- Burning of woodland can be prevented.
- Honey can be sold as a commodity and cash revenue can be obtained.
- Health of local residents and village economy will be enhanced.
- Will provide an opportunity to manage woodlands by local residents.
- Will provide an opportunity to plant flower trees in woodlands

3.3. Survey of Silvicultural System

3.3.1. Present situation of silvicultural operations in artificial and natural forests

Described here are the results of surveys conducted on silviculture operations such as forest nurturing, tree cutting, timber transportation, etc. During the 1960s and 1970s, experiments in afforestation were carried out using the direct sowing method and pot plant stock plantation. Now 20 to 30 years have passed and, in some areas where growth is satisfactory, trees have grown as high as 10 meters.

Since no other information is available on forest development in the study area, the results of this survey may be useful as reference materials for establishing silviculture systems for Mukusi forests in the southwestern part of Zambia.

(1) Experiments in afforestation using the direct sowing method

Conventionally, silviculture has been attempted by sowing seeds directly in a forest in the hope that they would germinate and grow into seedlings. This method is called the direct sowing. It eliminates the labor required for nursing, which means forests can be established more economically compared to those in which nursery stocks are used. To achieve natural forest silviculture, it is necessary to understand the development and growth patterns of naturally seeded young trees. In this regard, we can take advantage of reference materials based on our findings to make suppositions about these matters. Studies on the consequences of Mukusi species silviculture were carried out at a total of four sites; three were within the southwest area, and one was adjacent to the survey area. Also, similar surveys were conducted for the Mukwa species, whose timber, like Mukusi, is being grown for commercial use.

1) Assessment of Mukusi afforestation

a. Sisisi line 2 forest

The Sisisi line 2 experiment area, which is located in the northwestern part of the Masese forest station, was established in 1965. The original sowing took place 29 years ago. The distance between rows was 3 m and between stocks 1 m. The ten planted rows within the experiment area that extended 100 m in length, along the direction of planting, were selected for this survey. In the survey area, the number of remaining trees, stem conditions (trees having main stems only, plural stems, coppicing stems, dead stems), tree heights, DBH, the number of coppicing stems, and the height of coppicing stems were surveyed (Table 39). As the table shows, the number of trees (the population equivalent to per ha basis is shown in parentheses) is as follows: 612 (2,020) living trees, 276 (910) trees with main stems only, 319 (1,050) coppicing stemmed trees, and 17 (60) dead trees. Of the 276 trees having main stems, 30% grew with plural stems. Trees with coppicing stems accounted for half the total. Plural stems resulted from stem diebacks. The causes of diebacks appear to be burning and browsing by animals.

As described later in this report, most seedlings grown from seeds directly sowed and young growth regenerated by natural seeding were damaged by burning. Consequently, they were either dead or had generated coppicing stems. The height of the surveyed trees having main stems ranges between 2.8 m and 12 m, and the average was 7.6 m. The DBH of the trees ranges between 2 cm and 24 cm, while the average was 10.7 cm. The average number of coppicing stems per stock was 11. The average height of coppicing stems was 0.6 m. About 30% of main stems had sprouts near the ground level. Of the trees surveyed, 3% were in a damping-off state. The major cause for this seems to be the stem and crown fires caused by burning. Figure 31 shows the growth curve for tree heights obtained from a stem analysis of typical trees in the study area. As the curve indicates, the age at which trees reached heights of 4 m and 6 m was 10 and 20 years, respectively. The height of 29-year-old trees averaged 7.4 m. Although 29 years have passed since the original sowing, the tree age was calculated as 27 years. The reason for this is that the seedling development was delayed for 2 years by the effects of burning. Germination was promoted by soaking the seeds in water for 24 hours before sowing.

b. Sisisi main line forest

The Sisisi main line experiment area, which is located in the southwest of Sisisi line 2 mentioned above, was established in 1962. The original sowing took place 32 years ago. A space of 1 m was provided between rows. Ten planted rows extending 50 m in length along the direction of planting were selected for the survey and various items were measured (Table 39). As the table shows, the number of trees (the population equivalent to per ha basis is shown in parentheses) is as follows: 277 (5,540) living trees, 103 (2,060) trees with main stems only, and 159 (3,180) coppicing stemmed trees. Of the 277 living trees, 60% had dead main stems and had sprouted coppicing stems.

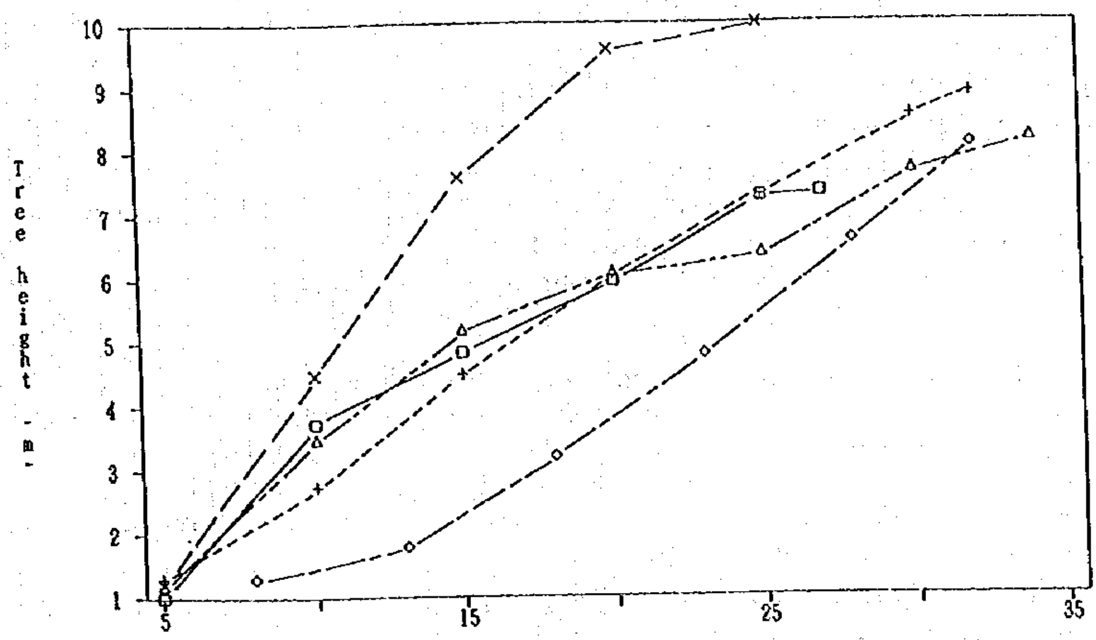


Figure 31 Growth of direct sowing and natural regenerated Mukusi

The average height and DBH of trees having main stems were 8.5 m and 11.2 cm, respectively. The average number of coppicing stems per stock was 6. The average height of a coppicing stem was 1.1 m. Figure 31 shows the growth curve of tree heights obtained from these results. As the curve indicates, the age at which trees reached heights of 3 m, 6 m and 8.5 m was roughly 10, 20 and 30 years, respectively.

c. Nalusoko forest

The Nulusoko experiment area is located on Line 15 on the south side of the Lilonga main line. The direct sowing method was used in this area, and the original sowing took place 32 years ago. The area was divided into three sections in order to trace the growth of Mukusi under a variety of conditions, which included the presence or absence of advanced growth and grass. In the Treatment A and B sections, all advanced growth and grass were removed at their roots. After that, in the Treatment A section, no advanced growth was allowed to regenerate, and grass was also removed completely. In the Treatment B section, advanced growth was allowed to regenerate, but grass was removed completely. In the Treatment C section, only advanced growth, whose height was short, was allowed to remain. The space between rows was 1 m. Five planted rows extending 45 m in length in the Treatment A section and Treatment B section, and 8 planted rows extending 20 m in length in the Treatment C section were surveyed.

The results of the survey are given in Table 40. The highest trees among trees having main stems were found in the Treatment A section, where the average height was 6.5 m, followed by an average height of 5.8 m in the Treatment B section. The Treatment C section had the shortest trees with an average height of 5.0 m. Similarly, the DBH in the Treatment A section was the largest with an average of 7.1 cm, followed by 5.4 cm in the Treatment B section, and 5.0 cm in the Treatment C section. Based on the results, it is clear that in the sections where advanced growth and grass were removed, adequate space for tree development was attained and the trees exhibited sound growth. However, in sections where the trees had to share the space with advanced growth, the tree growth was somewhat hindered.

The types of advanced growth in the Treatment B and C sections included Kangolo, Isunde, Mulianzovu, Mwangula, Namulomulomu, Mulalabainga, Nankala and Kabunbwamutemwa. As for grass, Sonko, which is a Mutemwa grass reaching a height 1 m to 1.2 m, was dominant in these sections. Seeds used both in the Main line and Nalusoko experiment areas were pretreated with sulfuric acid.

d. Dambwa local forest

The direct sowing method was used in the experiment area of the Dambwa local forest. Because the area is located in the Livingstone region adjacent to the Seshcke region, the area was selected to compare the growth conditions in the Sesheke and Livingstone regions and to prepare data to be used as reference material for formulating the silviculture systems. The area was established in 1962, and 32 years have passed since the original sowing. The survey was conducted in the area on 10 planted rows extending 45 m in length. The space between planted rows was 2 m.

The results of the survey are shown in Table 41. The number of trees (the population equivalent to per ha basis is shown in parentheses) is as follows: 103 (1,143) living trees, 87 (965) trees having main stems, and 16 (178) coppicing stemmed trees. The average height of trees having main stems was 5.3 m, and their average DBH was 8.3 cm. Both the height and DBH figures are smaller than those of the Sesheke region. In the Sesheke region, heights of 30-year-old trees ranged between 7 m and 8 m, having a DBH of about 10 cm, which are higher than those of the Livingstone region. According to the tree growth curve in Figure 31, the calculated tree height reached 8.1 m in 30 years. This is because healthy specimens were selected for stem analyses.

Table 39 Assessment of trial plantation

Tree Species: Mukusi

Location	Sowing year	Survey line No.	Stem condition	Number of trees	Tree height (m) Average	Tree height (m) Range	DBH (cm) Average	DBH (cm) Range	Number of coppices per stock Average	Number of coppices per stock Range	Height of coppices (m) Average	Height of coppices (m) Range
Sisisi Line 2	1965	Mean total (Line1-10)	Main stem	276	7.6	2.8-12	10.7	2-24				
			Plural stem	(78)								
			Coppicing stem	319					11	1-50	0.6	0.2-2.0
			Main s. + Copp. s	(100)					6	1-23	0.8	0.2-3.0
			Dead stem	17								
			Total	612								
Sisisi Main Line	1962	Mean total (Line1-10)	Main stem	103	8.5	4-11	11.2	2-26				
			Plural stem	(8)								
			Coppicing stem	159					6	1-26	1.1	0.3-2.5
			Main s. + Copp. s	(24)					4	1-9	1.2	0.3-3.0
			Dead stem	15								
			Total	277								

Table 40 Assessment of trial plantation

Tree Species: Mukusi Location: Nalusoko
Sowing year: 1962

Treatment	Survey line No.	Stem condition	Number of trees	Tree height (m) Average	Tree height (m) Range	DBH (cm) Average	DBH (cm) Range	Number of coppices per stock Average	Number of coppices per stock Range	Height of coppices (m) Average	Height of coppices (m) Range
A	Mean total (Line1-5)	Main stem	68	6.5	3.5-9	7.1	3-16				
		Plural stem	(28)								
		Coppicing stem	21					2	1-6	1.7	0.3-2.8
		Main s. + Copp. s	(1)							1.0	1.5
		Dead stem	9								
		Total	98								
B	Mean total (Line1-5)	Main stem	90	5.8	3-9	5.4	2-10				
		Plural stem	(35)								
		Coppicing stem	13					6	3-10	0.8	0.5-1.8
		Main s. + Copp. s.									
		Dead stem									
		Total	103								
C	Mean total (Line1-5)	Main stem	30	5.0	2.8-7	5.0	2-9				
		Plural stem	(10)								
		Coppicing stem	14					4	1-9	1.4	0.5-2.3
		Main s. + Copp. s.									
		Dead stem	1								
		Total	45								

Table 41 Assessment of trial plantation

Tree species: Mukusi
Location: Dambwa local forest (Livingstone)
Sowing year: 1962

Survey line No.	Stem condition	Number of trees	Tree height (m)		DBH (cm)		Number of coppices per stock		Height of coppices (m)	
			Average	Range	Average	Range	Average	Range	Average	Range
Mean total (Line1-10)	Main stem	87	5.3	1.3-10	8.3	1-18				
	Plural stem	(2)								
	Coppicing stem	16					6	1-17	2.7	0.7-3.8
	Main s. + Copp. s	(3)					6	1-13	2.0	1.4-3.2
	Dead stem									
	Total	103								

Table 42 Assessment of trial plantation

Tree species: Mukwa
Location: Dambwa local forest (Livingstone)
Sowing year: 1962

Survey line No.	Stem condition	Number of trees	Tree height (m)		DBH (cm)		Number of coppices per stock		Height of coppices (m)	
			Average	Range	Average	Range	Average	Range	Average	Range
Mean total (Line1-7)	Main stem	36	8.9	1.7-12	17.0	2-26				
	Plural stem	(7)								
	Coppicing stem	4					4	1-8	2.2	0.5-4.0
	Main s. + Copp. s.									
	Dead stem									
	Total	40								

2) **Assessment of Mukwa afforestation**

For Mukwa afforestation, the direct sowing method was used in the Dambwa local forest. This is in the same area as the Mukusi afforestation, discussed earlier, and was established in 1962. The survey was conducted on a test block of Mukwa. The block was comprised of 7 planted rows, each extending a length of 60 m. The space between rows was 3.5 m.

The results of the survey are shown in Table 42. The number of trees (the population equivalent to per ha basis is shown in parentheses) is as follows: 40 (272) living trees, 36 (244) trees having main stems, and 4 (27) coppicing stemmed trees. Trees having only main stems accounted for 90% of the total; 10% had coppicing stems. Trees with plural main stems accounted for 20% of the total. The number of trees per ha was as low as 270. The figure represents a mere 25% of the 1,100 Mukusi trees per ha growing in the same region, suggesting that only a small number of Mukwa had actually survived.

The average height and DBH of Mukwa having main stems were 8.9 m and 17 cm, respectively. The stem analysis data of the surveyed specimens and the tree growth curve are presented in Figure 32. When these figures are examined in isolation, Mukwa appears to grow more rapidly than Mukusi.

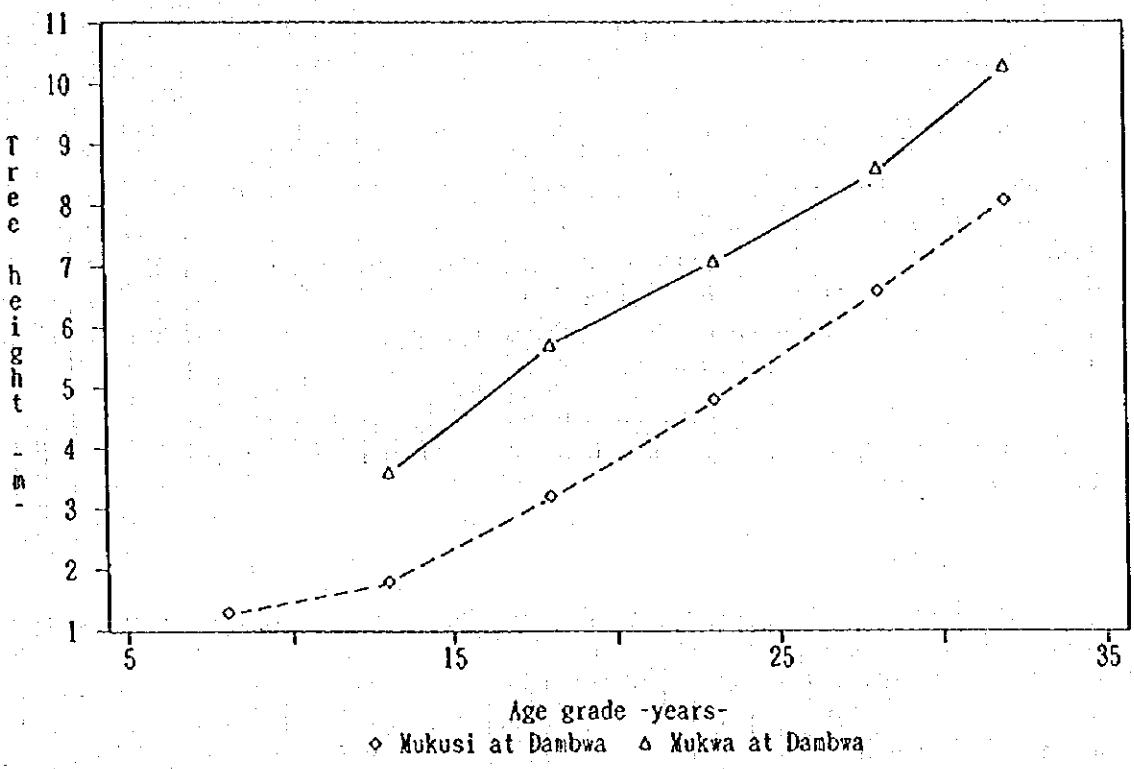


Figure 32 Growth of direct sowing Mukusi and Mukwa, Dambwa

3) Tree height growth in natural Mukusi forests

Forest creation using the direct sowing method is a system in which seeds are sown by human hand in a forest land, where they germinate and raise seedlings. Regeneration by natural seeding occurs as part of a natural system when forests reach a mature stage, in which seeds naturally fall to the ground, where they germinate and raise seedlings. It would be, therefore, helpful to understand how natural forests regenerate when assessing afforestation using the direct sowing method. Also, comparison data on the state of growth between artificial and natural forests could provide important research material when pursuing natural forest operations. Figure 31 presents data obtained from the stem analysis on the average height of Mukusi in the Buunda woodland and Simungoma east forest. According to the tree height growth curve for those in Buunda woodland, tree heights reached 3.5 m in 10 years, 6 m in 20 years, and 8 m in 30 years. These figures are similar to those found in the Sisisi line 2 and Sisisi main line forests, where the direct sowing method was used. On the other hand, in the Simungoma east forest, the tree heights reached 4.5 m in 10 years, 7.6 m in 15 years, and 10 m in 24 years. These figures for the Simungoma east forest exceeded the figures obtained in the two aforementioned areas where the direct sowing method was used.

(2) Afforestation experiments using pot plant stocks

In 1975, an experiment was carried out to establish an artificial forest using pot plant stocks in Simungoma west. In case regeneration by natural seeding cannot be expected, artificial afforestation using pot plant stocks may be a viable option. In preparation for that, a study on the growth of pot plant stocks is worth conducting.

1) Afforestation using pot plant stocks in Simungoma west

Figure 33 shows the remaining trees and their positions and profiles in the survey area. These trees survived 20 years after being planted from pot plant stocks. The size of the surveyed area is 20 m x 50 m, or 0.1 ha. The number of remaining trees was 22; so, the population equivalent to per ha basis is 220. Even the tallest tree did not reach 3 m in height. As Table 43 shows, the average tree height is as low as 0.6 m. This is a mere one-tenth the height of trees established by the direct sowing method as described earlier, in which trees grew to about 6 m over a 20-year period.

According to the person in charge of the plantation, most of the trees died within the first year that stocks were planted. Based on a survey of the root systems of the remaining trees, the tap roots grew to 1.0 m or more in depth.

2) Raising pot plant stocks

Through the above experiment on plantations using pot plant stocks, we discovered some problems that deserve further consideration. Trees die due to a lack of balance between the established subsurface root systems of the pot plant stocks and the transpiration from the branch leaves. It is reasonable to suspect that the dry season arrived before the root systems were well-established; so the trees simply died from drought damage. The root systems of the planting stocks that had been raised artificially and planted must have grown to the depth where the root systems absorbed sufficient water before the dry season arrived. Improvements in nursery practices and a review of the planting season are necessary to increase the survival rate of the pot plant stocks.

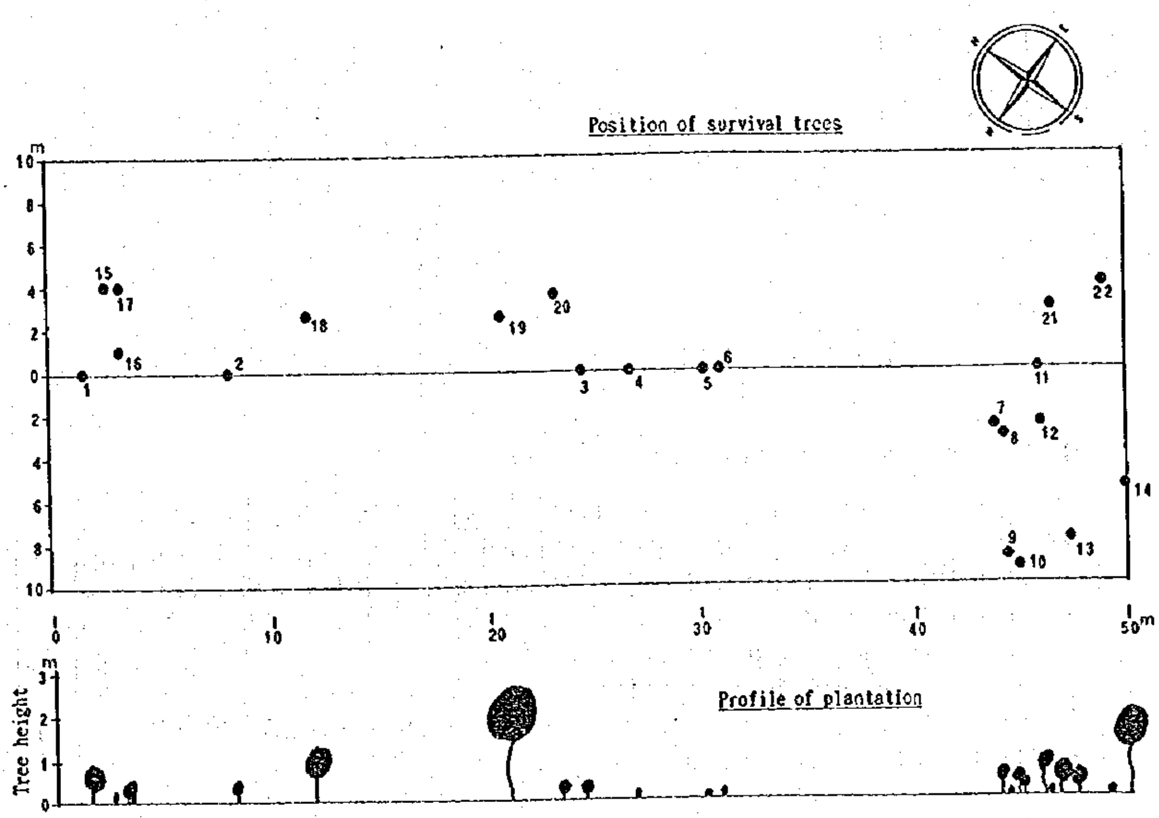
(3) Survey on root systems of artificial forests and natural forests

The seasons as they relate to the growth of plants can be clearly divided into dry and rainy seasons. Therefore, trees that make up a forest survive by adapting to long-lasting dry seasons. In formulating the silviculture systems, a requirement is that data concerning the root system development be assembled.

