	:	Coarse
Slope (Relief)	a	:	Level to gently undulating 0 to 8%

This map is a large scale soil map and includes everything from sandy soil in highland areas to flood plains of the Zambezi River. After publishing the Soil Map of the World, FAO/UNESCO has been revising its legends by accumulating new data and information thereafter throughout the world. This study classifies soil types using the latest revised legend.

Zambia is now producing national soil maps on the scale of 1/1,000,000. The soil types for the south-western part of Zambia shown in the maps are Aggregated Plateaus: Orthi-Ferralic Arenosols; Flood Plains: Gleyi-Dystric Fluvisols, Orthi-Calcic Vertisols; Dambos: Fiblic Histosols; and Orthi-Umblic & Dystric Gleysols.

In the soil unit stage, soil in areas with Mukusi forests (highland plateaus) is mostly reddish yellow to reddish brown Ferralic Arenosols. In some parts, pale yellow Haplic Arenosols soil is found. The soil is good soil, coarse-grained with good permeability. Soils produced from deposited sand that flowed out from the highlands, weathered subsoil of Kalahari sand and sediment from upstream of the Zambezi River, organic materials which have not decomposed and other soils are mixed around the rivers which flow through the highland plateaus, then in lowlands such as dambos and plains. The soil in the study is mainly Albic Arenosols with bleached layers and Gleyic Arenosols with gley horizons and iron mottle layers.

The soil units are distributed according to vegetation and topography as follows:

Forest or Woodland (Plateau)	Main :	Ferralic Arenosols	(ARo)
	Sub :	Haplic Arenosols	(ARh)
Grassland (Dambo or Plain)		Albic Arenosols	(ARa)
		Gleyic Arenosols	(ARg)

To further classify soil units, a method that combines the soil unit, slope and texture is generally used. However, the area under study has no significant fluctuations in topography or in texture. Therefore, slope or texture cannot be used as a criterion for further classification. After studying a method to further classify Ferralic Arenosols (ARo) which is widely distributed in the area under study, main soil colors of subsoils (B horizon) were used as classification indexes.

Ferralic Arenosols (ARo) were divided into three subtypes, reddish, orange and yellow-orange, based on the subsoil colors, with the following criteria for reclassification:

(1) Reddish Ferralic Arenosols --------------------------------------(ARo-R)

B horizon: 5YR4/4 to 2.5YR5/4

C horizon: 5YR, 2.5YR4/4 to 6/8

(2) Orange Ferralic Arenosols --------------------------------------(ARo-O)

B and C horizons: 7.5YR7/7 to 7/8 (partially 5YR)

(3) Yellow-orange Ferralic Arenosols ----------------------------(ARo-Yo)

B and C horizons: 7.5YR6/4 to 8/4 (partially 10YR)

Factors that can be considered as reasons why these soil colors have appeared are the differences in the sedimentary period of Kalahari sand as the parent material, the mixing of bedrocks with exposed weathered rocks, the illuviation of iron caused by migration, the illuviation of Kalahari sand, and the impact of illuviation and oxidation.

Table 16 shows the soil type classification in each soil survey plot.