1) Root systems of adult trees in artificial and natural forests

Figure 34 shows the root systems of adult trees established by the direct sowing method, as well as those of naturally grown trees. For the survey, the roots were studied at a depth of 1 m to 2 m below the ground. The Mukusi were found to have thick bar-shaped tap roots. At Sisisi line 2, trees that had produced many coppice stems were studied. Even in cases in which the main stems of trees died due to burning, their tap roots continued to grow and regenerated the coppice stems near the ground level, recurrently. In an artificial forest, too, the bar-shaped tap roots of Mukusi were observed in a naturally regenerated forest.

As for the state of root systems of adult Mukwa trees, only one tree was studied in the Dambwa local forest. The specimen did not have the long tap root like that of Mukusi, but it had a large, knotted root system at a depth of 60 cm to 70 cm below the ground surface.



Location: Simungoma west
Planted year: 1975

Figure 33 Trees that survived trial plantation from pot stocks

Table 43 Trees that survived trial plantation from pot stocks

Location: Simungoma west
Planted year: 1975

Tree No.	Height (m)	Basal diameter (cm)	Memo
1	0.9	1.0	Root depth: > 0.8m
2	0.5	1.0	Root depth: > 1.0m
3	0.4	0.5	
4	0.2	0.3	
5	0.1	0.3	
6	0.2	0.3	
7	0.7	1.0	
8	0.1	0.2	
9	0.6	0.5	
10	0.4	0.3	
11	1.0	2.0	
12	0.1	0.3	
13	0.6	0.5	
14	2.0	2.5	
15	0.3	0.3	
16	0.2	0.3	
17	0.5	0.5	
18	1.3	1.0	
19	2.7	3.0	
20	0.4	0.3	
21	0.8	0.5	
22	0.1	0.2	
Average	0.6	0.8	
Range	0.1-2.7	0.2-3	

2) **Root systems of naturally regenerated seedlings**

Figure 35 shows the root systems of naturally regenerated seedlings of Mukusi and Mukwa. For the survey, the roots were exposed at a depth of 1 m below ground, where no difference was found in terms of growth depth between the Mukusi and Mukwa. Characteristically, Mukwa had storage roots. The storage root functions to store water and nutrients for the growth of the above-ground portion of the plant. The physiological function of storage roots causes leaves to fall during the dry season. The knot-type roots of the adult Mukwa trees in the Dambwa forest, as described above, are thought to be a type of storage root. The coppice stems in Kalama forest shown in Figure 35 were only 0.3 m high. It was thought to be at a 5-year level based on the annual ring survey of the root.

(4) **Survey of natural forest operations**

1) **Logging survey of natural forests**

At a logging site in Simungoma west where Mukusi were logged in 1995, three quadrats, 100 m x 100 m each, were established to trace stumps. Figure 36 shows the location of stumps within each quadrat. Table 44 gives the diameters of the stumps. The average stump diameter and the diameter range (shown in parentheses) for each quadrat are as follows: 48 cm (30 cm to 65 cm) in quadrat 1; 45 cm (30 cm to 60 cm) in quadrat 2; 44 cm (40 cm to 50 cm) in quadrat 3. All of the average diameters satisfy the cutting regulation of 30 cm to 100 cm DBH.

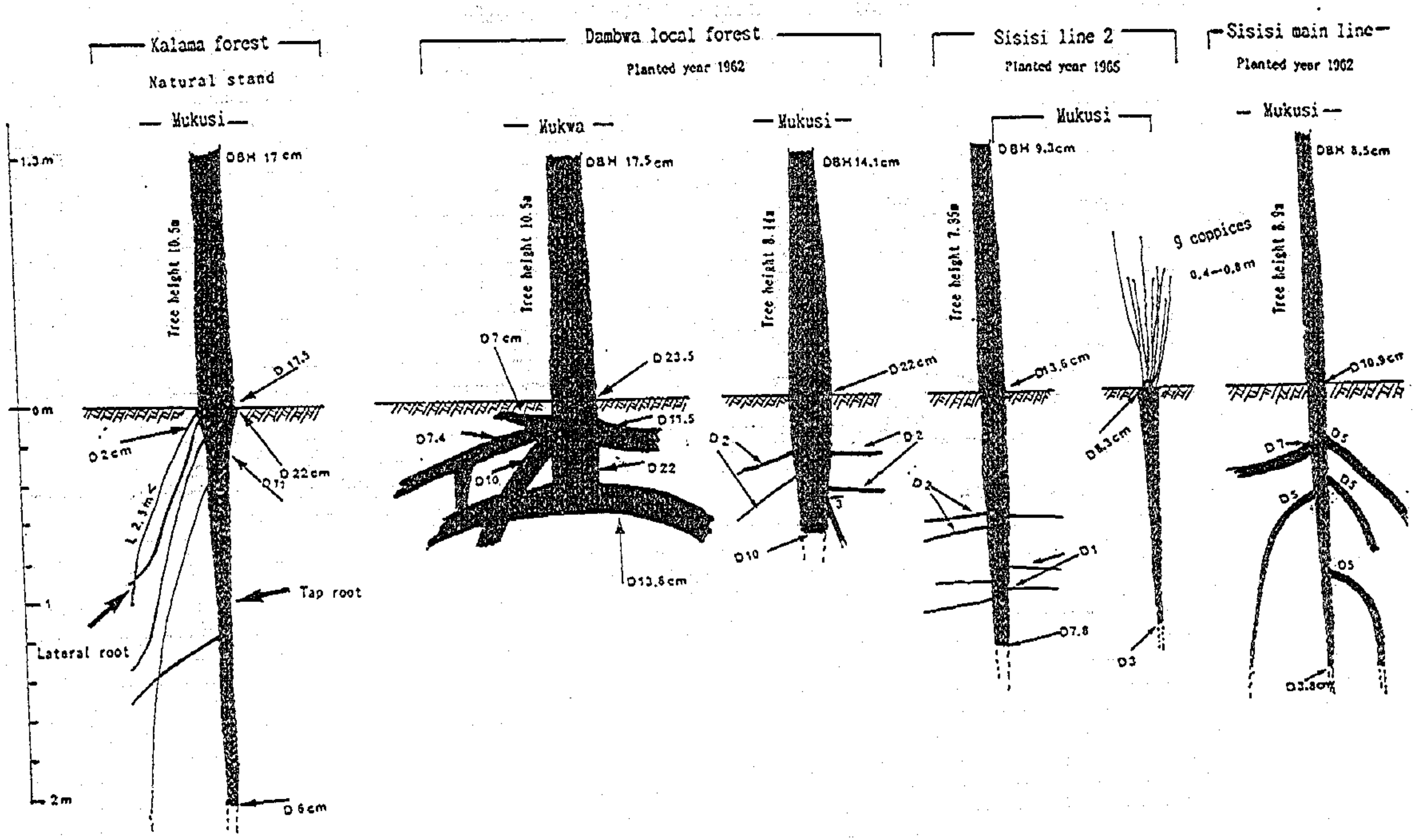


Figure 34 Root systems of Mukusi and Mukwa
-Growth of tap roots, lateral roots and storage roots-

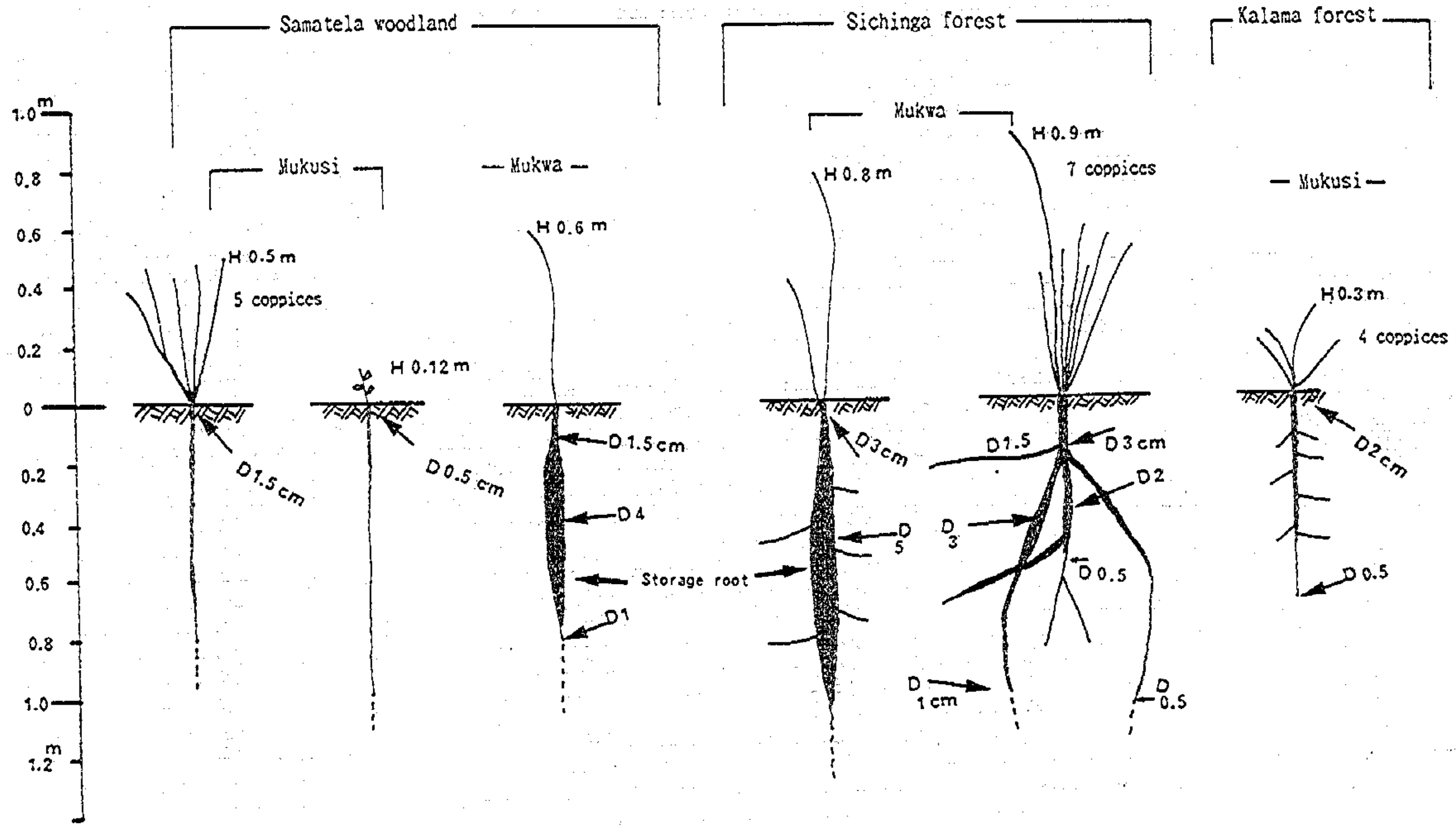


Figure 35 Root systems of Mukusi and Mukwa
-Growth of tap roots, lateral roots and storage roots-

In a natural forest near the logging site, the relation between the diameter and DBH was examined. As shown in Figure 37, a strong relation was found between the diameter at 0.3 m and DBH. Using this finding, the DBHs were estimated based on the stump sizes at the survey site. Then, tree heights were calculated using the relation factor between DBH and tree height. Finally, the cut volume was assessed using a volume table. The volume for quadrat 1 was 46.6 m^3, 46.1 m^3 for quadrat 2, and 56.6m^3 for quadrat 3. According to the Forest Inventory Book covering the neighboring cutover sites in Simungoma west, the volume of cut Mukusi per ha is about 150 m^3. Therefore, the logging volume of the surveyed quadrats represented between 30% and 38% of the book value.

Table 44 Logging traces

Location: Simungoma west

Stump No.	Diameter of stumps (cm)		
	Quadrat 1	Quadrat 2	Quadrat 3
1	50	50	40
2	50	50	45
3	50	40	40
4	50	40	40
5	60	50	45
6	40	40	50
7	40	40	50
8	60	40	50
9	50	50	40
10	40	40	50
11	40	50	45
12	40	60	50
13	50	60	40
14	30	40	40
15	40	60	45
16	40	50	40
17	45	45	40
18	50	45	40
19	60	40	40
20	60	30	40
21	50	50	40
22	50	40	50
23	50	40	40
24	65	40	50
25		45	45
26		40	50
27			40
28			50
29			40
30			45
31			40
32			50
33			40
Average	48	45	44
Range	30-65	30-60	40-50

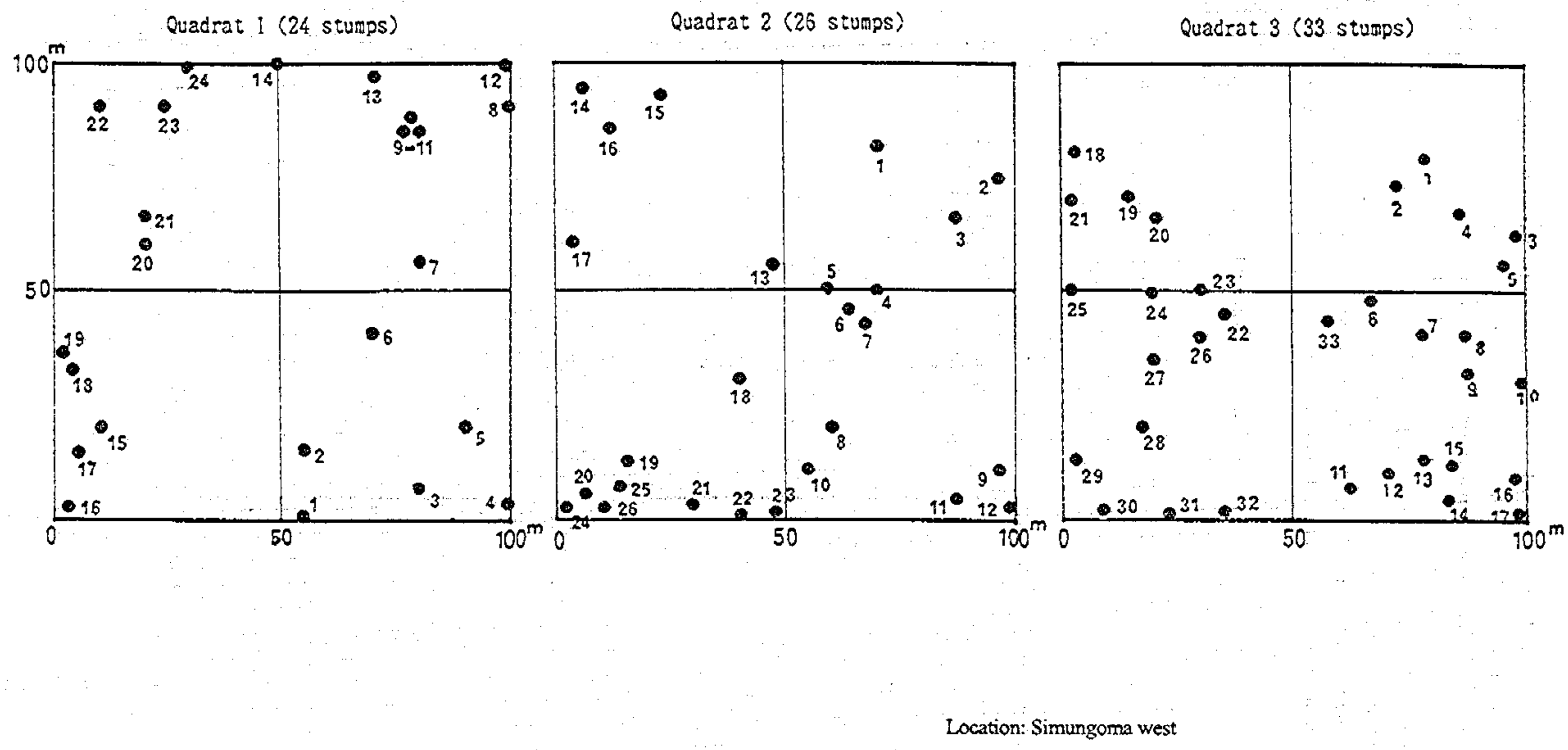


Figure 36 Logging traces

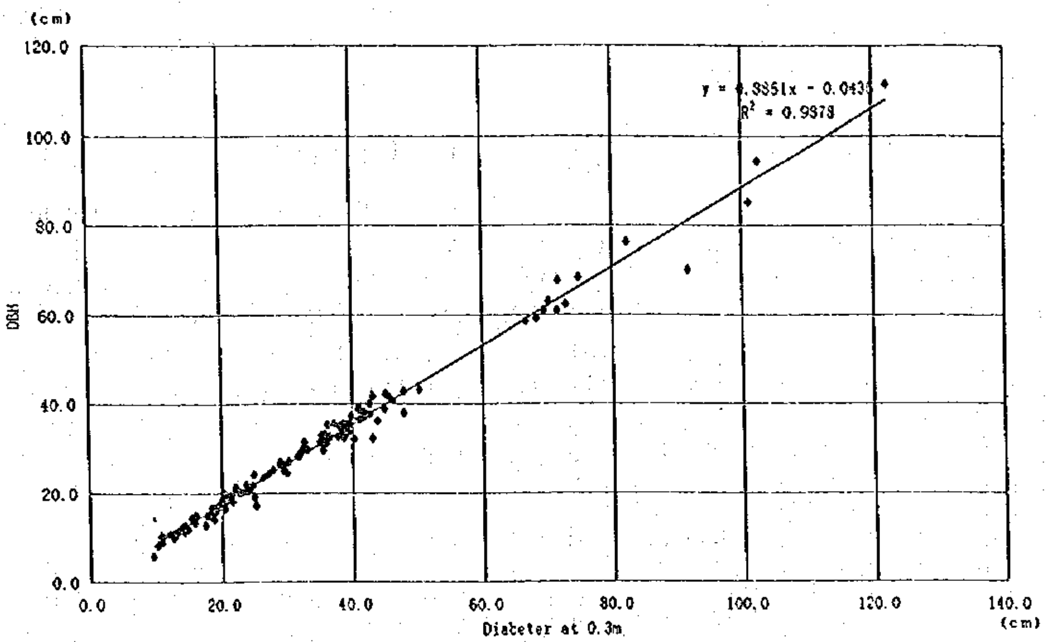


Figure 37 Relation between diameter at 0.3 m and at breast height

2) Improvement of selective cutting measures based on the results of the stump survey

Selective logging in the area means cutting trees selectively and leaving the cutover land to regenerate naturally. However, at the time of logging, the next generation of trees must have already begun to grow. In addition, a number of regenerated seedlings should be present or a suitable number of mother trees should be preserved in order to secure the seeding regeneration in the cutover land.

Mukusi seeds are relatively heavy so they cannot be expected to produce seedlings far from the mother trees. When stump locations in Figure 36 are examined, disparities are seen in the way the trees were selected. At some sites within the cutover lands, trees were cut in groups. When a group of trees is cut in an area, some mother trees that can potentially regenerate by seeding must be preserved in each vicinity.

In some areas of the forest floor, grass such as Sonko grows densely. This grass may hinder or prevent the seedling development. Therefore, some forest floor treatment for promoting the development of regenerated seedlings, including weeding after seedlings appear, may be necessary. These measures can actively assist natural regeneration.

3.3.2. Fact-finding survey on regeneration

To assume a sustainable supply of the Mukusi resources, regeneration must be ensured. First, we conducted a survey on regenerated seedlings developing in the round-shaped plots, which were established in a number of Forest Estates. Then, we analysed the tree stratum conditions of mature trees and seedings in each of the permanent plots in the Nange forest, Kalama forest and Samatela woodland.

(1) Regeneration of Mukusi and other species in round-shaped plots

A total of 112 round-shaped plots were established to collect data for the resource analysis. Among these, the state of regeneration of Mukusi and other species was surveyed at 100 plots. The findings are summarized in Table 45. Mukusi was found in 52 of the 100 plots. Among them, seedlings with a height of less than 1.5 m were found in 42 plots and the number of seedlings per ha was 125. Mukusi seedlings with a height of 1.5 m or higher were found in 30 plots; the number of seedlings per ha was 93. As for other species, 995 regenerated young seedlings were found per ha, whose height ranged from 1 m to 6 m. The number of different species found was 10 as shown in Table 46. Among them, the dominant species were Kangolo, Muchinga, Isunde and Mulyanzovu.

Table 45 Result of seedlings

	Mukusi			Other species
	H<1.5	H≧1.5	All	in shrub stratum
Plot	42(28)	30(13)	52	100
Height (m)	0.2-1.5	1.5-6.0		1.0-6.0
Mean num./ha	125±51	93±43		995±148
Max num./ha	810	560		3,840
Min. num./ha	10	20		180

(): Phase-II (Jan.-Feb.)

Table 46 Dominant species in shrub stratum

	Species(Lozi)	Symbos	Botanical name	Frequency
1	Kangolo	T	Combretum celastroides	52
2	Muchinga	S	Popowia obovata	44
3	Isunde	S	Baphia massaiensis /ssp. obovata	24
4	Mulyanzovu	S	Dalbergia martinii	20
5	Mulalabainga	T	Combretum elaegnoides	11
6	Mwalachi	T	Markhamia acuminata	7
7	Mulonbelombe	T	Strychnos potatorum	1
8	Silutombolwa	C	Combretum mossambicense	1
9	Mukena	T. S	Croton gratissimus	3
10	Nwani	T	Fagara trijuga	1

T:Trees/S:Shrubs/C:Climbers

(2) Regeneration in the Kalama forest

In the Kalama forest, permanent plot-3 (Table 49) was established. In the permanent plot, a survey site was set to trace the growth of regenerated seedlings. The dominant tree, Mukusi, grows thickly in the small and middle tree strata, but does not reach the large tree stratum. The DBH of large trees is the 30-cm level and the largest tree crown is about 8 m. In this Mukusi forest, 7 species, such as Muhonono, Mukena, etc. are mixed, and the number of trees per ha is 1,150. The site quality by the height of Mukusi is lower than that of the Nanga forest.

1) Tracing the regeneration of seedling

Regenerated seedlings are classified into two types: those having a main stem, and those having multiple coppicing stems. The seedlings were first surveyed during the rainy season in February, 1995. How were they doing in July 1995 during the dry season? Their condition was traced, and the results are presented in Table 47 and Figure 38. In the 20 m x 25 m survey area, the number of regenerated seedlings was 20. Of them, there were two that had main stems in February. These two seedlings were growing despite the damage caused by burning; one was 21 cm tall, and the other 39 cm. These seedlings were surviving as of July. Eighteen trees had coppice shoots. The number of coppice shoots per stump ranged between 8 and 60, and the average height of the stems ranged between 8 cm and 60 cm. The main reason for the regeneration of these coppice shoots was the burn damage.

In the July survey, survey tree No. 3 was found to have died from drought damage. Tree No. 4 was damaged by an early burning, and most of its stems above 10 cm point were dead. Early burning was not done throughout the survey area in 1995, and only tree No. 4 was affected because it happened to be located near the burning. In July, a portion of tree No. 4 near the ground was still alive; so coppice shoots might still be regenerated.

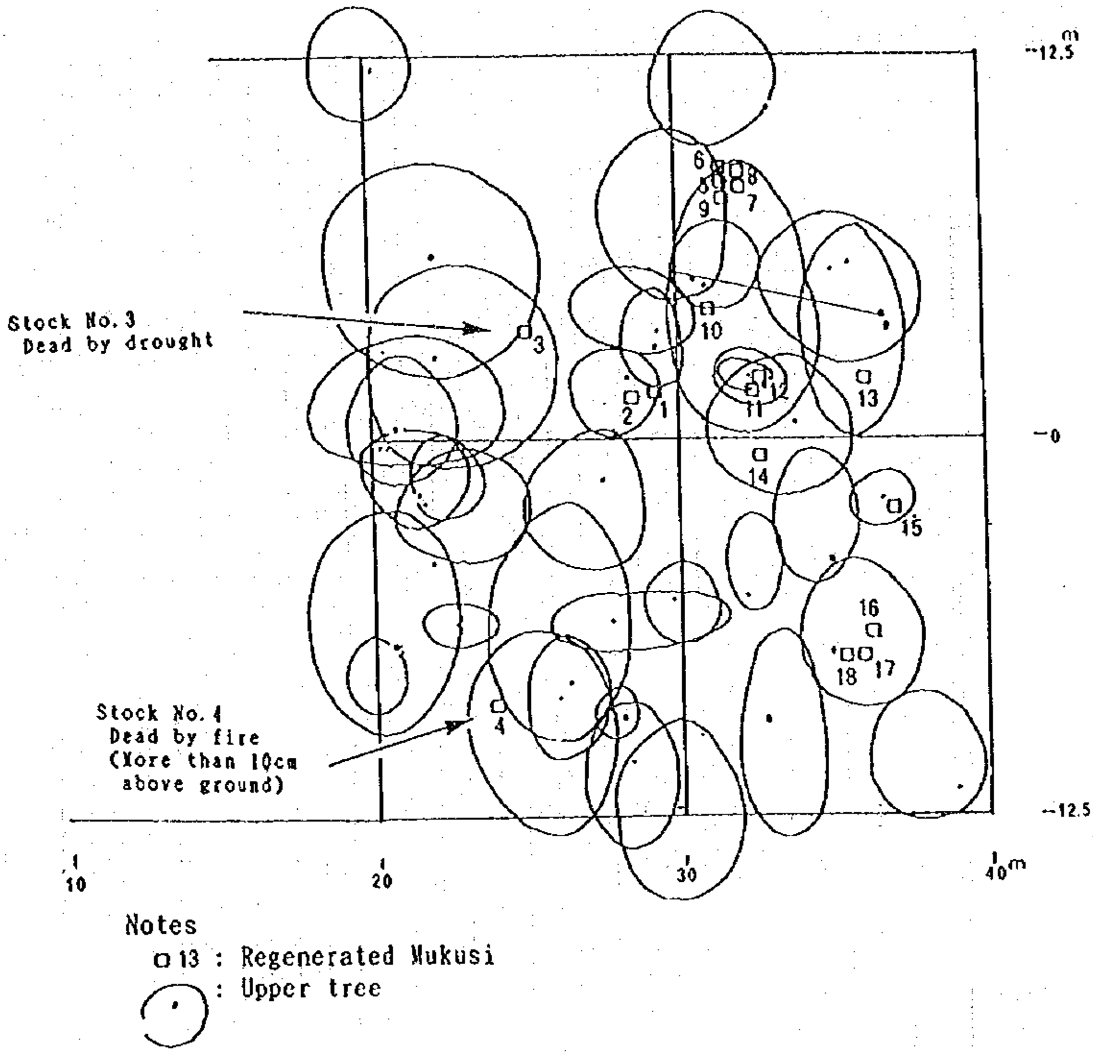


Figure 38 Regenerated young growth in Kalama forest

Table 47 Follow-up of regenerated young growth in Kalama forest

date	Stock No.	Species	Regene. seedlings		Regenerated coppices													Damage	Date	Memo
			Height cm	Diameter mm	Number of coppices	Height cm											Diameter mm			
						1	2	3	4	5	6	7	8	9	10	Mean				
1995.2	1	Kukusi			20	114 23	106 29	105 81	42 55	70 41	29 50	35 51	49 30	40 94	94 58	60	10	Fire	1995.7	
	2		39	3														Fire		
	3				23	53 26 9	35 27 14	39 26 49	26 60	38 23	46 46	46 72	32 28	42 19	46 21	36	7	Fire		Stock No.3 Dead by drought
	4				11	90 77	81	70	63	58	63	61	47	19	27	60	8	Fire		Stock No.4 Dead by fire (More than 10cm above ground)
	5				3	74	27	25								42	10	Fire		
	6				3	40	30	38								36	5	Fire		
	7				29	24 40 44	45 42 29	29 25 20	14 61 22	26 37 32	33 32 20	11 39 21	14 10 59	10 52 29	13 53	31	8	Fire		
	8		21	3														Fire		
	9				8	61	56	34	33	10	5	4	32			29	8	Fire		
	10				6	41	34	19	9	9	14					21	4	Fire		
	11				6	27	18	21	15	27	20					21	4	Fire		
	12				3	4	4	15								8	2	Fire		
	13				5	100	83	48	27	27						58	10	Fire		
	14				10	96	45	47	49	50	74	18	29	44	35	49	10	Fire		
	15				6	56	35	71	53	36	11					44	8	Fire		
	16				3	54	32	17								34	5	Fire		
	17				6	67	32	63	37	46	2					41	10	Fire		
	18				3	50	45	16								37	4	Fire		
	19				9	50	55	30	35	30	40	30	20	10		33	5	Fire		
	20				3	20	20	30								23	4	Fire		

2) Tree stratum structure of mature trees

As Figure 39 shows, Mukusi do not reach a large tree stratum, but grow densely in the small and middle tree strata. Also, as mentioned earlier, there was a large number of seedlings in the ground surface stratum of the areas surveyed. The tree strata in the forest stands were in series, and there was a healthy amount of natural regeneration in the Kalama stand. Therefore, resources for the next generation are guaranteed.

(3) Samatela woodland

Permanent plot-4 (Table 50) is a permanent survey plot established in the Samatela woodland, and the regeneration of seedlings was traced in this woodland. The number of Mukwa trees as well as the crown coverage are higher than those of Mukusi in this forest stand. The number of trees and the crown coverage for these two species are 10 and 36% for Mukwa, and 5 and 10% for Mukusi, respectively. In this forest stand, five species, such as Mupumangoma, Mulya, etc., appear near these two species. The number of trees per ha in this forest stand is 460.

Figure 40 shows the location of regenerated seedlings and mother trees that were surveyed in February, 1995. This plot was established in the woodland, and the number of Mukwa seedlings exceeded Mukusi. As Table 48 indicates, of the 12 regenerated Mukusi seedlings (having coppicing stems resulting from burning) that were confirmed to be alive in the February survey, only tree No. 5 was still alive, while the other trees were dead at the time of the July survey, because an early burning had taken place. As for Mukwa, 19 seedlings having main stems and 8 trees derived from coppicing shoots were confirmed alive in February. In the July survey, one seedling with a main stem and only three tree stems derived from coppicing shoots were confirmed alive: No. 1 (2 out of 7 coppicing stems), No. 6 and No. 9 (1 out of 13 coppicing stems).

Based on the results of the follow-up survey conducted on the Samatela woodland, it is evident that most of the regenerated seedlings were damaged by the early burning. So even early burning can have negative consequences, since, in this case, the degree of damage was quite severe.

(4) Tree strata compositions of a mature forest, Nanga forest

Permanent plot-2 (Table 51) has been established in the Nanga forest.

As shown in Figure 39, the Mukusi in the Nanga forest make up a multiple-layered forest stand that encompasses all three strata from shrubs to high trees. At the ground surface stratum, a large number of Mukusi seedlings were observed. The tallest tree in the area reached 18 m, and some trees had a DBH exceeding 50 cm. In the surrounding district where this forest is located, natural regeneration appeared to be in the best condition of all areas surveyed. The forest stand in Nanga is a mature Mukusi forest stand that reached the climax forest stage, with a crown coverage of 70% and the number of trees per ha 750.

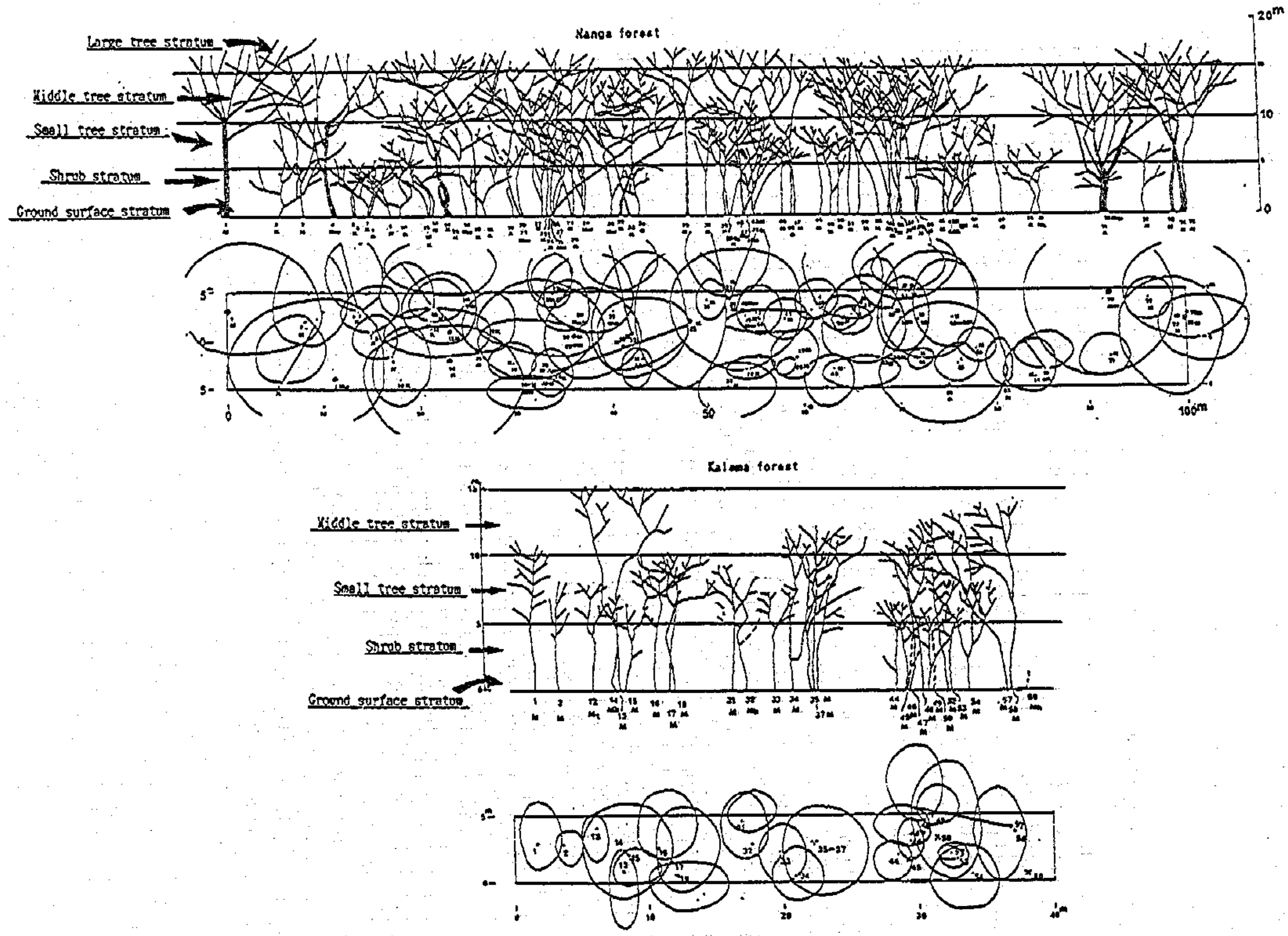


Figure 39 Structure of tree height stratum

Table 48 Follow-up of regenerated young growth in Samatela woodland

Date	Stock No.	Species: [illegible]	Species: [illegible]	Regen. seedlings: Height cm	Regen. seedlings: Diameter mm	Number of coppices	Regenerated coppices: Height cm (1–10)	Mean	Diameter mm	Damage	Date	Item
1995.2	1		o			7	110 55 50 90 70 50 15	61	5	Fire	1995.7	[illegible]
	2	o				15	[illegible]	19	4	Fire		
	3	o				6	11 14 8 18 21 35	17	5	Fire		
	4		o	8	2							
	5	o				18	[illegible]	11	2	Fire		
	6		o			16	[illegible]	44	12	Fire		
	7		o	14	2							
	8		o	12	2							
	9		o			13	[illegible]	36	15	Fire		
	10		o			5	42 34 34 28 21	33	5	Fire		
	11		o			3	30 13 5	43		Fire		
	12		o	8	2							
	13		o	16								
	14		o	6								
	15		o	11								
	16		o	13								
	17		o			5	35 56 19 19 19	30	5	Fire		
	18		o	8	1							
	19	o				5	23 8 6 9 5	11		Fire		
	20	o				3	19 9 7	14	6	Fire		
	21	o				4	19 32 7 4	14	9	Fire		
	22	o				8	16 23 8 5 7 7 8 14	12	6	Fire		
	23		o	19	6							
	24		o	12								
	25		o	10								
	26		o	8								
	27		o	14								
	28	o				63	[illegible]	18	5	Fire		
	29		o	4	1							
	30		o	5	1							
	31		o	10	1							
	32	o				21	[illegible]	11	4	Fire		
	33	o				30	[illegible]	25	6	Fire		
	34	o				10	5 7 2 3 3 3 1 1 2 5	5		Fire		
	35	o				33	[illegible]	12	3	Fire		
	36		o	3	1							
	37		o	7								
	38		o			4	10 4 19 5	8	3	Fire		
	39		o			3	2 3 2	3	1	Fire		

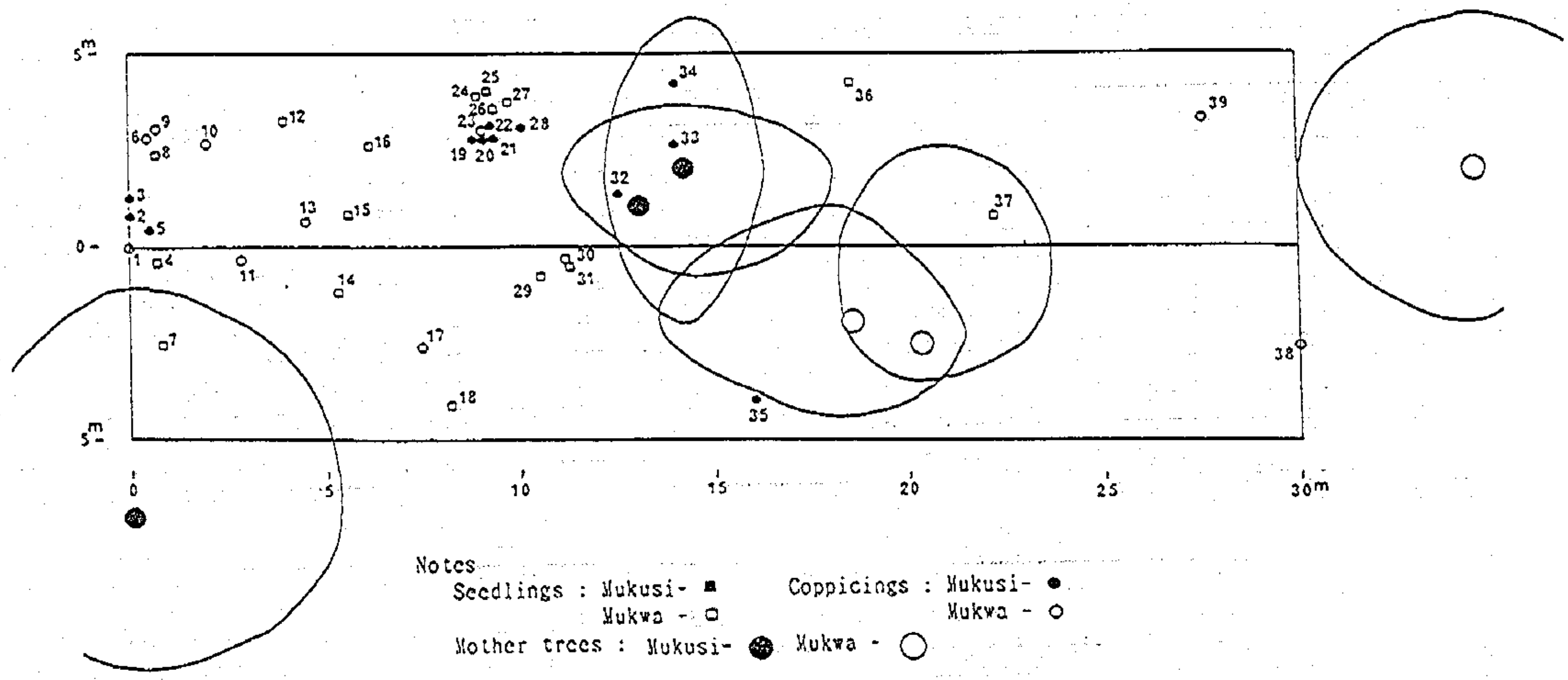


Figure 40 Regenerated young growth in Samatela woodland

Table 49 No. 3 Permanent plot (Kalama forest) (No.14 Belt-transect)

Species		Height m	Diameter of breast height cm	Crown Diameter m	Number
Mukusi	(M)	5 - 15	6 - 33	1.5 - 8	92
Muhonono	(Mh)	7 - 12	9 - 38	3.5 - 7.5	9
Mukena	(Mk)	6 - 8	7 - 10	4 - 5.5	4
Muhoto	(Mt)	8 - 12	10 - 33	2 - 8	3
Mukololo	(Ml)	4 - 10	6 - 15	3 - 5	2
Sibobo	(S)	3 - 5	8 - 11	1.5 - 4.5	2
Musilu	(Mu)	10 - 11	10 - 13	7.5	2
Isunde	(I)	4	6	3.5	1
Total					115

Table 50 No. 4 Permanent plot (Samatela woodland) (No.7 Belt-transect)

Species		Height m	Diameter of breast height cm	Crown Diameter m	Number
Mukusi	(M)	5 - 13	10 - 47	7.5	5
Mukwa	(Mk)	5 - 13	7 - 43	1.5 - 1.3	10
Mupumangoma	(Mp)	6 - 7	6 - 7	4	3
Mulya	(Ml)	4 - 8	8 - 21	3 - 6.5	2
Mukenge	(Mg)	5	8	4.5	1
Mububu	(Mb)	5	7	2.5	1
Muhamani	(Mm)	9	18	4.5	1
Total					23

Table 51 No. 2 Permanent plot (Nanga forest) (No.8 Belt-transect)

Species		Height m	Diameter of breast height cm	Crown Diameter m	Number
Mukusi	(M)	5 - 18	8 - 58	2.5 - 15.5	45
Kangolo	(K)	4 - 7	6 - 10	4.5 - 7	15
Mwangula	(Mw)	9 - 17	9 - 64	5 - 16	10
Isunde	(I)	6 - 8	6 - 8	4.5	3
Nzani	(N)	5	7	4.5	1
Nankala	(Nk)	7	10	5.5	1
Total					75

3.3.3. Guideline for natural forest operation technologies

(1) Promotion of seedling regeneration by natural seeding

Natural regeneration is a sure and economical method for Mukusi regeneration in this region. Mukusi seeds are relatively heavy so that their distribution range is limited to the area directly below the crowns. Thus, the seeds will not drift beyond that range. In effect, Mukusi regeneration is achieved by the so-called seed shedding from overhead trees. In order to promote the regeneration of seedlings, an appropriate number of the mature trees must be preserved to serve as mother trees. So, when conducting logging operations, it is important to secure the regeneration of succeeding trees which will be the constituent forest members of the next generation.

Operations to clear the forest floor including, for example, the removal of densely grown grass, are very important in order for naturally fallen seeds to germinate and thrive. Such operations are needed to help promote seed regeneration. The grass that grows densely on the forest floor obstruct the light coming from the above, reducing the light intensity to be received by the regenerating seedlings and, in extreme cases, causing them to die. While cutting the grass by manual labor is a simple forest floor treatment method, more effective methods are to expose the ground surface by plowing and to scarify the soils. These forest floor treatment operations should be conducted prior to seedling regeneration, in order to help promote natural regeneration. These operations can be achieved more effectively by using mechanical power such as bulldozers.

(2) Introduction of enrichment technologies

When there is a shortage of succeeding trees for the next generation, and the regeneration and thriving of seedlings cannot be expected, enrichment technologies can be introduced to assist in natural regeneration.

Methods of enrichment include line planting and gap planting. In line planting, a low quality natural forest is cleared, then the seeds are directly sowed or pot nursery stocks are planted in long and narrow strips of land. In gap planting, the gaps of the forest stand are cleared, then afforestation is promoted.

(3) Improvements in seed technology and nursing technology

1) Accumulation of phenological information

Forest operations are generally affected by the cycles of the rainy and dry seasons. In particular, the timing for direct seed sowing, pot plant stock nursing and stock plantation is influenced by weather conditions and soil moisture content. Therefore, an accumulation of phenological information is essential for increasing the seed germination rate and the survival rate of the pot plant stocks. Foliation, defoliation, flowering and seed bearing of the broad-leaved trees react sensitively to the changes in the rainy season cycles. Therefore, it is necessary to accumulate data through observation over a long period of time and improve the seeds and nursing technology.

2) Improvement in pot plant stocks

The result of an afforestation experiment using the pot plant stocks in Simungoma west presented several problems yet to be solved. The death of planted seedlings was caused by an imbalance between the growth of the pot plant stock roots and the transpiration from the branches and leaves. It is apparent that the trees died from drought damage because the dry season began before the roots had sufficiently grown.

Usually, two methods are adopted for nursing the pot plant stocks; one is to sow the seeds directly in a pot and rear the germinated stocks; the other is to transplant the stocks that have been cultured in a nursery to a pot for further rearing. Of these two methods, the former is recommended for the following reasons: the labor required for transplantation may be eliminated; drought damage may be avoided; the nursery practices are easier. When adopting this method in which the seeds are directly sowed in a pot, it is necessary to study in advance the number of seeds to sow per pot, the growth height of the seedlings, and the growth of root systems before they can be planted.

The number of seeds to sow is determined by conducting a germination test on the seeds. When using seeds that showed a germination rate of 30%, five seeds should be sowed in a pot. When determining the size of the pot, the most important factor is the depth which limits the growth of the roots. Usually, the pot should have a depth of 15 cm to 20 cm. The number of days required for germination of the seeds sowed in this pot and the height growth after the date of germination must be recorded to be used as basic reference material. It is also recommended to record how deep the roots have grown, at least twice a week. Seedlings whose roots have grown to the bottom of the pot may be planted.

Seedling planting must take plan during the rainy season. Measure the growth depths of the roots of the planted pot cultured stocks several times until the end of the rainy season and, when the dry season starts, check to confirm that they are surviving. Since the growth pattern of the roots of the planted pot cultured stocks is unknown, it is necessary to grasp the relation between the growth depth of the roots and the survival rate by digging in the earth to expose the roots. The roots must have grown deep enough to absorb water before the dry season starts, and such a depth is estimated to be more than 1 m ~1.5 m below the ground level.

(4) Improvements in selective cutting operations

When conducting cutting operations, it is recommended that a selective cutting method which securely preserves the succeeding trees in the next generation forest be chosen. Selective cutting is superior to clear cutting because the sere may be secured more readily and the forest land preserved more effectively. Of the selective cutting methods, group selection cutting and strip selection cutting are superior to single tree selection cutting because intensive management is possible. Trees must be felled after they have dropped their seeds in abundance and a great number of seedlings have grown.

Group selection cutting aims to promote seed shedding from overhead trees by cutting a certain number of Mukusi trees as a group. Also, when conducting strip selection cutting, the cut width should be the same as the tree height. The maximum tree height of Mukusi is about 20 m. This may be used as the standard. Regeneration by seeds shedding from overhead crowns may be expected on the both sides of the strip, but in order to cover any insufficient seed regeneration, it is recommended that artificially enriched seeds be selected.

Although the mother trees play a role, various things must be taken into consideration, such burning damage and the disappearance of regenerated seedlings after cutting mature trees, when selecting the trees to be cut. At this time, a sufficient number of mother trees should be preserved so as to secure the seed source.

Based on the results of surveys conducted on naturally regenerated forests and plantations, how the Mukusi trees regenerate coppice stems, grow to having multiple stems and eventually become a forest were observed. It was made clear from this observation that Mukusi is a species having an extremely high sprouting power. At the above-mentioned site, coppice shoots were not observed because the survey was conducted shortly after a cutting. However, it is expected that the coppice shoots from the cut stumps will grow to become coppice stems. In order to realize this, it is necessary to properly conduct forest floor treatment around the ground surfaces of the cut stumps.

(5) Expanding the dispersion of Mukusi seeds by utilizing rodents

Damage by rodents, for example, Mukusi seeds taken away by rats and regenerated seedlings eaten by duikers, may be prevented in an experimental scale by applying a chemical agent to the seeds or by surrounding the seedlings with nets. However, these measures cannot be adopted in the actual cases. Proposed below is an approach to facilitate the distribution of Mukusi seeds by utilizing animals, regarding them not as pests but as members of the forest ecosystem participating in regeneration.

In Japan, it has been confirmed that the Apode mus speciosus ainu (large Japanese field mice, Apode mus speciosus ainu) participates in the regeneration of Japanese oak trees. The rodents usually store the seeds in shallow underground places within a dispersion area of several tens of meters. There is a report that the dispersion and storage of seeds by rodents serve to help maintain the population of Japanese oak trees and gradually expand the distribution range. The seeds of Japanese oak trees are relatively heavy and seeding regeneration is limited in the gravitational direction. Therefore, it can be safely said that the Japanese oak trees are dependent on animals for dispersing their seeds to wider areas. Regenerated seedlings are often found at such places where the underwood is cleared.

When more knowledge concerning the regeneration of Mukusi forests in Zambia is accumulated, and data on the participation of rodents for the dispension of Mukusi seeds are collected, it will be useful for the future recovery of the forest ecosystem.

3.3.4. Forest damage due to burning and preventive measures

(1) Destruction of the forest ecosystem due to burning

The direct damage to forests from burning in the survey area amounts to the destruction of the forest ecosystem. Coppicing stems seen in such large numbers at the site were derived from the main stems, which were killed or damaged by burning. The coppicing stems not only cause a significant delay in growth, but they also tend to become plural stems, resulting in a poor tree form and degraded quality. If the burning is repeatedly conducted, the ecological succession, in which a forest goes through the natural sere and reaches its climax, would be hampered. As a result of secondary succession caused by burning, a retrogressive succession takes place, the destruction of the forest stand structure progresses and, eventually, a woodland or grassland appears.

As such, if the vegetation is destroyed by burning, the humus, the source of nutrients to the soils, will be lost, lowering the forest productivity and reducing the diversity of the forest ecosystem. Eventually, the forest will be exhausted and head for barrenness.

(2) Prevention of burning damage

1) Installation of firebreaks and management

Since grass tends to thrive and shrubs grow at the edges of forest stands, the stands are vulnerable to burning damage. A ground fire that occurs at a grassland located at an edge of a forest stand spreads to the inside of the forest, becoming stem fires, growing to branch fires, and then crown fires, killing and burning the standing trees. In order to prevent this, firebreaks are required. The reason why the experiment areas for direct sowing method have been saved from the fire for approx. 30 years is because firebreaks were established around these areas. The width of firebreaks surrounding the plantations is 4~5 m.

In Japan, fire prevention forests have been created as a part of the forest protection management policy. The practices adopted in Japan are to plant fire-resistant species and to create bare lands by removing the surface ground. European countries along the shore of the Mediterranean have been employing the firebreaks as the forest fire protection measures since these regions have little rain. In France, besides creating firebreaks, the practice of removing the undergrowth in the forests was adopted. In Italy, the establishment of firebreaks and fire-prevention forest roads is specified by law. In Greece, forest lands are subdivided by the firebreaks for the management of shrubs which are the major combustibles.

The establishment and management of forest roads that also serve as the firebreaks were discussed in section 3.3.5. In addition, it would be a good idea to construct administrative roads at the boundaries between forest lands and agricultural lands, because they would constitute the fire-prevention buffer zones. As firebreaks, bare lands could be created by removing the surface ground. In such bare lands, herbs and shrubs cannot easily grow and, therefore, the fire-prevention effect will be maintained. Firebreaks can be easily created using bulldozers.

2) Review of early burning system

There is a need to review the importance of the early burning system as a forest management procedure. Follow-up surveys conducted in the Kalama forest and Samatela woodland showed that the seedlings of Mukusi and Mukwa withered and were damaged by early burning. It is said that early burning is useful because it protects the forest from complete destruction of its vegetation, possibly caused by late burning. However, as a result early burning is recommended, so it is feared that unrestricted and ill-timed burnings may increase.

In addition, it has been suggested that the germination of Mukwa seeds is improved by burning, but experiments do not support this claim. However, in the cases of Lodgepole pine and Jack pine in the U.S.A., fires play a certain part in the improvement of germination of forest tree seeds. But in the case of Zambia, which is suffering from constant forest fires caused by burning, unless the benefits of burning can be scientifically established, it is nearly impossible to justify early burning because thoroughly controlled burning cannot be expected.

3.3.5. Cutting, hauling and transportation of timber

(1) Present state of cutting

Currently, decisions on cutting are reached through applications from contractors having a license to cut forest trees. Forest Department regulations specify that the minimum and maximum diameters at breast height of trees to be cut shall be 30 cm and 100 cm, respectively, and trees whose DBH falls within this range may be cut. The regulations also specify that the minimum log length shall be 1.2 m and that the cut log shall not be decayed or deformed.

Cutting licenses include the following three types:

1.	Sawmilling Concessions	5 years
2.	Pitsawing Concessions	8 years
3.	Casual Licences	14 days

As per cutting method, single tree cutting is adopted and appropriate and mature Mukusi trees are being cut. Contractors are instructed to cut trees so that the stump is no more than 15 cm above ground. However, based on our observation at the sites, the heights of the remaining stumps were, in many cases, between 30 cm and 40 cm, probably because it is easier to cut trees at these heights when chain saws are used. Only the first trunks of the trees are harvested and other stems and branches are left behind around the stumps.

(2) Forest roads and spur roads

Since forest roads are indispensable for efficient forest management and proper forest maintenance and control, it is important to keep such road in good condition. However, there is no concept of forest roads in Zambia, so the matter must be considered based on the nation's road standards. Road standards are classified as follows:

Road standards

Type 1	—	Roads, paved roads
Type 2	—	Local roads, gravel roads, all-weather-type roads
Type 3	—	Seasonal roads, roads with ditches and roads with cross sectional grades
Type 4	—	Roads made by simply clearing herbs and shrubs and leveling

The survey area is comprised of sandy soil covered by Kalahari sand. Therefore, the type 3 and type 4 roads can be used even during the rainy season. When constructing roads in the survey area, type 3 roads for the forest roads and the type 4 roads for spur roads would be adequate.

1) Current state of timber hauling and transportation

In the survey area, logging and forest management operations are carried out using the roads (types 2, 3 and 4) which connect between villages and spur roads.

In the survey site, two companies, Zambezi Sawmills and Mukusi Sawmills, as well as pitsawyers and those with casual licences are cutting trees. The two companies mentioned above are constructing spur roads. Yarding is conducted by skidders and forwarders and the timber is transported by trucks.

Zambezi Sawmills has two sawmills in the survey site, which are used as the basis for logging operations. The spur roads running from the sawmills to the logging sites are used more frequently and, for a longer period of time, than those located at the logging sites; therefore, these roads may be called forest roads. The spur roads at the logging sites are used only for hauling timber and their surfaces are quickly covered by shrubs and closed.

Spur roads are made by simply clearing the herbs and shrubs, and leveling. Since these roads are constructed on sandy soil which has excellent permeability, they can be used even during the rainy season. However, the vegetation quickly returns after the logging operation is over. Therefore, the clearing work is sometimes required in order to secure the traffic before the next logging operation.

2) Forest roads and firebreaks

The boundaries of the Forest Estate located in the survey area are not clear. Clearing the shrubs using manual labor and establishing fire-prevention forest roads would require about 146,000 laborers. This figure suggests that it is not practical to clear these boundaries using manual labor. Since the survey area is flat where the winds blow only intermittently, major fires may be prevented by creating the firebreaks at certain intervals (fire prevention spur roads that can also be used for forest management operations).

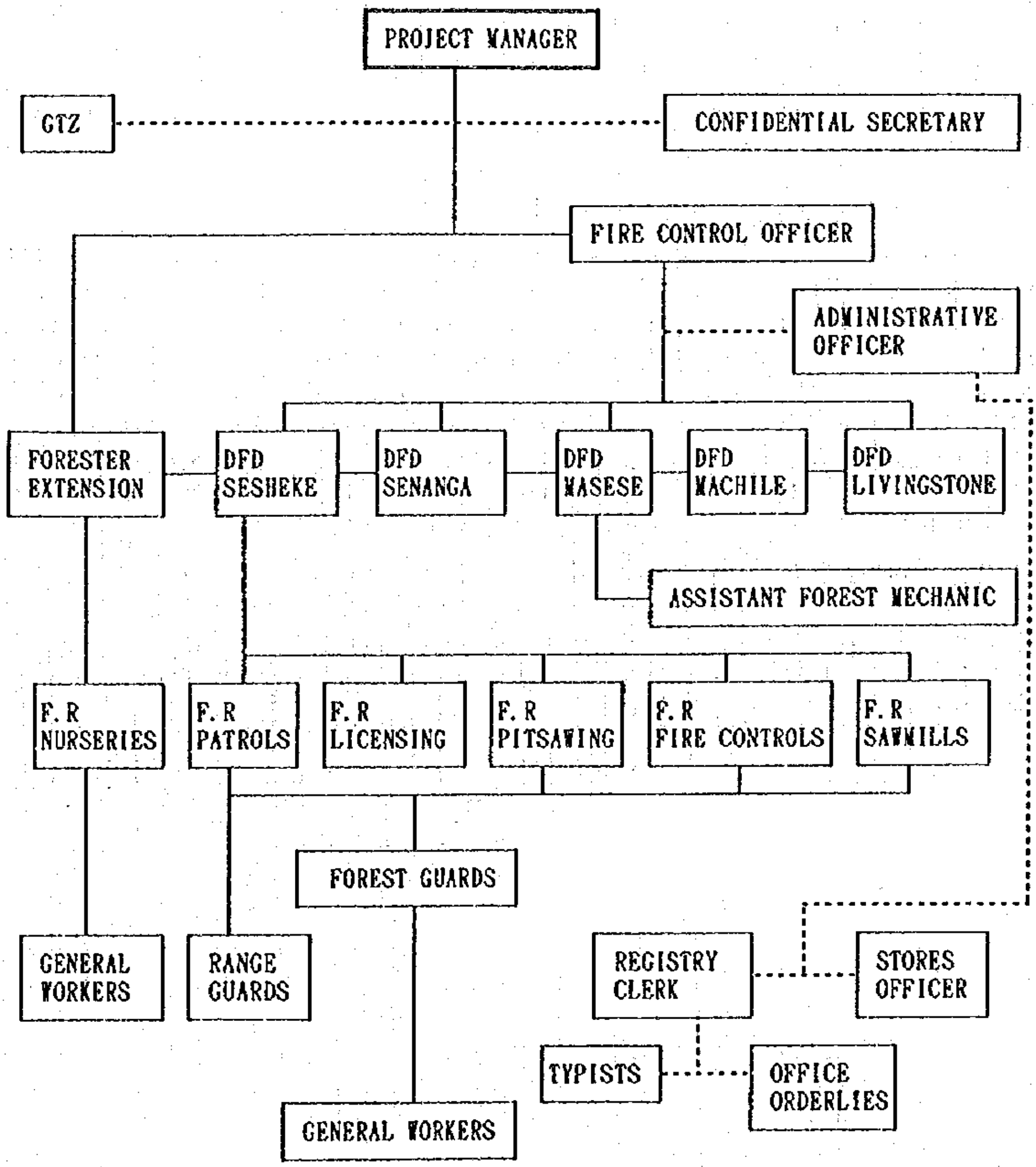
Based on the above findings, it is urgent that facilities be provided that function to prevent fires caused by burning, such as forest roads (fire prevention forest roads) and the firebreaks (fire prevention spur roads) in order to protect forests against the retrogressive succession caused by fires and to facilitate the sound growth of forest trees. It is recommended that forest roads be constructed along the boundaries of the Forest Estates, and that they be maintained and managed to function as fire prevention forest roads as well as the firebreaks.

Ideally, firebreaks (also utilized as spur roads) should have a width of 5~6 m and be provided at intervals of 500~1,000 m, from the forest management and timber management points of view. Such firebreaks may be created relatively easily by using bulldozers.

3.3.6. Forest management organisations and forest management

The forests in Zambia are, in principle, state-owned. The Forest Estates where Mukusi trees are distributed and growing are managed and controlled by a national project, The Teak Forest Project, of the Forestry Department.

The Teak Forest Project is comprised of the following organisations:



Note: F. R.: Forest Ranger

The staff engaged in the Teak Forest Project number 48 and the workers 67.

Project responsibilities include the following:

a. Forest Fire-fighting and Control
b. Forest Demarcations and Surveys
c. Forest Boundary Maintenance
d. Forest Managed Early Burning
e. Forest Research (Indigenous Silviculture)
f. Commercial Sawmilling Supervision
g. Forest Produce Licensing
h. Revenue Collection and Banking
i. Forest Extension
j. Forest Tree Nursery Establishment
k. Protective Forest Patrols

The organisations established for this project appear to have adequate human resources but lack sufficient budget allocations and mobile powers. In addition, the number of automobiles and the instruments necessary for surveys and management are not sufficient. Consequently, surveys of current conditions in the forests, research at experimental sites, control of wood harvesting, and management of existing firebreaks are being not conducted in a satisfactory manner. Moreover, the inadequacy of the fire-fighting equipment and mobile forces in the event of a forest fire is one of the causes that prevent active action from being taken, action that is needed to check the spread of fires in their early stages. Urgently required are the sufficient budget allocations that permit those organisations to take the necessary measures for forest management and the prevention of forest fires.

Furthermore, the total forest area and the volume of resources in Zambia have not be accurately grasped, and it seems that no operational plans for logging, afforestation and nursing have been drafted. Under such circumstances, the findings and data obtained from a number of afforestation experiments conducted in the 1960s and 1970s, in an attempt to clarify these facts, should be utilized as a guideline when conducting future forestry in this region.

3.4. Survey for Land-Use Management

3.4.1. Land-use based on the natural conditions of each locale

The goals of land-use planning change according to a society's needs, which are generally determined by a society's stage of social evolution. For example, there is land use for the direct production of daily necessities based on farming, forestry, livestock breeding, etc., land use for industrial, urban and residential areas, land use for environmental protection, land use for human well being derived from public parks and green belts, and land use for public facilities.

The land use proposals in this survey are given as a part of the forest management plan, and they focus on productive environmental organizations. However, the proposals, which aim at achieving perpetual productivity for land, are not simply limited to the issue of applying production technologies, but include consideration for natural conservation issues.

In this survey, it was found that the land used for farming, forestry, grazing, etc. depends on the natural characteristics. Therefore, this survey concentrates on local conditions within each survey area, and how land there is being used.

Although Forest Estates exist, until a letter understanding is obtained from the local villagers, the problem of farmers seeking to expand their farmlands will continue. Also surveyed was the relation between farm land and forest land, as viewed from a natural habitat standpoint.

3.4.2. Classification of site characteristics

(1) Method and results of terrace and flood plain classification

Figure 41 illustrates the land conditions of a 639,800 ha area that includes the area of study.

When the summit level map that is included in this figure is surveyed, the survey area appears as a plateau, somewhat dissected and gently sloping in a southeasterly direction. Although, the plateau classification is not accurate, due to the fact that the area is covered with the Kalahari sand layer, areas above the elevations of 1,040 m to 1,060 m are classified as high terraces, areas with elevations less than 940 m to 960 m (along the Zambezi River) are classified as low terraces, and areas with elevations of 960 m to 1,000 m are classified as middle terraces. West of the Loazamba River, however, the division between high and middle terraces is not clear.

In the case of many tributaries, middle and high terraces appear shallow, yet have wide trench cross-section profiles. For this reason, in many cases, even low terraces sometimes extend to banks, and the delineation between higher terraces cannot be easily determined. Particularly, in the case of valleys with cross-section profiles that fail to exhibit a terrace structure, it is difficult to distinguish flood plains from low terraces and middle terraces. Therefore, when deciding on a low terrace classification, the point at which a terrace structure could easily be identified was used as a bench mark. And, for sites that could not be classified easily, they were classified by assuming a low terrace edge along a line extending from the bench mark, using the relative elevation differences.

For classifying flood plains, we relied on, without amending, the results of interpretations done by engineers at the Zambia Survey Department for their 1/50,000 topographical maps.

By using the above classification method, the area of high terraces was known to be 119,148 ha, or 18.6% of the area. Middles terraces were 309,939 ha, or 48.4%, the low terraces along the Zambezi River 21,454 ha, or 3.5%, and the low terraces along the tributaries 56,701 ha, or 8.8%. The area of the flood plains and marshes was 132,557 ha, or 20.7%. But the area along the Zambezi River alone was 24,136 ha, or 3.8%. However, the low terraces and flood plains along the Zambezi River are numerous, and are not included in the survey area. So the actual area is considerably larger.

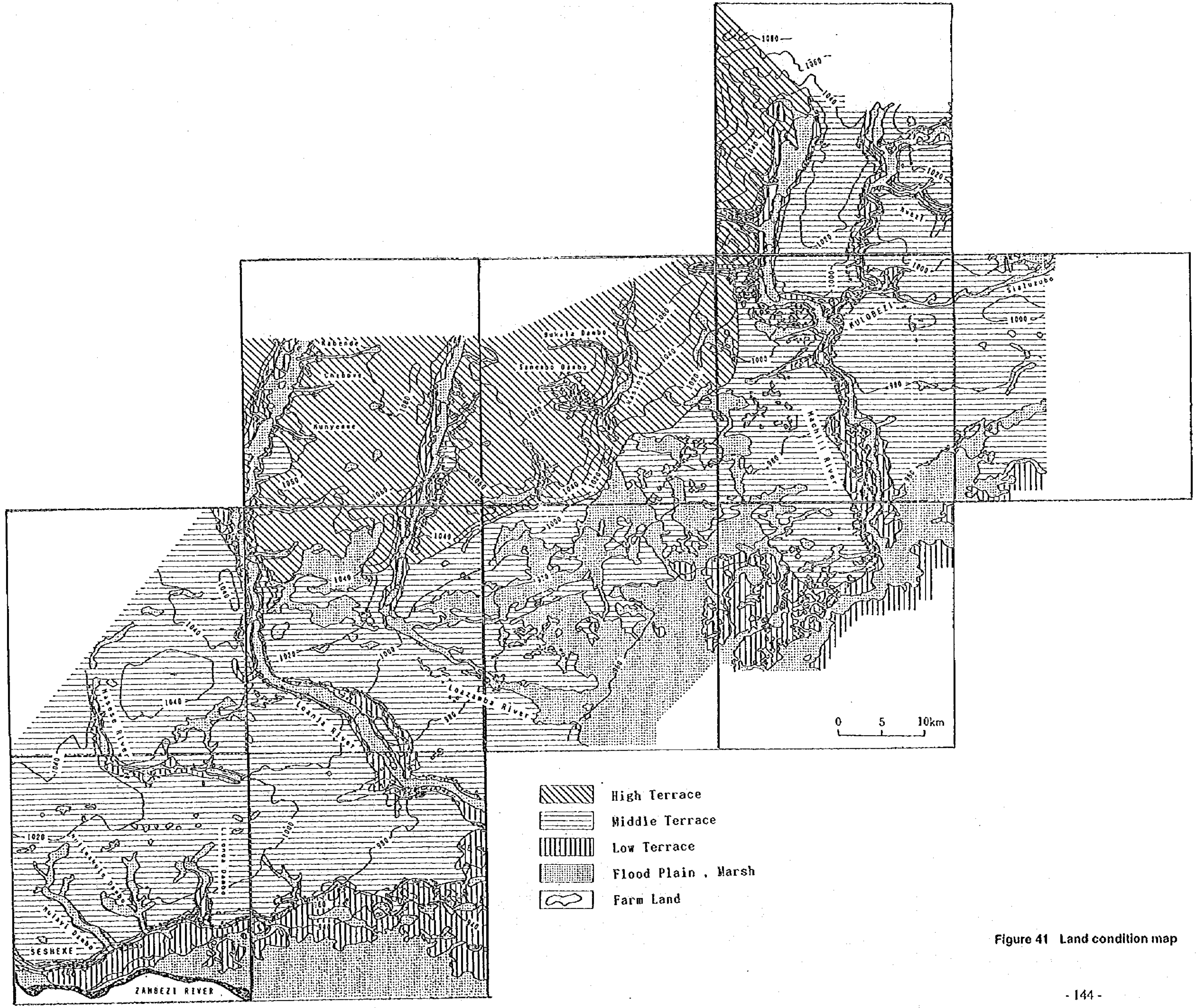


Figure 41 Land condition map

(2) Site characteristics of alluvial plains of rivers

Alluvial plains of rivers are divided into two types: flood plains covered by River water during the rainy season, and non-flooding plains and lowlands including low terraces. Significant differences in the features of sediment plains and soil forming plains were observed between flood plains along the main River, where turbulence constantly churns up sediment, and the flood plains along the tributaries with their modest water flows, enabling the retaining of old sedimentation layers. For this reason, the different flood plains are discussed separately.

a. <u>Flood plains and low terraces along the main course of the Zambezi River</u>

The area is composed of highland terraces covered with a thick layer of Kalahari sand. The Zambezi River winds through the area, forming wide flood plains and low terraces.

In the upstream portions of the river in the northwestern part of Sesheke, the bedrock is close to the surface. There are segments with swift currents and rapids, and the main river courses through a slightly valley-shaped terrain. (At this point, the river has not formed a canyon, but rather small-scale flood plains and rocky low terraces.) The river changes direction from southeast to east near Sesheke, and then a short distance on, suddenly encounters a gentle slope. From this point, traveling downstream, to near Livingstone (about 150 km), the river forms large-scale flood plains with widths of 10 km to 20 km as it flows toward the Namibian border to the south.

Historically, the area is assumed to have been a desert during the latter part of the Neogene period, when it was covered by a thick layer of aeolian soil, which originated from the central part of the Kalahari desert and western plains. Furthermore, during the most recent Diluvian episode of the geological age, it is believed that the area again became a large-scale desert. The Zambezi River formed low terraces and even lower formations by eroding the aeolian soil and redistributing sand. Perhaps, because the history of river erosion and sedimentation is relatively recent, the sand layers that comprise the flood plains and low terraces consist of relatively fresh materials for this region. Interestingly, as the aeolian soil was flushed by water activity over the years, the grain size of the flood plain soil is larger than that found in the sediment layers of the middle and high terraces, and the grains are slightly square. These are characteristics of a sandy soil, so because of them, an abundance of pores is seen in the sand layers. As a whole, the layers share sand characteristics and forms, but detailed soil texture and the degree of hardness and density vary according to the geographic relation to the main course of the river and the river's velocity at a given site.

All of the low terrace surfaces share a similar history of sedimentation after being deeply eroded by the Zambezi River. In the course of the river's winding, seemingly, the low terrace surfaces were divided into either water channels having deep river beds, or sediment plains of different thickness, which together formed the present topography. Given this phenomenon, although the relief of ground surfaces differ, the bases of their sediment layers seem to have the characteristic of being deeper than current river level while, at the same time, sharing continuous sand layers at the lower parts. Thus, it seems that the groundwater levels of low terraces and flood plains have a strong tendency to fluctuate in response to the water level of the Zambezi River's main course.

It is further suspected that the relative elevations of flood water surfaces during the rainy season together with the groundwater levels are essentially characterizing water conditions which influence the development of soil horizon levels. If the groundwater levels are influenced by the water level of rivers, it is reasonable to postulate that the water environment of sediment layers has been characterized by the difference in the relative levels of the rivers to their topography.

Because the groundwater level in a sand layer near the flow channels of the river does not change quickly, even during the heavy rains common to the rainy season, the groundwater sometimes maintains a higher water level than the river as the dry season approaches. (On the other hand , there are instances when the river water level rises rapidly due to heavy rainfall upstream in the early rainy season—a time of little rainfall locally or downstream—while the groundwater level in sand layers remains low. But we regard this phenomenon as exceptional.)

Thus, it is reasonable to suspect that if sand layers are continuous, shifts in inland groundwater levels are usually a bit behind river water level changes, and, in many instances, the average annual level may be higher. Here, we have assumed a direct correlation in the up/down movement of groundwater levels with those of the river (Figure 42).

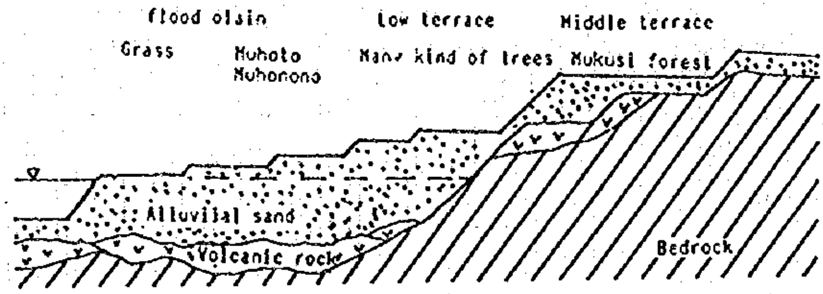


Figure 42 Schematic profile of low terrace

a1. Low flood plains

Low flood plains are flooded almost every year during the rainy season. Since the plains are dry for more than 6 months of the year, it is possible for herbs to grow. Many of the plains have been turned into grasslands. But at some places, tributaries have created flow channels into rivers during rainy seasons, eroding the top soil and exposing sand layers, which has prevented to be grasslands.

The plains, where herbs can grow unimpeded, are slightly higher than the exposed sand layers. The A and B horizon, which are partially comprised of humus, are seen on these plains.

When herbs start to grow, erosion is prevented by the dense root systems, even if the plains should flood. Furthermore, sedimentation is accelerated by dense foliage. Gradually, sediment layers thicken and become higher than the flow channels. The horizons of the A and B layers develop rapidly, because root systems die each year and rot, providing humus to the surface layers of the soil.

a2. High flood plains

The high flood plains are slightly higher, and therefore less flooded, than typical flood plains. Plants grow more successfully on high flood plains than low flood plains. Not only herbs but also shallow-rooted trees and moisture-tolerant trees (e.g., Muhoto, Muhonono) grow there. In addition, since the groundwater level is close to the surface, the water supply is reasonably assured during dry seasons; so plant growth is vigorous.

In general, the plains that provide surfaces for sedimentation are called alluvial plains. When examined in detail, their surfaces can be broken down into two to three classifications according to their elevation.

a3. Low terraces

Low terraces are generally 2 to 4 m higher in elevation than flood plains. Even during the dry season, as groundwater levels fall 5 to 7 m below the surface layer, water is supplied by capillary action in the B and C horizon, which are made up of relatively dense sediment deposits. The B and C horizon seem to maintain a continuous supply of water with a value of around pF 2.7 (a soil moisture value indicating easy absorption by plant roots). The top horizon, the A horizon (20 to 30 cm in thickness), is often dry because its non-capillary porosity is too great, so the resulting lack of continuity between macro and fine pores hampers capillary action. This indicates that soil is a suitable environment for wild trees and shrubs to grow because of their relatively deep root systems, but it would be a severely dry environment in which to cultivate farm crops. (Hereafter, the A horizon (mold) is excluded, unless cited, and only horizon B, C and below are subjects of the report.)

Owing to its relative elevation that is more than 2 m above the flood plain, a low terrace is not likely be overly wet. Therefore, all species including shallow-rooted, deep-rooted, and hygrophytic plants can grow on low terraces. And, with regard to the crown coverage (stand density), where, by degree, the competition for light overtakes the competition for water, this area of the plain is the most favored in terms of water resources. The development of the soil horizon is sound, having nutrient rich A and B horizon. The area provides excellent conditions for both forest trees and herbs. When focusing on soil near the surface, many problems arise since the top soil dries out during the dry season.

In recent years, the excellent soil conditions originally found at many sites are disappearing as a result of soil overuse, including slash-and-burn practices on cutover lands by agriculture interests, which is often followed by excessive grazing, uncontrolled burning, and consolidation. If efforts are made to promote the growth of herbs for the recovery of humus layers, the soil actually has the potential to recover quickly because of its supreme location. Therefore, care should be taken in using land (in terms of cycles).

b. <u>Lowlands along tributaries (flood plains and low terraces)</u>

As a whole, lowlands possess unique sand characteristics. However, along the tributaries, a higher percentage of fine sand has been ground by the progression of weathering than that found on the flood plains and low terraces along the main channel of the Zambezi River, which explains the denser sedimentation found along the tributaries. This is due to the fact that exposed surfaces of the tributary lowlands retain more of the older deposits because the flushing action of the water flows is weaker than that found in the main channel of the Zambezi River. So, soil hardness and density depend, in part, on factors such as to whether the area experienced swift or leisurely water flows. Also, the evolution of the soil horizons and groundwater conditions have been influenced by a site's elevation relative to rainy season flood surfaces.

b1. Areas of swift water flows on flood plains

The River runs through fixed channels when passing through ravines. However, when the river enters a low flatland, the land can be viewed as a wide flood plain. Relatively narrow channels wind across the surfaces. In the areas surrounding these channels and the recently discontinued channels, white sands are exposed during rainy seasons. The reason for this lies in the swiftness of the current, which has continued to promote a soil erosion and sedimentation cycle, resulting in the loss of soil formation. On most flood surfaces, however, where water flows are moderate, the formation of soil was observed, as described in the following section.

b2. Areas of moderate water flows on flood plains

Many areas that flood only during rainy seasons are not main water channels, and water movement in these areas is gradual. Although the areas are subject to mild surface erosion during occasional flooding, it seems that in most instances, sediments that had been dislodged and suspended by river currents resettle for sedimentation. The annual volume of deposits might not be large, since the discharge is not large, but, on the whole, the area is thought to typify a sedimentation environment.

b2.1 Concave land formations with bad drainage—dish-shaped, gently sloping surfaces

In an environment where the groundwater level remains at or near the surface level after rainy seasons, providing moist conditions throughout the year, herbs will fail to thrive; so soil formation will be severely hampered. In such places, some erosion was apparent, which was due to the activity of currents unimpeded by herbs. When currents taper off near the end of the rainy season, sediments begin to settle into a dense inorganic state. Through the recurring cycles of dry-rainy-dry seasons, large gaps are created and large pores are formed at some places within the strata. But, since the main composition of sedimentation is fine grain sand, which tends to float even in slow currents, as a whole, the sedimentation lacks pores and is very hard and dense. The hardness of the layers exceeds 30 mm (a figure equivalent to some rock), which prevents the penetration of root systems.

Still, even in this environment, as sedimentation progresses and the high humidity subsides during the dry season, herbs start to take root. At spots where herbs begin grow, the tight binding of the herb root systems inhibit soil erosion. Also, the foliar holding accelerates sedimentation. As a result, the sediment layer gradually deepens. Furthermore, since there is an active life/death cycle, the herb root systems begin to contribute humus that allows soil formation to progress rapidly.

At sites where herbs grow, flood surfaces have formed with the soil horizon becoming one step higher than exposed lands (mentioned above). In many cases, hard and dense layers (also mentioned above) develop as hard pan under the sediment layers which have become soil. This soil structure is not good. When soil layers have been established, leaching materials from the A horizon settle and are deposited onto the denser layers, with the result of making the hard pan even harder and denser.

Generally, the portion of land on which herbs grow is greater than that of the barren surface. Next to the herb growing areas, and one step higher, the high flood plains and low terraces take shape. When the depth of the sediment layer reaches about 1.5 m, the adverse situation caused by stagnant water trapped by the hard pan lessens, and good soil conditions appear.

b2.2 Flat land formations with relatively good drainage—high flood plains

Herbs also grows in areas where water drains with relative ease after rainy seasons, as long as the area remains relatively humid during dry seasons. In these locations, the probability for a good sedimentation environment is high. This happens because soil erosion is prevented by the tight root systems of herbs and the damming action of dense foliage. The result is that sedimentation layers gain depth with each flooding and topographic features usually develop, which average around 1 m in height, one step higher than the barren, low marshy land.

Because humus is supplied every year by rotting herb root systems, the soil horizon develops rapidly. Many A and B horizon with a depth of 0.3 to 0.5 m were found. Also, many white layers were found to have developed beneath the humus layers. The white layers are the result of a process in which metals, such as iron, attached to sand grains are dissolved and discolored by humic acids. Since the dissolved and discolored materials containing fine soils settle and deposit on lower layers, the pan becomes increasingly hard and dense.

As a characteristic of tropical areas, often basic features are created because of the rapid humus decomposition in the A horizon. A result of this process can be the dissolution and discoloration of the silicic acid contained in lower layers; thus, strong basic white layers are formed. When a surface layer suddenly disappears, the strong basic sand layers are exposed, making plant growth quite difficult.

Usually, in the first stage of flood plain formation, the river establishes the main winding channel by eroding a rather deep groove in the landscape. In the next stage, along with movements in the winding course, the location of the main channel changes, and the old grooved beds become buried. A flood plain gets created by these ongoing actions, and a wide, flat topographic surface is formed. When only a deposit profile with a depth of 2 to 3 m is examined, old sediment layers are rarely found within the profile, but the same soil layer structures are commonly found. In high flood areas, shallow-rooted and moisture tolerant species, such as Mupane, are distributed.

b2.3 U-shaped valleys—gently sloping landscapes

With tributaries that have only small catchment areas, the flat flood surfaces (described in the previous section) cannot be formed. Instead, gently sloping surfaces are created. The surfaces appear as U-shaped curved surfaces when viewed in profile. Under the Kalahari sand sediment layers, often ancient topographies (predating the last diluvian episode) lie buried. And above them, as if covering them, a dark reddish pan (abundant in iron and aluminum), known as curasse, is spread. Different characteristics distinguish these locations; i.e., either the new U-shaped slopes were formed when currents eroded and destroyed the old topography along with the pan (Figure 43a), or the ancient hard pan and its surface contours have remained intact so that the current U-shaped topography was formed over the ancient topography (Figure 43b).

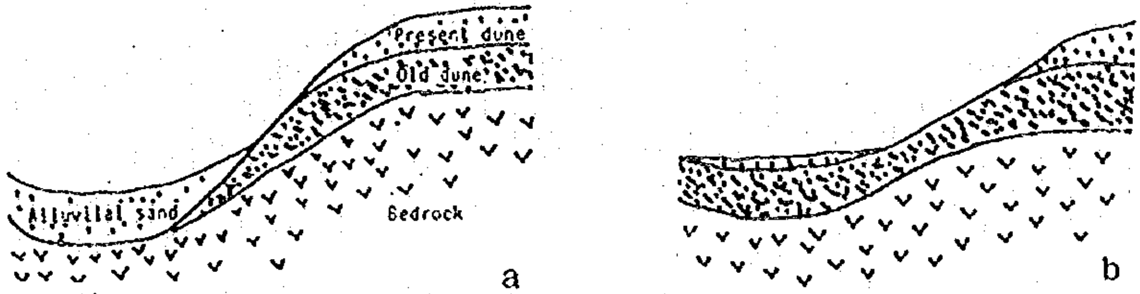


Figure 43 (a, b) Schematic profile of rivulet

In the former case, the ancient hard and dense sediment layers were gone, and the hard pan, which can trap stagnant water, was also gone. The entire sediment strata have relative swelling characteristics. As for plants, a suitable environment has been formed (Mulayi dambo, Mulimakule dambo, etc.)

In the latter case, not much new material has been deposited. Even if soil had formed, the present environment is not suitable for plants (especially in the valley bottom), because the hard pan that traps stagnant water is so evident. Also, when the surface soils have been lost to soil erosion, hard and dense subsoil is exposed, making plant growth difficult. Thus, the environment may be easily destroyed (Sanembo dambo, etc.).

b3. Low terraces

The low terraces along the tributaries do not get overly wet during the rainy season. And, in the dry season, water is supplied from groundwater and from the upper level slopes (middle or high terraces). Therefore, low terraces provide good conditions for all plants. At present, many of the terraces are used as farmland. However, the soil in the farming areas has too high a level of porosity to enjoy the benefit of a good water supply. On the other hand, for trees whose root systems can reach the B and C horizon, low terraces provide good conditions since they can easily absorb water from the lower strata via capillary action.

(3) Middle and high terrace characteristics defined

a. <u>The geology of plateau strata and sand layer formation</u>

The types of bedrock discovered are sandstone (Kalahari sedimentation), shale, and metamorphic rock (the old bedrock), including gneiss and crystalline schist. On top of the bedrock lies basalt (surface layers weathered to red), reddish weathering gravel layers, and dark reddish fine sand layers (hard and dense, conforming to the shape of the lands and mountains). The deposits formed in the above order exhibit a few exceptions. (These were formed before the middle of the Diluvium.)

There are no sand layers that originated from the desert during the course of the above formation. The sand layers that originated as deserts formed between the late Neogene period and the end of the Diluvium age. Sand layers that formed before the middle of the Diluvium are reddish orange in color and were deposited in contours that conformed to the shape of the lands and mountains. In contrast to this, the sand layers formed at the end of Diluvium to the post-glacial epoch buried the land and mountain contours, with the resulting sediment surface having flat, highland contours. Many of the sand layers beneath C horizon are (orange) yellow in color (Figure 44).

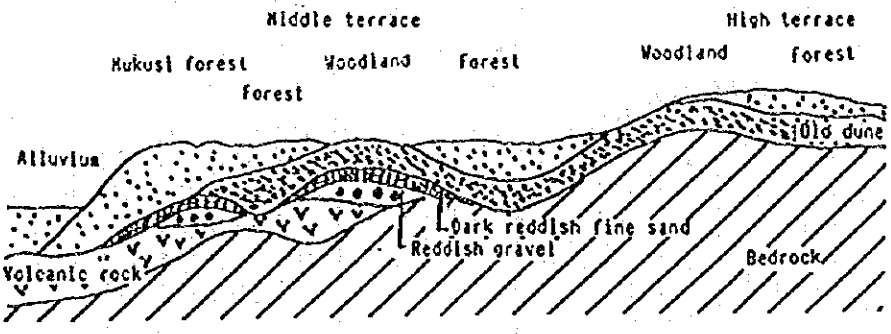


Figure 44 Schematic profile of high and middle terrace

The desert formed during the mid-Diluvium acted in a tyrannical fashion and formed a very thick sand layer. After that, in the late Diluvium, the surrounding environment was affected by a shift to a humid climate. Under the regimen of this climate and weathering system, soil was formed, weathered and eroded, becoming what are now the current soil layers. In short, it is suspected that vegetation had been recovering for a long period of time.

The region had not functioned as a desert for a long period of time. Reddish sand layers formed, conforming to the basement's shape. Dark reddish curasse was formed at the base (the surfaces of bedrock). The course of these formations is indicated by the state of reddish sand layers deposited along level lands and mountains. Once again, a desert formation occurred during the end of Diluvium to the postglacial age. The massive volume of sand that covered all land and mountain contours was comprised of reddish sand layers, which ultimately created a flat highland topography.

Since then, probably starting a few thousand years ago, the progress of the desert ceased as the climate changed to one in which vegetation could thrive, leading to the situation found today (Figure 45).

We can examine the history of two prominent desert formation episodes in the mid- to late Diluvium by studying the status of sand layers found in the geological profile. In the case of the reddish sand layers, erosion of the layers progressed in a moderate fashion in the presence of vegetation after desert progression ceased. This analysis is based on the way the sands were deposited in parallel with the concave-convex topography.

The soil layers that formed in parallel with the curved surfaces of the basement suggest that the sedimentary sand layers were being stabilized by vegetation, and, at the same time, small amounts of sand were being transferred to and settled in the area. That is to say, we can assume that as normal erosion progressed, a hilly topography was created that had a greater relief than presently seen. The big differences in color tone, grain size, and hardness and density in the sand layers give evidence to the great differences in the mechanisms of redistribution and degrees of weathering that took place during their formation. It also indicates that for a long period of time the process of sedimentation was suspended.

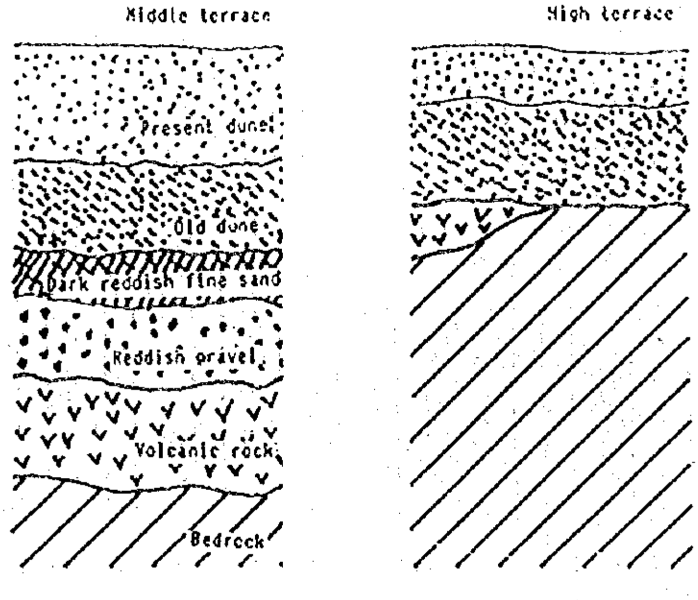


Figure 45 Schematic profile of high and middle terrace

On the other hand, the final desert formation (end of Diluvium to early post-glacial age) took place in such a severe manner that the existing concave-convex topography was destroyed and buried. There was no evidence found that vegetation resisted the sand layer deposits during the time. This clearly indicates that not only large quantities of aeolian sand were transferred from the adjacent Kalahari desert, but that the region itself was in a desert state. As the present period approached, climate conditions again changed, with heavy rainfall patterns emerging causing desert formation activity to cease. To date, this latest climate characteristic has remained unchanged, so the recent period has witnessed a recovery of greenery in the region.

As to whether these conditions will continue, there has not been enough phenomena uncovered or information collected to make such a prediction. According to the memories of local elders, both the discharge of the Zambezi River and its tributaries has been steadily decreasing over the past decade. This indicates that rainy season precipitation has been decreasing. It is unknown, but worrisome, as to whether the climate is going to lead directly to desert conditions. [A few decades ago, the water level of the Zambezi River was much higher than it is today. A fork branched off the left bank of the main course near Pimbwae, about 25 km upstream from Sesheke, and ran through the Mulayi dambo. In short, the plateau located from the left bank of Zambezi River downstream to the right bank of the Loanja River (downstream from the Masese area) was presumed to be a fan.]

b. <u>Surface soil layers</u>

b1. Surface soil layers in dissected areas

In the area surrounding both banks of the Zambezi River from Sesheke to 40 km upstream, as well as the upstream areas of the Loanja and Machili Rivers, deep valleys traverse the plateaus, and hilly topographies are common. Along with the deep valley dissections through which the rivers' main channels flow, the valleys containing the small tributaries are also deep, having rather steep slopes. Soil movement in these areas seems to be intense. As a result, the distribution of yellow to gray color Kalahari sand layers is less pronounced than that found in the highland areas. More succinctly, the gray color Kalahari sand layer distributions are limited to wide, gently sloping surfaces, such as the upper surfaces of broad, ridge-shaped plateaus. In many places, orange to reddish color sand layers (base courses) are exposed. As a result, in many places the orange to reddish color sand layers, which were formed when the reddish sand layers mixed with gray sand layers, now form the surface soils.

b2. Surface soil layers of flat highland areas

As mentioned earlier, at one time or another Kalahari sand layers covered all valleys and ridges in the region. When this was examined in detail, it was found that the buried topographies have affected the soil character and color tones of surface soil layers.

At places that once were ridges of buried hills, Kalahari sand layers are either thin, or do not exist. The surface soil layers of the region are a mixture of reddish sand layers and gray sand layers, or orange to reddish sand layers. The layers are band or clod-shaped. These are old sand layers and are predominantly found buried in the highland areas.

In the rare case of a rise, one step higher than its immediate area, its surface and every other surface, whether higher or lower, including the scarp, are covered with layers of Kalahari sand. In many cases, however, the surface of the scarp and the edges of the upper hill surfaces are covered with only a thin layer of Kalahari sand.

Many mixed layers comprised of old and new sand layers, or base courses (old sand layers), were found.

c. <u>Middle to high terraces and groundwater levels in dry seasons</u>

A few middle and high terraces share groundwater (connected with the water levels of rivers) with low terraces or flood plains. However, most of the upper terraces have old, hilly terrain (with substantial relief) buried beneath them. On top of the plateaus, Kalahari sand, with a minimum thickness of 1 to 3 m to a maximum of several meters, covers the plateaus, making them flat. Therefore, the groundwater conditions under many plateaus are influenced by the buried topographies. Thus, many middle to high terraces inherently have varying groundwater tables, which also differ from low terrace tables.

In the event a middle terrace shares a groundwater table with a low terrace, the relative depth to the groundwater becomes significant. In such a circumstance, a smooth capillary climbing action to the B and C horizon, which are close to the surface layer, may be impossible. Therefore, the water-retaining capacity is a key factor in determining the soil water environment, rather than the presence of a groundwater table. In cases where topographies exist beneath layers of Kalahari sand, groundwater might be contained within the geological structure of the old topography at some places. In any event, middle to high terrace groundwater tables do not seem to maintain high water volumes in dry seasons. And, in this circumstance as well, the water-retaining capacity within the strata would be a key factor in the soil's water environment.

Frankly, the deeper the sedimentation strata, the greater the potential water storage volume on a plateau. This is an advantageous condition for Mukusi, a deep-rooted species. However, the water environment of plateaus is not quite that simple, and the reasons why will be described in the following sections.

d. <u>Water held in sand soil layers</u>

As for the water-retaining capacity of the soil layer, many places can be expected to retain stored water at a value lower than 2.7 pF in macropores during the rainy season and the 20 days immediately following the rainy season. After that, stored water, like gravitational water, gradually gets deeper and deeper. Viewed in detail, although the macroporosity is low (about 5%), the existence of stored water with a value lower than 2.7 pF can be expected for 2 to 3 months into the dry season at deep points (about 5 m) within the soil strata. Eventually, all the stored water will disappear. Thus, almost all layers are characterized by exhibiting retained water in fine pores (porosity: about 15%), with values between 2.7 pF and 4.2 pF. {Shallow-rooted species, including Mukwa, Mwangula, Mungongo, Muhonono, and Mubuyu, shed their leaves quickly when the value of groundwater near the surface drops below 2.7 pF. Then, the trees become dormant. But, deep-rooted species, such as Mukusi, can utilize the deeper water of the soil strata and, thereby, postpone dormancy for a while. If Mukusi leaves never turn color, the area is considered to have a stable reserve of water beneath the soil layer.]

e. Swamps and swampy lands

Often, at inland sites on a plateau, aquiclude layers can be found below the surface, which make sideway draining difficult and downward infiltration nearly impossible. Such places become quite wet during the rainy season.

It is not unusual to find basins or concave-shaped areas on dunes. This is also true for plateaus that are covered by Kalahari sand. At these concave-shaped places inside plateaus and concave-shaped gentle slopes, rainy seasons create wet soil conditions. The resulting swamp formation (inland dambos, flood plains, grasslands) and swampy lands (at elevations higher than swamps, and where only hygrophytic trees grow, including Muhoto, Muhonono, Mubako, Mupane) are in evidence. More precisely, at concave-shaped sites where the thickness of the Kalahari sand layer is 2 to 3 m or less, and assuming a porosity of 45%, if there is rainfall of 300 mm to 500 mm during the rainy season, then a swamp is likely to form. Moreover, at similar sites on high terraces and highlands covered by thin layers of Kalahari sand, the buried concave-shaped topographies easily trap water (Figure 46).

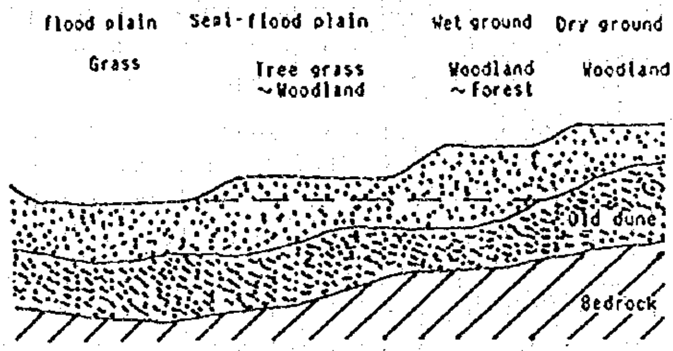


Figure 46 Schematic profile of thin sand layer

f. High surfaces around inland swamps

Even with ground adjacent to the over-humid ground mentioned before, the lower soil layers, which are 1.5 to 2.0 m higher than the over-humid ground, become overhumid during the rainy season. In comparison, the top layers are always moist, and many species grow there. In such cases, owing to perhaps plant roots rot in over-humid soil, many root systems do not travel down deeply. In this circumstance, even the deep-rooted Mukusi develops root systems to a maximum depth of 2 m. Thus, deep-rooted species cannot take advantage of their deep root systems and shed their leaves early. In addition, there is greater competition among all species for the water available down to a depth of 2 m. As a result, open forest conditions (woodlands) appear (Figure 47).

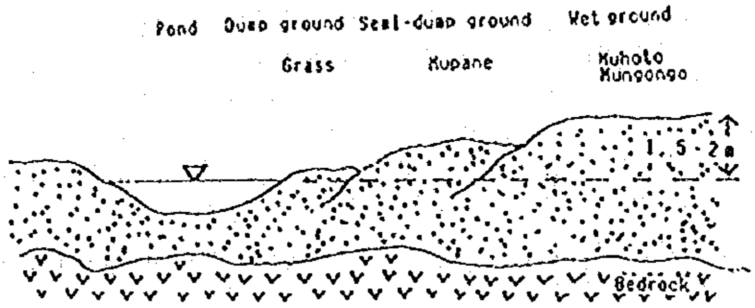


Figure 47 Schematic profile of flood plain

g. In the case of deep Kalahari sand layers

In areas where the depth of the Kalahari sand layer (gray - yellow) reaches 4~5 m down and covers old low and middle terraces, even when the lower layers reach saturation during the rainy season, it is believed that there is little chance the surface soil layer will experience an over-humid state. The water storage condition in the deep soil layers remains stable in dry seasons. And, since deep-rooted species can take advantage of deep root systems, the competition for water is alleviated. Thus, such an area can be assessed as having a high potential for growing trees. Under this condition, forests develop where leaves are shed late, and the canopy closure rate is high. The Mukusi species thrives in this type of environment.

h. Old orange to reddish sand soil layers

The relatively high elevations, such as old topographic ridges and highlands, had little chance of being covered by Kalahari sand. At many of these locations, the chief composite material of the soil is the orange to reddish sand soil layers. The reddish weathering action takes place in relatively good water drainage conditions. In the case of areas where the orange to reddish sand soil layers are being exposed at present, it is assumed that the water-retaining condition relies on the reddish soil layer's water-retaining capacity rather than the layer's relation with the swamp condition. This type of sand layer was subjected to reddish weathering activity. So it is estimated that the soil layers contain more fine grain sediment than new Kalahari sand layers and have a large water-retaining capacity per cubic meter.

Because of the residual sedimentation, it is assumed that layers 4 to 5 m in thickness were not distributed on ridges of narrow width. The distribution of thick layers of 4 to 5 m are found on many ridges with large widths and on plateau type areas. If the thickness of the sedimentation layer is substantial, say, more than 4 m, there would sufficient water storage capacity; so a high canopy closure type forest consisting of deep-rooted species mixed with others could emerge. In contrast, if the thickness of the sedimentation layer is less than 2 m, then the absolute water-retaining capacity would be inadequate. In this circumstance, a type of woodland where the competition for water overtakes the competition for light comes into being.

In many instances, a dark reddish pan was distributed beneath the flat or gently sloped red sand layers. So, if the red sand layer becomes thin, the influence of this impermeable, hard and dense layer becomes strong. In such an event, the probability of environmental degradation becomes high.

i. Subsoil

Recently (20 to 25 years ago), civil engineering for road construction was carried out in the region, and large-scale cutting, banking, and soil sampling took place. As a result, surfaces of the subsoil layers beneath the soil layers and inorganic sediment layers were excavated from deep underground and are now exposed here and there. After some 20 years, the current conditions for vegetation at these sites remain poor, and the herb survival rate is extremely low. Moreover, the growth of individual plants is not good. In places where sand layers were dissolved and discolored under the humus horizon and are now covered by only a few centimeters of soil, no herb growth was seen. The wide distribution of subsoil beneath the soil layers indicates that there was no influence of vegetation.

The site classifications and the characteristics discussed so far are summarised in Table 52.

Table 52 Site classification

Location: big-L.	Location: middle-L.	Location: small-L.	Characteristics
Flood plains and Low terraces			
	Flood plains and Low terraces along the Zambezi River		
		Low flood plains	Annual grass only can grow
		Middle flood plains	Annual grass only can grow
		High flood plains	Shallow-rooting and moisture-tolerant tree species and herbs can grow
		Low terraces	Various indigenous trees and grass can grow in the best water conditions in the study area. Soil genesis is also good. (Suitable area for trees and grass.)
	Flood plains and Low terraces along Zambezi River tributaries		
		Low flood plains	Annual grass only can grow
		Channel of flood plain in rainy season	Bare area of sand appeared due to soil erosion
		Concave and dish-like slope of diminishing gradient in the flood plain	Sedimentary condition is too hard for root elongation. In case the relative height is more than 1.5 m above the flood level, the water condition is suitable for vegetation.
		High flood plains	Moisture tolerant tree species (Mupane, etc.) can grow. Poor drainage. The middle flood plains are distributed outside the study area.
		Concave and valley-like slope of diminishing gradient	In covering buried landforms, growth of vegetation is bad and devastation by erosion is feared. In case buried landforms are absent, growth of vegetation is good.
		Low terraces	Suitable area for all kinds of indigenous trees and grass
Middle and High terraces			
	Overhumid places in back of plateau		
		Marshes	Annual grass only can grow
		Wet places	Hygrophytic trees can grow
		High places around the marsh	Many kinds of indigenous trees and grass can grow but the root system can not reach the overhumid horizon. Open forest conditions are normal.
	Thick Kalahari sand layers		Forest is dominated by Mukusi
	Distribution areas of yellow-reddish sand layer		
		Thickness of sand layer is more than 4 m	Deed-rooting tree species are distributed
		Thickness of sand layer is less than 2 m	Woodland is distributed and devastation is feared by erosion
	Bare area of subsoil layer		Entry of vegetation is difficult

*The middle flood plain is distributed outside the survey area.

3.4.3. Site characteristics and forest tree growth

The growth of trees in locations with little rainfall depend on their root systems to find those soil layers where moisture can be obtained. It is not possible for us to publish the results based on real data, since we conducted no detailed investigations on underground root systems. However, we would like to express our views from the standpoint of ecological inferences regarding matters that we observed.

(1) The depth of root systems

The depth of a root system depends on the tree species. Many deciduous species which shed leaves early in the season are known to be shallow-rooted. These include Mukwa, Mungongo, Mwangula, Muhonono, Muhamani and Mubuyu (Baobab). Those species which shed leaves late in the season are deep-rooted. (Mukusi is included among these species.) It should follow, then, that those species which shed leaves in mid-season have middle depth root systems.

The depth of tap roots is restricted by the state of the land. If there is hard bedrock not far beneath the soil layer, the depth of root systems is restricted by the depth of that bedrock. If the bedrock is soft rock (hardness factor of less than 30 mm), the root systems elongate in the rock.

The depth of root systems is also restricted by the rainy season's groundwater level. If a root system elongates below the groundwater level, the main part of the root system will probably rot during the rainy season. So root systems seem not to elongate below the highest groundwater level.

The moisture-tolerant species, including Mupane and Muhoto, retain vital roots and have longer root systems than other species. The long root systems help to store water for dry seasons, which is why these trees remain green well into the leaf-shedding season.

(2) Water-retaining capacity of soil and the state of forest tree growth

1) Water-retaining capacity of soil

Macropores in the soil hold water values of pF 2.0 to pF 2.7 during the rainy season (December - March), thereby promoting the growth of plants. After the rainy season ends, the soil looses stored water and drops to a value less than pF 2.7 (easy to absorb, gravitational water) in about 20 days. Then, during the 6- to 7- month-long dry season, plants use the water in fine pores with a value between pF 2.7 (-500 gF) and pF 4.2 (wilting point: -16,000 gF). Those trees and herbs that cannot absorb this water retained by the strong negative power shed their leaves during the dry season and enter a dormant state. The water-retaining capacity of sandy soils was estimated from the average hardness factors shown below. (Note that assumed values which are close to real values are used in this estimation.)

Depth of soil stratum - 1 m (containing A and B horizon):

Macropore - storing water capacity in rainy season	150 mm
Fine pore retaining water capacity in dry season	100 mm

Depth of soil stratum - more than 1 m (containing C horizon):

Macropore - storing water capacity in rainy season	40 mm/m
Fine pore retaining water capacity in dry season	150 mm/m

Table 53 Calculated holding water in sandy soil

Depth of soil stratum	m	1	2	3	4	5	6
Storage volume during rainy season (Aggregate)	mm	150	190	230	270	310	350
Dry season ponding volume	mm	100	250	(400)	(550)	(700)	(850)

Note: Values in parentheses refer to an groundwater level of 5 to 6 m.

2) Required transpiration of forest trees and the stand density

Assuming the required transpiration volume for a forest during the rainy season to be 500 mm, then, according to the above calculations, a stored water supply of 150 mm, a retained water supply of 100 mm, and a percolating water supply of 50 mm mean that a total water reserve of only 300 mm is available for forest trees that have root systems of less than 1 m in depth. This being the case, it is impossible for all trees in this soil to survive. Only 60% of them will survive. (300 mm/500 mm = 0.6).

When water supplies are not a problem, then the competition for light becomes the key restrictive factor to stand density (total crown closure rate), and the canopy closure rate approaches 100%. On the other hand, when the water contained in the soil is in short supply, then the competition for water between forest trees is the factor that lowers density (canopy closure). This means that even if the total spread of root systems reached 100%, the crowns in the above example forest would stay at about 60%. Those forests without full canopy closure are called woodlands. This type of forest is viewed as one in which the competition for water overrides the competition for light in terms of forest tree growth.

Forests maintain their vitality by absorbing small amounts of water during the dry season (some species keep growing). The retained water available in dry seasons is very scarce, restricting growth density.

In addition to forest stands comprised of shallow-rooted tree groups, stands with a mix of deep-rooted (assumed depth of 5 m) and shallow-rooted species and stands of deep-rooted species groups are discussed below. In these forest stands, the available water volume is generally sufficient in both rainy and dry seasons. So the competition for water is usually not a restricting factor to stand density (canopy closure rate). In this case, canopies reach nearly 100% (the total crown closure rate will exceed 100%), and the forest attains a state of completion.

However, even in the case of deep-rooted tree species, if the depths of the root systems are shallow due to high groundwater levels during rainy seasons, then the available water is limited to the stored water and retained water in the upper 1 m to 2 m portion of the soil layer. The competition for water becomes intense, and similar to a woodland, the canopy composition (stand density) thins.

If the groundwater table is at a depth of 4 to 5 m during the rainy season, then the groundwater capillary action from the table alleviates the competition for water, and the canopy closes creating a state of forest completion.

3) Groundwater level and vegetation distribution

So far, details on the "relation between the growth of vegetation and the water environment" have been described. The following sections summarize the relation between the growth of vegetation and groundwater.

a. Areas flooded during rainy seasons

These areas include major river bed systems (including dambo) and inland swamps (including flood plains). The vegetation is natural grassland.

b. Topography that is 0.5 to 1 m higher than the flood surface

These areas include high flood beds, high surfaces around the flood plains, and dry and old flood plains. The natural tree grasslands appear where Mupane, Mubako, Muhoto, and Musese grow.

c. Topography that is 1 to 3 m higher than the flood surface

These areas include low and middle terraces along with tributaries. All tree species can grow here, and forests appear.

d. Dry surfaces

Woodlands are distributed on the ridged plateaus (sometimes, old ridge type sediment layers are exposed). These are areas where clay soils (red to orange in color) with large water-retaining capacities are distributed; deep-rooted tree species also appear.

e. Plateaus 5 to 7 m above the flood surface

These areas include middle to high terraces. If the soil layer (sand layer) is thick, then forests appear in which deep-rooted species, such as Mukusi, dominate. Particularly, if the groundwater table is 4 to 6 m below the surface in dry seasons, then growing conditions are good. If the soil layer (sand layer) is thin, then woodlands appear.

f. Drought progression and changes in plant distribution

Over the past decade, the water level of the Zambezi River has been declining. Reports indicate that the water volume of tributaries has also declined, which makes sense. Many flood plains and Dambo that were distributed among terraces and within terraces are now dry, becoming land. Affected by this, changes such as a decline in groundwater levels and even the disappearance of groundwater have occurred. The distribution of vegetation has also gradually changed. Based on the progress of groundwater decline, trees have encroached upon natural grasslands, turning them to natural tree grasslands, then open woodlands. Due to the progress of drought and even the disappearance of groundwater, old forests have been denuded, becoming forest stands similar to woodlands. Some woodlands have turned to natural tree grasslands. Repeated burning is preventing herb regeneration, stopping soil recovery and accelerating the changes.

3.4.4. Land-use guidelines

In this section, we shall describe land-use methods that will be hereafter used for forest management.

(1) Suitable sites for forest land

The areas along the main channel and tributaries of the river where low terraces are distributed are the sites with the best water conditions. These areas provide the conditions suitable for the growth of all tree species, including shallow-rooted, deep-rooted, drought-tolerant and moisture-tolerant species. These areas are best suited as forest areas. Also, among middle terraces along the tributaries, some areas that are 1 to 3 m higher than flood surfaces in rainy seasons are favored with good water conditions and are also suitable for forests (premier sites for forest lands).

The middle and high terraces where thick Kalahari sand layers settled and which are more than 5 m above the flood surfaces are suitable for deep-rooted tree species forests, places where Mukusi trees will dominate. In particular, if the groundwater level is 4 m to 6 m below ground, Mukusi will grow soundly. If the Kalahari sand layers are thick, these areas will not be used for any other purpose, such as farming, because of the poor water situation. These areas are and will be suitable for use as forests.

Those forests that are currently dominated by Mukusi, or were once Mukusi dominated, have already been designated as Forest Estates. In keeping with the land-use plan based on site characteristics, such a designation represents a wise measure (a second grade site for forest lands).

In areas where the Kalahari sand layers are thin, even if the height from the flood surface is more than 5 m, the water conditions are poor and forests are continually subject to denudation. These areas are not good targets for forestation (third grade site for forest land).

In areas where the ancient orange to red sand layer sedimentation is 4 to 5 m thick, forests can be expected to grow. However, there are problems for growing forest stands due to the high percentage of fine grade sediments. If the orange to red sand layer thickness is less than 2 m, then, these areas are suitable for woodlands but not a good target for forestation (third grade site for forest land).

On high surfaces and hygrophytic areas that surround swamps within plateaus of middle to high terraces, or on high surfaces within the flood plains of low to middle terraces, mainly hygrophytic tree species grow. These areas are affected by floods, torrential rains and other extreme weather. In light of this, it must be accepted that these areas are unlikely targets as commercial timber production areas. The areas may possibly be precious resources for local villagers as supply sites for home use materials (e.g., charcoal and firewood). (A third grade site for forest land.) Although this forest land is given as a third grade site, Mupane distribution areas have the potential of being used as permanent sites for the production of forestry products and for processing, provided preparations for natural and social conditions are carried out (given later).

Note that some of the high surfaces of flood plains and high major river beds that are currently natural grasslands, natural tree grasslands, dried swamps, and low flood plains should be excluded as targets for forest lands for the time being.

(2) Potential target areas for agroforestry and farmland adjustment areas

Areas with good water environment, particularly the low terraces along the main channel of the Zambezi, where water conditions are stable throughout the year, have the best conditions for the introduction of agroforestry.

Basically, all types of trees can grow in these areas. Their bountiful water environment allows the areas to be used for agricultural purposes at the same time. However, the reality is that most of the areas have been reclaimed.

Excessive, repetitive farming practices and burning have brought land to the point of exhaustion. Currently, at many sites, even farming has been abandoned. Yet, the areas remain suitable for agroforestry development, including soil recovery through compost introduction or herb growth. The low terraces along tributaries, and the areas within middle terraces along tributaries that are 1 to 3 m above the flood table during rainy seasons have relatively good water conditions, though they remain vulnerable to each year's weather conditions. These areas are potential targets for the introduction of agroforestry.

Regarding forest management in the potential target areas for agroforestry, there is a need for adjustments in usage with farming.

For shallow-rooted tree species, the soil should have a depth of 2 to 3 m below the surface, and the water conditions and soil conditions in that depth range are important considerations. With farming, these conditions are crucial in the 1 m depth range. So, it is necessary to conduct on-site surveys at individual target sites on water and soil conditions, and their distribution scales and stability. It is also necessary to survey the horizon development process and the soil's tilling probability by experimenting with the tilling means to be used on the land. Based on survey results, policies can be decided and adjusted regarding the long-term, effective and productive use of the land. Finally, people should be mindful of the danger that the exposure of old hard and dense layers or inorganic subsoil of middle terraces presents. The environment could be devastated by such exposure, possibly making plant growth quite difficult.

Regarding the site classification already discussed, land suitable for forestry, agriculture and animal husbandry is shown in Table 54 as reference data.

Table 54 Site classes

Location (big-L. / middle-L. / small-L.)	Forest land	Farm land	Grazing land
Flood plains and Low terraces			
Flood plains and Low terraces along Zambezi River			
Low flood plains	*	*	◎
High flood plains	*	○	◎
Low terraces	1	◎	○
Flood plains and Low terraces along Zambezi River tributaries			
Low flood plains	*	*	◎
Channel of flood plains in rainy season	*	*	*
Concave and dish-like slopes of diminishing gradient in the flood plain	*	*	*
In case the relative height is more than 1.5 m	2	◎	○
High flood plains	3	○	○
Concaves and valley-like slopes of diminishing gradient			
In covering buried landforms	3	○	○
In case the covering buried landforms is absent	2	◎	○
Low terraces	1	◎	○
Middle and High terraces			
Overhumid places in back of plateau			
Marshes	*	*	◎
Wet places	*	*	◎
High places around the marsh	3	◎	○
Places of thick Kalahari sand layer	1~2	*	*
Distribution area of yellow-reddish sand layer			
Thickness of sand layer is more than 4 m	2	○	○
Thickness of sand layer is less than 2 m	3	○	○
Bare area of subsoil layer	*	*	*

(Notes) 1-3: site class, ◎: suitable land, ○: usable land, *: unsuitable land

(3) Use of land in Forest Estates

A Forest Estate is defined as a forest area according to use of the land. Therefore, forest management overrides other interests in the estate. According to the regulations, people living around a Forest Estate are allowed to harvest forest materials only after completion of prescribed procedures (application and payment). The existence of Forest Estates has not been fully understood by local people; so sometimes problems occur with farmers who want to expand their farmlands.

The Forest Estates located in the survey area are forest areas where the Mukusi species dominates or once dominated. As mentioned earlier, forests where Mukusi dominates appear in those areas where thick Kalahari sand layers exist, where the water environment in the soil surface layers is insufficient for many species of plant, and where the deep-rooted Mukusi thrives by utilizing its distinct advantage to absorb water from deep within the soil. The shallow-rooted Mwangla species are also seen in these areas. However, as described before, only 300 mm of water exists deeper than 1 m below the surface of sand layers. Therefore, the appropriate land use of Forest Estates is, and will remain, its use as forests. Furthermore, the use of Forest Estates for purposes other than forests should not be condoned.

3.4.5 General inquiry into use of land

The areas most in need of attention are farm lands, as it is here where burning management and the prevention of soil exhaustion need to addressed. The distribution of farm lands now in use is shown in Figure 41. In this Figure, most of the farm lands are located in the low terraces (including the lower part of the middle terrace scarp) that are found along the main stream of Zambezi River, the low terraces distributed along the tributaries, and at a height of 1 to 3 m from the flood surface, around the flood lands during the rainy season, in the middle terraces distributed along the same tributary. These areas are in the same site zones as the area subjected to agroforestry. This shows that the farmers in this area have already been selectively utilizing areas favored with water from long years of experience.

But even in the low terrace areas distributed along the main stream of the Zambezi River, areas extremely favored by the water conditions, the humic nutrient decreases and traces of abandoned farm land are conspicuous. In these farm lands, growing herbs supply humic substances through death and regeneration of high density root systems and should provide favorable conditions for the recovery of exhausted soil. But herbs compete against productive crops and, after farming, a trend harmful to herb growth is maintained. Frequent burning is a cause of anxiety as the soil exhausted by farming turns into a sand layer with a lesser nutrient content. Excessive grazing accelerates this tendency. Especially, the grazing of goats kills even the roots of herbs and rapidly accelerates the exhaustion of soil. Even in the most favorable land, the rotating cultivation cycle in soil recovery - production - soil recovery is inhibited and lower productive land is spreading. In avoiding the easy introduction of chemical fertilizers, soil recovery, with plants providing the supply of compost along with the use of herbs, is urgent. Thus, recovery is possible, even for local residents not having the funds to purchase fertilizer.

With the progression of soil exhaustion, the movement of arable land to the upper part of a hill can be read from the arable land distribution map of Figure 41. But the new place is in even worse condition. The land is influenced by the amount of a rainfall every year and soil is also relatively slow to recover. It is not regarded as land to be used for a long time. In addition, the recent trend towards dryer climates is a cause of additional uneasiness.

Recently, burning has been conducted without purpose and forest fires caused by burning have frequently occurred. For a land used as forest land, the need for burning management is extremely high. Fires kill succeeding trees and obstructs the growth of sound forests.

In a sandy layer zone, infiltration capacity is higher, and erosion from water current is not readily apparent, so soil deterioration is not conspicuous. But the sand layers destroy the nutrient-supplying mechanism through vegetation destruction. It is important not to make a poor nutrient inorganic sandy stratum appear. The phenomenon, that a sand stratum of low nutrient civil work does not allow herbs to grow in that place, seems to indicate that the important thing is to prevent the desertification of the sandy stratum zone. These are matters that require our attention.

3.4.6. Proposal for future land-use

(1) Proposal for securing farm land

In this area, both burned-out forests and soil exhaustion are progressing rapidly. Moreover, there is a trend towards dry climates and a reduction in farm products. The use of land to support residents in this area is considerable, so in the future its main use may be agriculture. Even though the study period is short, we propose a plan for the preservation of arable soil in accordance with the results of the survey.

The low terraces distributed along the main stream of the Zambezi River have a groundwater level of 5 to 7 m from the surface horizon, though the water level falls during the dry season. Soil water absorbable for the roots of plants is always retained in the B horizon and C horizon through the supply of capillary water from the groundwater level. For a wood plant or shrub having a relatively deeper root, this environment is suitable. However, A horizon (20 to 30 cm thick) composed of the surface horizon of soil has a high porosity and is in a dry condition. This indicates severe conditions for farming.

The fact that groundwater exists near the surface and connects to the water level of the main stream of Zambezi River is an extremely favorable condition for farming. The dry surface layer, however, is the problem. To overcome this problem, digging many shallow wells of 5 to 7 m and supplying water to the arable soil would make farming possible even during the dry season. The Zambezi River is a large river and the development of its low terraces is sufficiently extensive to have a scale sufficient to supply the nutrients for the area's residents. Ground water is drawn up in large quantities, and the supplied water is returned to the main stream of the Zambezi River through the ground. It does not have a bad influence on the natural environment. Also, in this case, it is natural that the management of burning, soil recovery by means of herbs, and the production and supply of compost are essential.

The high flood plain distributed along the main stream of the Zambezi River is a vast plain having a low frequency of flooding. This area, however, has a hard and steadfast soil and is difficult to plough with the farm implements that the local residents now possess. If periodical ploughing is possible through the introduction of some new power tillers, then the area can be used as suitable farm land favored with water and soil recovery powers. However, in flood years, there is a danger that harvests cannot be realized during the rainy season.

These two areas are expected to guarantee the future living standards of the residents at a comparatively small investment. Its realization is desired by the authorities and the persons concerned.

(2) Proposal for land use of flood plain

From the midstream and downstream basins of the Machili River to the midstream and downstream basins of the Loazamba River, a very large-scale flood plain can be found. As the downstream basins of these rivers are excluded from the survey areas, the full picture cannot be grasped, but its area is estimated to be 50,000 to 80,000 ha. A part of this area is submerged during the rainy season and forms a natural grassland. But in the area spared from submergence, pure forests of Mupane grow.

The use of Mupane in this area is now permitted, but it is mainly limited to poles for resident homes. As a result, only a small quantity of the smaller and medium diameter trees can be cut down. Most of the Mupane resources are in a state of preservation and cannot be used.

The reason for all the attention given to the Mupane is due to the large scale of Mupane resources; also, burning has not been carried out. It has permanence as a resource with very vigorous seeding regeneration and coppicing. It can be used as a raw material for charcoal production, and is already being used for this purpose.

Grasping the amount of Mupane resources is not the direct subject of this survey. Accordingly, its quantity can only be roughly estimated. Supposing that the area of the flood plain (includes the low flood plains of grasslands), where Mupane is distributed, is given as 50,000 ha, the utilisation cutting age is given as 20 years and the growing stock per ha is given as 10 m^3 (a conservative estimate), a perpetual supply of standing trees of 25,000 m^3 is possible. This corresponds to about two times the present cutting quantity of Mukusi.

The trend in flood plains is towards dryness, and along with this trend the distribution range too has expanded. As a means of overcoming an overall decrease in farm products production due to dryness in the survey area, an investigation into the possibility of using Mupane resources in the survey areas is proposed.

The subjects are as follows, and the points at issue for each subject to be overcome:

- Possibility of cutting trees for use as charcoal. (Barotse Royal Establishment forbids cutting trees for this purpose.)
- Possibility of opening domestic and foreign markets.
- Knowing the exact amount of resources; the possibility of managed cutting.
- Possibility of a thoroughgoing fire-prevention strategy, including the establishment of firebreaks coupled with roads for the transportation of materials.
- Possibility of introducing charcoal production using a constant charcoal kiln.
- Possibility of an organisation in which residents can participate, and the realisation of profits by the residents.

4. FOREST MANAGEMENT PLAN

The forests and woodlands of the region, primarily the Mukusi forests (Zambian teak forests) in the southwestern region of Zambia, were examined by ground surveys and observation and interpretation of aerial photographs. The information obtained from these surveys was analysed and examined. As a result, the natural state of the forests in the southwestern region of Zambia has become considerably clear. Here, based on the composition, state, and features of the forests, the results of the areas covered in the chapters up to here will be summarized and the most suitable approach for forest management will be considered. At the same time, guidelines will be given and proposals made as to necessary matters.

4.1. Region Surveyed

Zambia is a central African country located slightly south of the equator. The region surveyed this time is located in the forest belt at the southwestern portion of the country with a tropical semi-arid climate.

The Zambezi River, which runs down from the northwestern portion of Zambia (region stretching from Zaire to Angola), flows southward for a while, but when crossing Mongu and flowing a further 170 km downward approaches the region near the Kalahari desert, where it turns eastward or east-southeast and then proceeds toward the Indian Ocean. On the left bank near this bend in the river is the town of Sesheke. Nearby, the Zambezi River cuts lightly into the highland belt (relative height of within 10 to 20 m) while having a broad flood plain. The region surveyed was the approximately 500,000 ha highland areas (including the alluvial land of the tributaries of the left bank of the Zambezi River) stretching from Seshehe 120 km to the Northeast to Mulobezi.

This region mainly consists of highland areas and includes national forests (including some local) and traditional lands controlled by chiefs around the alluvial area of the tributaries cutting through it (including surrounding highlands) (see Figure 1). The Mukusi forests mainly covered in this survey are distributed widely over the former National Forest Estates, so the main region surveyed was the 120,000 ha of the Forest Estates. The other forests and woodlands were surveyed on a secondary basis.

Highland area : Medium to high terraces: 430,000 ha (67%)

Alluvial low land : Low terraces: 60,000 ha (9%), flood plains: 130,000 ha (21%)

4.2. Basic Matters Relating to Forest Improvement

4.2.1. Characteristics of Location

The southwestern region of Zambia was once a desert area in a previous geological period, but presently has changed in climate to one receiving 600 mm to 1,000 mm of rainfall in the rainy season. It is characterized by becoming a green forest belt in the rainy season. Accordingly, the region as a whole is covered by a thick layer of desert-derived sand called "Kalahari sand". In general, the image one receives when hearing a "sand layer" is of poor retention of water and poor fertility. In most cases, such land is considered a typical case of infertile land. The thick layer of sand of this region, however, has the following advantages and therefore forms an environment conducive to the growth of certain types of plants.

The generally known beach sand is composed of the quartz-like components left as residue after weathering and is characterized by a poor content of bases and other inorganic fertilizer components. The sandy particles from the desert, however, are chemically speaking unweathered rock particles, so some of it contains abundant amounts of mineral particles rich in bases. This region is one of little rainfall, so even though the environment is tropical, there is no marked weathering. Inside the sand layer where the water is held, however, there is chemical weathering of the base minerals and therefore replenishment of the inorganic nutrients.

In particular, the sand layer formed in the past had once been under a humid tropical climate in the diluvial epoch, so there was considerable weathering. The change in the base minerals caused an increase in the clay particles and in quite a few cases created properties close to those of general soil.

In general, a sand layer has little small and fine pores per unit volume (capillary action height: 1 to 5 m-5 to 100 m), so compared with ordinary soil, which is rich in silt and clay, is considered inferior in terms of a water environment. A thick sand layer, however, compensates for its low porosity by its thickness. If a sand layer is over 5 to 6 m in thickness, then overall it may be deemed to have an amount of pores superior to or at least not inferior to that of general soil (usually 1 to 1.5 m thick). In the dry season, the capillary action of water held in the deep layers moistens the surface layer, though poorly. Further, deep-rooted trees whose root systems extend down to the deep parts of the soil are able to absorb water directly.

A general soil layer, which is rich in fine grained soil, has low water infiltration, so when tens of meters from a river, generally is no longer affected by the water level of the river. A sand layer, however, features good water infiltration, so in the alluvial land along a large river, there is a ground water belt linked to the water level of the river formed even at points 2 to 3 km from the river. Accordingly, since alluvial land, even when somewhat higher low terraces, does not have that higher a relative height compared with the water level of the river, relatively low locations in all areas will hold an abundant amount of ground water, which will moisten the surface soil (sand layer) by capillary action. In some locations, there may even be overly wet ground. This region, due to the large area of the alluvial land along the river, can be said to be blessed with a good location.

4.2.2. Ecological features

Kalahari sand soil has large pores in the surface layer (30 to 50 cm), so in many cases is traversed by networks of small to fine pores. Even if there is an abundant ground water belt in the deep layers, therefore, the water cannot be expected to rise smoothly by capillary action. Further, about 1 m of the surface layer of the highland area has a high relative height from the water holding belt, so it becomes remarkably dry in the dry season. In this way, during the dry season, the level of moisture of the soil differs tremendously depending on the depth.

Plants differ greatly in the state of development of their root systems depending on their species. Due to this and to the changes in the state of dryness in the soil during the dry season, an ecosystem of the following features is assumed.

Most herbs have root systems extending to a shallow 40 cm or less, so during the dry season are not supplied with water by capillary action. Their above ground portions wither and die and their root systems either die or become dormant. In the rainy season, the root systems rapidly develop and grow. On the other hand, in flood land and overly wet land, growth is inhibited in the rainy season, but after the water is drained at the end of the rainy season, there is growth for a short period.

The depth of the root system of shallow rooted trees differs somewhat depending on the environment, but generally is from 1 to 1.5 m (as much as 2 m in deep cases). Since the surface layer of the soil is extremely dry in the dry season, these trees substantially become dormant in the dry season. Almost all the trees shed their leaves. On alluvial plains and at low terrace areas where the ground water level is close by, however, there is substantial replenishment of moisture, so the trees in quite a few cases remain continuously green even in the dry season.

Trees like the Mukusi and Muzauli which remain green year round or semi-year round are deep-rooted species. They have the ability to make direct use of the water held in the deep layers of the ground even during the dry season at locations with deep sand layers. Accordingly, even at highland regions, they continue to remain green even in the dry season. In particular, there are many cases where they remain constantly green throughout the year at locations with large water retention or at low terraces near the ground water level.

At locations where the soil is shallow and locations where the ground water level is high and which are overly wet in the rainy season, even the deep-rooted species have root systems which penetrate only shallowly. Therefore, like with shallow-rooted species, they are forced to compete for water at the surface layer of the soil. In this case, when the dry season starts, they quickly shed their leaves and enter a state of dormancy.

Even in the highland regions, at areas where the soil layer (sand layer) is deep, when deep-rooted Mukusi and shallow-rooted species intermix, it is believed that they segregate in habitat in the soil in the vertical direction, thereby easing the competition for water. Under such conditions, high stock forests with high stand densities and closed forest crowns appear. The same configuration is believed to be seen even in low terraces which are favored by moisture the year round. Conversely, in locations where even deep-rooted species are inhibited in root growth and cannot derive the benefits of their natural characteristics, such as locations of a shallow soil layer or locations where the ground water level is too shallow in the rainy season, this vertical segregation of habitats is not possible, so the competition among trees for water becomes fierce in the dry season. Accordingly, even with a composition of species similar to that of a forest, the stand density and the forest crown coverage become low and forests or woodlands with little stock appear.

In such an ecosystem, evergreen or semi-evergreen saplings (young trees) have to have root systems which grow by at least 1 m during the rainy season or else will not be able to secure water in the dry season and will die. Cultivation of seedlings of such deep-rooted young trees, however, is technically difficult at the present time and therefore the practice has been for reforestation by direct sowing.

4.2.3. State of stand stock and causes of destruction

The survey on stands revealed that the greatest stock in the region was of over 250 m^3/ha. The standard stand stock for a healthy condition was, however, estimated to be about 200 m^3/ha at Site I.

In the beginning, the survey on resources was commenced with the assumption that forests of such stock accounted for the majority of the 120,000 ha of the National Forest Estate, but as the survey progressed, it was learned that there has been remarkable forest destruction. Table 55 shows the stock and area of forests by species as calculated from the totals of the inventory books obtained by this survey. From the figures in the table, it is clear that the stock and area of stands which can realistically be utilized are extremely small.

Here, if forests with stocks per ha of over 75 m^3/ha are defined as cuttable stands, then the area would be just about 32,000 ha (25%) of the 120,000 ha of the National Forest Estate. The average stock per ha is a small 156 m^3/ha as well (80% of standard).

Even if the standard is lowered and the area of the parts of the National Forest Estate with forest or woodland ecologies is counted, the result would be only 64,000 ha (about 52%). The average stock per ha would be 104 m^3/ha or just about 52% of the standard stock. Further, if the average stock in the entire National Forest Estate including deforested areas (but excluding plain grasslands) is counted, the figure would become an even lower 55 m^3/ha (28%).

In a forest with a high forest crown closure, in stands with a high volume occupancy and closed forest crowns, Mukusi is intermixed at a rate of about 55% (in ideal standard stands, estimated to account for 80%), but in stands with a low degree of closure, it is intermixed at a rate of less than 50%.

At the present time, of the cuttable stands of about 32,000 ha, the total stock is about 4.95 million m³, of which Mukusi accounts for about 2.67 million m³. If this stock can be obtained in 80 to 100 years, the annual growth (yieldable volume) can be roughly estimated to be 50,000 to 60,000 m³/year for all species and 27,000 to 33,000 m³/year for Mukusi. Since the current demand for Mukusi logs is about 6,500 m³/year, if the rate of use of standing trees is 50%, there would be a cutting demand volume of 13,000 to 14,000 m³/year in terms of standing tree volume. This demand is under the maximum allowable level even now with advancing forest destruction.

Normally, excessive cutting is mentioned as the cause of forest destruction, but as mentioned above the amount of cutting is less than the amount of growth. Even if there had been a large amount of cutting in the past compared with the present, healthy forests should have grown by more than three times the current forest volume, so the cause could not have been excessive cutting. Accordingly, the forest destruction may be considered to have progressed due to causes other than cutting. The first cause taken up here is forest fires spreading from burning.

Table 55 Forest stocks of individual forest types (National forest) (summarised from inventory books)

Forest Crown \ Clousure / Crown \ Size		D_1 20%<Cc<45% Σm³ / Σha	m³/ha	D_2 45%<Cc<70% Σm³ / Σha	m³/ha	D_3 Cc>70% Σm³ / Σha	m³/ha	Total Σm³ / Σha	m³/ha
C_3	All tree	879,165	63	1,816,328	116	3,100,720	196	5,796,213	127.6
Cd>10m	Mukusi	370,258	26.5	986,319	63	1,673,958	106	3,030,535	66.7
Site I	area	13,955ha		15,658ha		15,820ha		45,433ha	
Abailable	All tree							4,917,048	156.2
Forest	Mukusi							2,660,277	84.5
only	area							31,478ha	
C_3	All tree	69,216	42	42,735	77	29,920	136	141,871	58.6
Cd>10m	Mukusi	30,638	18.6	14,935	27	7,453	34	53,026	21.9
Site II	area	1,648ha		555ha		220ha		2,423ha	
C_2	All tree	268,520	35	165,900	60	218,875	85	653,295	50.2
6<Cd<10m	Mukusi	71,026	9.3	35,964	13	37,387	14.5	144,377	11.1
Site II	area	7,672ha		2,765ha		2,575ha		13,012ha	
C_1	All tree	29,053	17	21,398	26	21,245	32	71,695	23.9
Cd<6m	Mukusi	3,732	2.2	385	0.5	2,160	3.2	6,277	2.1
Site II	area	1,709ha		823ha		669ha		3,201ha	
Forest	All tree	1,245,954	49.9	2,046,361	96.8	3,370,760	174.8	6,663,025	104.0
Total	Mukusi	475,654	19.7	1,037,603	52.4	1,720,958	89.2	3,234,215	50.5
	area	24,984ha		19,801ha		19,284ha		64,069ha	
Abailable	All tree							4,946,968	156.1
Forest	Mukusi							2,667,730	84.2
only	area.							31,698ha	

D_1, D_2, D_3 : classified by forest crown closure.

C_1, C_2, C_3 : classified by crown size (crown diameter) of forest tree.

4.3. Cutting Yield

Even in Zambia, regions with relatively abundant rainfall, for example, the Ndola region in the Mid-North, man-made forests of pine (uniform forestation) have been formed and are already reaching harvesting age. In the southwestern region where there is little rainfall and the land is covered by Kalahari sand, there are no successful examples of man-made forests. All of the forests are natural. Accordingly, the cutting yield in this region is derived completely from natural forests.

4.3.1. Cutting method

In uniform man-made forest belts accompanied by clear cutting, if conditions such as normal layout of stands within the region are satisfied, it is considered that effort is being made to sustain the forests. That is, effort is being made to sustain forests for the region as a unit. However, within natural broad-leaved trees, regeneration is under natural conditions, so cutting has to be performed while ensuring the continued existence of seed trees or succeeding trees and therefore the selective cutting method is employed.

A look at the composition of trees among healthy broad-leaved trees, which are mainly Mukusi, shows that when the trees are classified by diameter class, the number of trees increase as the tree diameter becomes smaller. Even in the main tree group, there is a characteristic tendency for there to be fewer trees as the diameter increase. That is, when cutting and harvesting older trees in a stand, a normal composition is considered to be one where succeeding trees are successively prepared (in the form of a greater number of young trees), so a forest is sustained in units of stands. Accordingly, there is an iron rule that selective cutting be performed so as not to destroy the sustainable composition in the stands.

4.3.2. Allowable amount of cutting

Here, the rate of volume use is high with trees having a breast height diameter of 40 cm or more, so the study was conducted covering stands comprised mainly of trees of large diameters of at least 40 cm. The allowable amount of cutting, by common sense, must not be more than the growth of the stand. As explained earlier, however, the growth of a stand in the strict sense differs considerably even with stands of closed forest crowns if the age and diameter of the trees comprising the stand differ. No uniform quantitative value can be given. Still, the general trend is for the maximum stand stock to be exhibited at an average age of 80 to 100 years. After that (100 years or more), the stock declines somewhat, but a constant value is shown. Accordingly, the average growth is judged to be within the following range:

Maximum average growth $\Delta v_{max} = V/80$ (year)

Minimum average growth $\Delta v_{min} = V/100$ (year)

where, V: present stand volume (m^3/ha)

If the cutting cycle of selective cutting is Yc, the allowable amount of cutting per each cutting cycle, that is, ΔVc, is

$$\Delta Vc = Yc(V/100) \text{ to } Yc(V/80)$$

The allowable amount of cutting ΔVcm in the case of selective cutting of only Mukusi is

$$\Delta Vcm = 0.5Yc(V/100) \text{ to } 0.5Yc(V/80)$$

The suitable cutting cycle is considered to be 20 years since the cutting efficiency falls if the number of the Mukusi trees is small. The allowable amounts of cutting ΔV_{20} in 20-year cycles for stand, ΔV_{20m} for Mukusi, are

$$\Delta V_{20} = 20(V/100) \text{ to } 20(V/80) \quad \text{..............................(4.1)}$$

ΔV_{20m} = 10 (V/100) to 10 (V/80) ....(4.2)

For open forests or woodlands, a stand of $V \geq 75$ (m^3/ha) is considered as cuttable stand and the allowable amount of cutting ΔV_{20}' and ΔV_{20m}' become

ΔV_{20}' = 0.35 (V - 75) .... (4.3)

ΔV_{20m}' = 0.10 (V - 75) ....(4.4)

As a result, of the cuttable stand that is applicable, Site I D_3 C_3, D_2C_3 and Site II D_3 C_3, total about 32,000 ha.

4.3.3. Large succeeding trees to be left (Mother trees)

At the present time, the only guideline for allowable cutting is the diameter class. In this case, even if trees of a certain diameter class or more are cut, there should be no problem in ensuring tree seeds so long as a large number of trees of smaller diameters are left alive. There has been a problem in the past however where there are large diameter trees, but no small diameter trees. Under the present rules, trees of a diameter at breast height of over 30 cm may be cut, but even if this rule were observed, there is a high risk of not only succeeding trees, but also seed trees being eliminated. This situation is considered unsuitable in ensuring continuation of the forest.

The present survey found that the merchantable volume becomes higher with a diameter at breast height of over 40 cm, so raising the standard could be one means of ensuring the survival of succeeding trees. Just raising the standard, however, would leave the same problem as mentioned above, so again would not be enough.

When considering the continuation of a stand, such a diameter standard or allowable cutting is unsuitable as a standard of allowance. The question is to what extent large diameter trees (here meaning trees of diameters of at least 30 cm) able to serve as seed trees remain. Here, since the seeds of the Mukusi are poor in driftability and do not fall over that much wider a range than the spread of the tree crown (about double the spread of the crown is considered to be the limit), to maintain a rate of intermixing of at least 50%, it is considered necessary that at least 30 trees of diameters of over 30 cm (tree crown area: 90 m^2) remain per ha. Ideally, the rate of intermixing should be close to 80%. In this case, survival of at least 50 trees per ha is required. Accordingly, if 30 seed trees cannot be left standing per ha, then it is necessary to prohibit cutting or, when there are few saplings or young trees able to serve as succeeding trees, that is, fewer than 100 per ha, to reforest the stand (reforestation by direct sowing) or necessary to make reforestation in the cutover land obligatory.

Assuming a stand has a Mukusi mixing rate of 50%, it is recommended that the allowable cutting area be limited to about 10,000 ha in stands where mother trees are to be preserved.

4.3.4. Guidelines

Cutting method: Selective cutting in 20-year cycles

Allowable amount of cutting: According to formulas (4.1), (4.2), (4.3), and (4.4), the allowable amount of Mukusi should be this multiplied by the intermixing rate, that is, a standard of about 50%

Cuttable diameter of cutting of Mukusi: diameter at breast height ≥ 40 cm

Number of main trees to be left standing: At least 30 trees/ha (diameter at breast height ≥ 30 cm) should be left as seed trees for natural sowing. If this condition is not met, cutting is not allowed. Further, if the number of saplings or young trees is less than 100 ha, reforestation (reforestation by direct sowing) in the stand must be performed.

4.4. Reforestation and Management

In this region, there are large areas of forest land damaged by fire. There are extremely open stands (25,000 ha 20%) and almost treeless forest land (50,000 ha 40%) in just the National Forest Estate. Restoring these forest lands or treeless land (former forest lands) to forests once again is important in sustaining the resources and environmental protection. Further, raising the rate of intermixing of Mukusi and other useful trees in the forests is necessary as a resource measure.

4.4.1. Regeneration by natural sowing

The seeds of the Mukusi do not drift far, so seed trees are important if regeneration by natural sowing is to be expected. In healthy Mukusi mixed forests, there are about 65 to 100 trees/ha with large diameters of over 30 cm diameter at breast height and the crown coverage of Mukusi is from 55 to 70%. It appears that there has been a steady replacement of generations of trees. In the past, however, perhaps because there had been selective cutting of only Mukusi, even in considerably good forests, there appear to be many locations in which the number of Mukusi trees of large diameters of over 30 cm (DBH) has fallen to 30 to 80 trees/ha and the crown coverage has dropped to 40 to 55%. Further, if just Mukusi is selectively cut, the ratio of Mukusi in the upper story trees serving as the seed tree group will increasingly fall and their continuation will be endangered. In particular, in the past 20 to 30 years, frequent forest fires have reduced the number of succeeding trees of 30 years age or younger. This downward trend is accelerating.

At the present time, it is important to scratch the surface and take other action so that regeneration by sowing from the upper story trees continues smoothly and also take other supplementary action such as reforestation by direct sowing as discussed next.

4.4.2. Reforestation by direct sowing

Mukusi is a deep-rooted species with long vertical roots. These trees have the ability to absorb water held in the deep parts of the earth even after the end of the rainy season, so continue to remain green and grow for a while even after the start of the dry season. To deal with this situation, it is important to ensure that young trees which have sprouted during the rainy season be encouraged to grow below ground rather than grow above ground and grow deep root systems of at least 1 m by the end of the rainy season.

In the process of production of seedlings, such rapid growth of the root system is observed, but it is said that if the roots are cut to facilitate transplanting, subsequent growth of the root system is inhibited and the reforestation ends in failure. As opposed to this, the growth of the root system is not inhibited in reforestation by direct sowing, so healthy growth after sprouting can be expected.

If good quality seeds are selected and these are buried, even lightly, in the soil, there is smooth acclimation in the earth after rooting and damage to the seeds by animals can be prevented, so this is considered advantageous. In particular, this should be done in cutover land.

Reforestation of Mukusi by direct sowing would be done under shade trees as mentioned later, so the planting density would not be that high, but in view of the fact that there are fewer trees of less than 30 years age at the present time, reforestation of at least 100 trees per ha, in extreme cases, about 400 trees per ha, is envisioned.

4.4.3. Planting of seedlings

Transplanting and establishment of seedlings with long root systems without cutting is technically difficult, so production of Mukusi seedlings has not been successful. However, if a special method of shoot growth is devised, such as sowing simultaneous with the start of the rainy season, growing for a short time as pot seedlings, then planting early at a stage where the root system is less than 20 cm in length, then it might be possible to overcome these problems.

Mukusi is a unique species adapted to a special environment of thick sand, so creative thinking is important when growing the seedlings.

As explained later, a certain amount of shading is necessary for saplings or young trees of Mukusi to achieve smooth growth. To create the preceding trees necessary for the creation of this shaded environment, it is necessary not only to directly ensure the growth of Mukusi seedlings, but also to grow seedlings of intolerant species able to withstand simple forestation.

Compared with Mukusi, Mukwa and other intolerant deciduous species are shallow rooted, so the seedlings are considered easy to raise and easy to plant. Systemisation of the technology is desirable.

4.4.4. Protection of young trees and saplings

The new leaves of young trees and saplings are favorite foods of animals, so are considered remarkably susceptible to animal damage. It is important to lighten this damage. This survey, however, did not attempt to learn about this situation, so this is only mentioned as a pending issue.

Seen overall, however, the cause of the greatest damage to young trees and saplings may be considered to be forest fires caused by burning.

4.4.5. Preceding reforestation

As a result of a survey of the state of growth of young trees at different areas, it was found that in Mukusi forests with normal states of growth, there were more trees the smaller the diameter class. This was interpreted to mean that saplings sprout and grow in the forests and form a group of succeeding trees. That is, this shows that when the trees are young or saplings, leaving aside the strong shading, they grow healthily under the crowns of upper storey trees and middle storey trees. Mukusi is a semi-shade bare (tolerant) species in its sapling and young tree years and is believed to change to a intolerant dominant trees when it reaches the stage of an adult tree (40 to 50 years or more). This trend is a general one seen in trees forming climaxes in different climates. Mukusi is judged to be a similar species.

It is known that species of trees which favor a shaded environment in their young years do not exhibit a healthy growth of leaves under an environment exposed to direct sunlight and therefore there tends to be inferior growth of height and diameter. This is believed to be the reason why the growth of the trees in Mukusi land reforested by direct sowing in the past has been inferior to the growth of Mukusi under natural conditions. The fact that trees planted near existing large trees and the medium and lower storey trees in the stands grow well while trees planted in open areas exposed to sunlight at all times wither at the tops and have trouble growing is considered to be an example of this.

In the Forest Estates, over 40% of the land had lost almost all forest crown coverage and became treeless or else had become extremely open due to forest fires. These were all environments with strong direct sunlight. When trying to restore forests in such denuded areas, it is impossible to introduce species forming climaxes directly in view of the light environment, so first it is crucial to introduce intolerant species and then, after a certain level of shaded environment is formed, introduce Mukusi and other climax species. The root systems of intolerant species are shallow, while the root systems of Mukusi are deep from the young years, so even if growing later, there should be no friction with preceding species in terms of competition over water. Accordingly, so long as there are no extremely heavy shading conditions, it is not anticipated that there would be any obstacle in growth.

Note that the shading requirement of saplings spoken of here does not mean a resistance to shading enabling the saplings to grow even when suppressed by herbs or bushes. When suppressed by herbs or bushes, it is crucial to quickly remove the herbs and bushes even in the case of shade species.

Here, in some locations, reforestation is necessary by growing seedlings of intolerant species and by planting of the same etc., but at the present time the idea of first growing forests of such intolerant species has not become established, so the technology is not perfected yet. Accordingly, it is crucial to survey the ecological characteristics of Mukusi in its young years to confirm its properties and to clarify the composition of the upper storey trees enabling smooth growth in the forest. Specifically, it is necessary to develop technology such as a method of selecting suitable intolerant species for the composition of the preceding covering trees (nurse trees) and growing seedlings or young trees of the same, a method of planting them in forest land, and a method of tending them after planting. As for such species, if possible, a useful deciduous species like Mukwa would be preferable, but whatever the case, any shallow rooted species comprising the woodlands which do not produce dense branches and leaves would be candidates.

4.4.6. Guidelines

- There is a great possibility of strain being caused in the seed tree composition due to selective cutting of Mukusi in the forests and posing a danger to the continuation of Mukusi. It is necessary to provide technical assistance for regeneration of Mukusi by natural sowing and to artificially grow saplings in the forest by reforestation by direct sowing.
- In forest land where the forest crowns are open, increased planting of saplings and growth of succeeding trees must be promoted by reforestation of Mukusi by direct sowing.
- It is necessary to develop creative shoot growing techniques commensurate with the vertical rooting of Mukusi.
- Mukusi and other climax species are believed to be strong in nature as semi-tolerant trees when they are young and saplings. When trying to regenerate forests in treeless areas or extremely open areas where the direct sunlight is strong, it is crucial to first introduce intolerant species (species comprising wood lands such as Mukwa) and when these have matured to a certain extent and a certain extent of shaded environment is formed, then introduce Mukusi and other climax species (reforestation by direct sowing: 100 to 400 trees/ha).
- It is necessary to develop techniques for the creation of preceding covering trees.

4.5. Management of Reforestation for Forests of Different Stand Compositions

Up to now, consideration has been given to management of reforestation focusing on the continuation and regeneration of forest. In the Forest Inventory Book, the stands are classified taking note of the magnitude of their forest crown coverage (D_1, D_2, D_3), the magnitude of the size of the individual tree crowns comprising the forest crowns (C_1, C_2, C_3), and the site quality (H_1, H_2) ($C_1D_1H_2$, $C_1D_2H_2$... $C_3D_2H_1$, $C_3D_3H_1$) (see Table 55), but in this section a study will be made of the detailed management for reforestation for each individual stand classification.

a. $C_3D_3H_1$

This is a mature forest of a complete forest crown closure, a stand volume of 200 m³/ha, and site quality I. The allowable cutting volume is 40 to 50 m³/ha, corresponding to 20 to 25%, of which about 50 to 60% is Mukusi. In cases where the rate of intermixing of Mukusi is particularly low, sometimes cutting is prohibited due to the number of seed trees which should be left, but in general this constitutes a healthy forest with no such concerns.

b. $C_3D_2H_1$

This is a forest which has been opened to a forest crown closure of 50 to 70% due to cutting, forest fires, and other factors (site quality I). It is necessary to restore it to a forest with a forest crown coverage of over 80% in 30 to 50 years, so it is necessary to restrain cutting, but if the current stand volume is 120 m^3/ha, then according to formula 4.3 and formula 4.4, cutting of about 16 m^3/ha for all species and 5 m^3/ha for Mukusi is allowed. When there is a lack of saplings and young trees, reforestation is performed.

c. $C_3D_1H_1$

This is a forest destroyed by fire or other reasons, with a forest crown closure of 20 to 45%, and of a site quality I. Since the stand volume is a low 60 m^3/ha, cutting and harvesting are not performed. The goal of the management becomes solely restoring it to the healthy forest state. If the distribution of remaining high trees is uniform, even if sparse, then reforestation of Mukusi by direct sowing is possible as is, but when there are large treeless areas, it is desirable to first plant sun broad-leaved trees and later reforest by direct sowing or reforest by natural sowing.

d. $C_3D_3H_2$

This forest is of the site quality II and therefore is inferior in terms of site, but is a healthy forest with a substantially closed forest crown. The stand volume is a low 140 m^3/ha, but since it is a closed forest where no further major growth may be expected, the allowable cutting yield is anticipated to be 20 to 25% or 28 to 35 m^3/ha. (Mukusi is about 35% of same.) No special treatment is required for continuation.

e. $C_3D_2H_2$

This is a forest with a forest crown closure of a low 50 to 70% caused by forest fires and cutting. In addition, it is inferior in terms of location being a site quality II, so the stand volume is a low 75 m^3/ha and the forest is not suited for cutting and harvesting. It is crucial to keep the growth of the existing trees from being hindered so as to achieve a closed forest in 30 to 50 years. When there are few saplings or young trees in the forest, it is desirable to positively reforest it by direct sowing.

f. $C_3D_1H_2$

This is a destroyed forest with a low forest crown closure of 20 to 45%. Since the stand volume is a small 40 m^3/ha, the forest is not suited for cutting and harvesting. To increase the number of trees and stock, positive reforestation efforts are required.

g. $C_2D_3H_2$

This is a young forest which is covered by the tree crowns, but is comprised mostly of medium diameter trees (or a forest which is particularly low in site quality and is comprised of high age trees of poor growth). The stand stock itself sometimes is over the allowable level, but since the trees are small, the forest is not suitable for cutting. There is no particular need to take steps for reforestation, but full-scale cutting should be put off for several decades.

h. $C_2D_2H_2$

This is a young forest or woodland with a low forest crown closure of 50 to 70% and comprised mainly of medium diameter trees. Since the diameter class is small, it is not suitable for cutting and, further, even if left alone, it will have difficulty in growing into a healthy forest, so some auxiliary reforestation means such as reforestation by direct sowing in the forest is required.

i. $C_2D_1H_2$

This is a medium diameter class woodland of a destroyed state with a forest crown closure of 20 to 45%. Cutting is not performed and some positive reforestation measures are necessary to promote crown closure. Consideration may be given to partially reforesting by direct sowing while planting sun species.

j. $C_1D_3H_2$

This is a forest with a closed forest crown, but comprised mostly of saplings or young trees of small to medium diameter. At the present point of time, almost all of the stands are not suitable for harvesting, but if the forest is allowed to grow as is it can be expected to become a healthy forest in the future.

k. $C_1D_2H_2$

This is an incomplete forest of saplings or young trees with a forest crown closure of 50 to 70%. Due to the increase in saplings caused by natural sowing, it may grown into a healthy forest or woodland even if left alone, but some help in reforestation such as planting of sun species or reforestation by direct sowing would be desirable.

l. $C_1D_1H_2$

This is a forest with a low ratio of saplings or young trees with a forest crown closure of 20 to 45%. There is little hope of it growing into a healthy forest or woodland if left alone, so reforestation steps are necessary. This forest land, however, often is of a type which becomes overly wet in the rainy season, so it should be given a low priority.

m. $C_0D_3H_1$

This is a location which used to be a good quality forest of the site quality I in the past, but became treeless due to forest fires. If becoming a forest, it would very probably become a high stock resource supplying area, so positive reforestation is desirable. The method of reforestation and the management system are not yet established at the present time, but since close to 20% of the National Forest Estate is constituted by this, it is crucial to proceed while experimenting with them. The method for the time being should be to first plant sun species, then, after a certain extent of shaded environment has been formed (after 20 years), reforest by direct sowing.

n. $C_0D_2H_2$

This is a treeless area of the site quality II and constitutes 10% of the National Forest Estate. It is a location where reforestation and management should be encouraged on a positive basis like with the preceding type. The same is true of the management.

o. $C_0D_1H_2$

This is a location with a strong tendency toward a grassland. Afforestation is desirable while studying the site conditions such as whether the site becomes overly wet.

4.6. Soil Conservation Measures

The soil in this region is not inherently fertile by any means, but there appear to be large areas where the local inhabitants depends on the fertility of the soil for farming and raising livestock. In fact, however, there is a contradiction in that the inhabitants themselves are causing the fertility of the soil to fall by burning off land while not being aware of this. It is important that they understand the mechanism of soil formation and take steps for its conservation.

4.6.1. Basics of soil conservation

Viewed overall, the central role in maintaining and promoting the functions of the soil is played by herbs.

(1) Soil erosion and herbs

If the surface of the soil is exposed and struck by direct rainfall (including rain from the tree crowns), the infiltration structure at the surface will be destroyed and clogging caused to thereby cause a reduction in the infiltration. As a result, surface flows will occur and soil erosion will be caused. In particular, during strong rains, strong concentrated flows will occur and cause rill and gully erosion. This erosion causes a loss of the A horizon and B horizon, which are the storehouses of the soil nutrients, and further a loss of the soil as a whole.

To avoid this situation, it is necessary that the surface of the soil be covered by some sort of buffer against rain drops so as to protect the surface structure from their destructive force. This protective role is played by the layer of fallen leaves and stalks and leaves of the herbs. In the tropics where the rate of decomposition of fallen leaves is fast, the role of the herbs is particularly great.

In Zambia, this type of devastation is remarkable in the red soil belt.

(2) Soil organisms and herbs

To express the fertility of the soil, use may be made of the content of the humus at the soil surface. The humus is derived from the residue of living matter, in particular plants, but more directly is derived from the residue of root systems distributed in the soil. The fallen leaves, fallen branches, etc. supplied to the surface also may be mixed into the soil, but they are limited to the surface-most portion and their effect on the A horizon and B horizon of the soil may be considered to be small.

Here, a comparison of the root systems of the trees and herbs in the soil shows that the density of the small and fine roots of the herbs is 20 to 30 times that of the trees. Further, the root systems of herbs are shorter in lifetime, so dead systems are supplied to the humus layer on a yearly basis. The root systems of trees extend deeper than herbs and when they die help to improve the soil at the deep layers, but since they are long in lifetime do not work to improve the fertility of the soil every year.

That is, the fertility of the soil in the short term or on a yearly basis may be considered to be supported by the herbs.

(3) Surface leaching and herbs

Sandy soil is formed by rough particles, so basically has a high water infiltration. Even without covering protection of plants, it will not drop in water infiltration. Further, it tends not to suffer much from soil erosion. Therefore, with sandy soil, there is no quantitative reduction in the soil and even if devastation occurs, it does not appear to progress. However, there is progressive qualitative deterioration at the surface portion of sandy soil, though not noticeable.

If sandy soil is exposed and is struck directly by rainfall, the bases, iron, and other weathering substances and organic substances which had been held at the outside of the sand particles are leached out and a situation occurs where only the mineral-like sand particles which are poor in fertilizer content (mostly white or grey quartz) remain. If a layer of such leached out sand particles covers the surface of the soil, then even herb-like plants, which have a strong ability to proliferate, will be hindered in growth and recovery of the plant life will become difficult. Therefore, once leaching occurs, this phenomenon spreads and in some locations white layers of more than 20 cm thickness are found.

This whitening of the surface soil is accompanied with not only chemical deterioration, but also movement of fine particles freed or suspended by the leaching to the lower layers. These deposit or accumulate at locations of a depth of 30 to 50 cm to form an impermeable pan, which becomes a problem. If such a pan is formed at a relatively shallow location of the soil, then infiltration of the water to the deep parts of the soil will be inhibited even with the precious rainfall of the rainy seasons and conversely a layer of stagnant water will be formed at the surface layer to cause an overly wet state. If this situation occurs, then even if plant life regenerates and there is a recovery in intermixture of humus in the surface soil, there is a good chance that the forest will not return to a good quality. It is believed that desertification and formation of savannas occur in this manner.

4.6.2. Coexistence of herbs and trees

When forests are burned and the resultant land is used for shifting cultivation, the fertile soil formed during the forest period becomes a source of nutrition for the crops, but many people appear to believe that the humus which had served as the storehouse of the fertilizer components is created solely by the trees. The direct suppliers of the humus layer which supports the fertility is, however, as mentioned above, the herbs. If there is no undergrowth of herbs in the forest, then rich soil will not be formed.

When cultivating crops by shifting cultivation, herbs become competitors of the crops for water and nutrients, so people seem to tend strongly to view herbs adversely. Even when cultivation ends, herbs continue to be viewed adversely. It is perhaps because of this that there is frequent burning in the forests.

If the role of the herbs in supporting the fertility of the soil is understood, then the meaning of the existence of herbs on the forest floor should be viewed more importantly. Forest management from an environmental viewpoint should end up by consequence promoting of the coexistence of trees and underground.

Note that in the rainy season, if conditions are conducive to the strong regeneration and recovery of herbs, when the undergrowth has sufficiently grown, use of the above ground portion (in some cases even burning) will not obstruct the decomposition of the root systems, so human usage is not completely rejected.

4.6.3. Guidelines

Forest management from the standpoint of environmental protection aims at the coexistence of herbs and trees. Fortunately, the forests and woodlands in this region are of a type enabling sufficient coexistence with herbs even under natural conditions, so there is no particular need for more positive technical measures. However, the following is important as a negative measure:

"Forest utilisation or treatment which reduces the herbs on the forest floor should be avoided."

4.7. Fire Prevention Measures

It has become evident that almost 40% of the National Forest Estates have become treeless, that the average stock per ha in all regions is 25% of the stand value deemed standard and 50% even viewing just the forest land, and that the cause of this is all forest fires spreading from burning. Up to the previous chapter, consideration had been given to the continuation of forests by observation of suitable amounts of cutting or forest management, but if forest fires cannot be prevented, all of this patient study and action would become meaningless.

4.7.1 Herbs and burning

There is a strong tendency to set fire to any dry herbs seen. These fires frequently spread and cause forest fires.

When cultivating crops by shifting cultivation on cutover forest land, herbs are viewed as an adversary to the crops. From this viewpoint, even when not cultivating crops, perhaps because the herbs continue to be viewed adversely or perhaps because of the misunderstanding that the fertility of the soil is supported by the trees, the function of herbs in maintaining the environment is viewed lightly and there is a tendency for them to be easily eradicated.

Local residents should be made to understand that herbs are the major factors in maintaining and restoring the fertility of the soil and should be made to protect the growth of herbs in forest land, cultivated cutover land, and pastureland and in turn observe orderly burning.

4.7.2. Bushes and burning

The root systems of bushes, according to the example of temperate regions (Japan), are between those of large sized trees and herbs, but in the end fall among the class of trees. They are not as dense as those of herbs and are not as short lived as herbs. That is, bushes are evaluated as not having that great an ability to supply humus on a continual basis to the soil.

Most bushes have little value as materials for use in the lives of local residents or as fuel. Further, a feature of the bushes in dry tropical regions is the large number of species with strong thorns. Therefore, these become major obstacles to human action and in many cases rather are considered negative presences. In addition, they have stems which, while thin, are extremely tough and flexible and therefore cannot be easily eliminated by mowing.

If most bushes are species which are valueless to people and have such many defects and further are difficult to cut or clear, then burning would be understandable in the sense of eliminating them. These bushes are difficult to burn in the early part of the dry season, however, so the optimal period for their eradication by burning would be around the end of the dry season when their stems and branches are the driest. This would be one acceptable reason for burning at late periods when burning is in principle not allowed. Whatever the case, it is difficult to set fire to only bushes, so it appears that the practice is to first set fire to the herbs.

Thorny bushes are difficult and dangerous to clear even using machinery and equipment like bush cleaners, so care must be taken in trying to eradicate them.

4.7.3. Reevaluation of efficacy of burning

Various objectives are given for all of the burning including early burning method. Officially, almost all burning is for specific objectives. There seems to be a strong tendency for evaluating it in this way. In fact, however, as mentioned already, it inflicts destructive damage to the forests. From the standpoint of forest management, first priority should be assigned to suppressing it.

The practice of burning itself is a traditional one long observed in southern Africa, but it is believed to have intensified in the past 20 to 30 years. It is considered that the damage reached the national forests in the southwestern region and spread at around the same time.

Once early burning begins, a considerable amount of burning can be justified for various reasons, but this may simply reflect the fact that burning is easy and seems socially acceptable to residents. The biggest reason for the increase in fires may be considered to be the spread of devices such as matches and lighters enabling fires to be easily started into the hands of the general populace, but it is feared that the encouragement and allowance of burning by official organisations serve to incite burning when viewed from the perspective of the general populace.

In the fields of agriculture, animal husbandry, and prevention of disease, burning is actually justified and encouraged, though with restrictions. One feels that the time has come for the efficacy of this to be reassessed and a study made of how this action is perceived in the minds of the general populace. Note that the problem of burning will be studied in further detail in the chapter on the environment.

4.7.4. Guidelines

Prevention of fires in the forests basically means restriction or rectification of the burning which directly leads to forest fires. An important means for improvement