Table 16 Classification and soil survey plots

Pit No.	Forest Name incl.Woodland,Dambo,Plain	FAO/UNESCO classification Soil Unit (sub-type)
No. 1	Malavwe (B.R.)	ARh
No. 2	Namakwa Dambo	ARa
No. 3	Kateme	ARo-O (Orange type)
No. 4	Samatela Woodland	ARo-Yo (Yellow orange type)
No. 5	Sijulu	ARo-R (Reddish type)
No. 6	Lumino	ARo-O (Orange type)
No. 7	Kangubu Plain	ARg
No. 8	Lumbomba	ARo-R (Reddish type)
No. 9	Kayumbwana	ARo-R (Reddish type)
No. 10	Kalama	ARo-O (Orange type)
No. 11	Kangubu	ARo-R (Reddish type)
No. 12	Samatela (East)	ARo-O (Orange type)
No. 13	Samatela Woodland	ARo-O (Orange type)
No. 14	Samatela	ARo-O (Orange type)
No. 15	Sisisi	ARo-O (Orange type)
No. 16	Kanyanga	ARo-R (Reddish type)
No. 17	Nanga	ARo-R (Reddish type)
No. 18	Situmpa (North)	ARh
No. 19	Situmpa (South)	ARh
No. 20	Namena West	ARo-O (Orange type)
No. 21	Namena East	ARo-O (Orange type)
No. 22	Kazu	ARo-O (Orange type)
No. 23	Nalwama	ARo-O (Orange type)
No. 24	Lwangula	ARo-O (Orange type)
No. 25	Lonze	ARo-O (Orange type)
No. 26	Sikubingwa	ARo-Yo (Yellow orange type)
No. 27	Simungoma West	ARo-Yo (Yellow orange type)
No. 28	Katemazana	ARo-O (Orange type)
No. 29	Zungubo	ARo-O (Orange type)
No. 30	Simungoma East (East)	ARo-Yo (Yellow orange type)
No. 31	Simungoma East (West)	ARo-O (Orange type)
No. 32	Buhunda Woodland	ARo-O (Orange type)
No. 33	Monze	ARo-O (Orange type)
No. 34	Sichinga	ARo-R (Reddish type)
No. 35	Kasiki	ARo-O (Orange type)
No. 36	Malavwe (West)	ARo-O (Orange type)
No. 37	Nanyota	ARh
No. 38	Mululwe	ARo-Yo (Yellow orange type)

ARo:Ferralic Arenosols , ARh:Haplic Arenosols
ARa:Albic Arenosols , ARg:Gleyic Arenosols

2.2.5. Preparation of soil maps

The soil maps show the distribution of soil types obtained in the soil survey using the 1/50,000 topographical maps prepared in Phase II as the base map. The soil maps show single soil types or combinations of several soil types. These soil types are divided in the topographical maps and are represented by symbols.

(1) Explanation of soil maps

The main soil groups found in the survey, the characteristics of soil units and identification of them are defined in the Soil Map of the World, Revised Legend of FAO/UNESCO, as follows:

ARENOSOLS (AR): Soil which is coarser than sandy loam down to 100 cm from the surface, having less than 35% of the rock fragments or other coarse fragments in all subhorizons within 100 cm of the surface, exclusive of materials which show fluvic or andic properties, and having no diagnostic horizons other than an ochric A horizon or an albic E horizon.

Haplic Arenosols (ARh): Arenosols having no diagnostic horizon other than an ochric A horizon; lacking ferralic properties; lacking gleyic properties within 100 cm of the surface; non-calcaric.

Ferralic Arenosols (ARo): Arenosols showing ferralic properties, and colouring of the B horizon expressed by chromas of 5 or more or hues redder than 10YR; lacking a clay increase or lamellae of clay accumulation within 125 cm of the surface; lacking an albic E horizon with a minimum thickness of 50 cm; lacking gleyic properties within 100 cm of the surface; non- calcaric.

Albic Arenosols (ARa): Arenosols having an albic E horizon with a minimum thicness of 50 cm within 125 cm from the surface; lacking gleyic properties within 100 cm of the surface; non-calcaric.

Gleyic Arenosols (ARg): Arenosols showing gleyic properties within 100 cm of the surface.

Diagnostic horizons are summarized as follows:

Albic E: Bleached, usually sandy material, lacking clay and free iron oxides.

Ferralic B: Highly weathered sandy loam or finer texture. Low CEC, illuvial clay and weatherable minerals.

Ochric A: A horizon of dry area. Pale, low organic matter and/or thin or hard and massive. Excluding finely stratified material, e.g., alluvium.

Diagnostic properties are summarized as follows:

Andic properties: Recent volcanic deposits: high Al and P retention, low bulk density; and/or high volcanic glass content.

Calcareous material: Strong effervescene with 10% HCl, or > 2% $CaCO_3$ equivalent.

Ferralic properties: B horizons with CEC of < 24 me/100g clay.

Fluvic properties: Fluviatile, marine and lacustrine sediments. Regular additions of fresh materials and irregular organic matter content and/or stratification in at least 25% of soil volume.

Gleyic properties: Reduced conditions caused by ground-water saturation; capillary fringe reaches surface; evident Fe reduction and segregation; > 95% of matrix white to black (N), or blue to green (GY, BG, G or B) colours, unless low or inert Fe colouring.

The soil type of each soil-profile survey plot is decided by a single soil unit. However, soil maps allow associated soil and mixtures with several soil types if planar expansion is taken into consideration. They are shown by symbols: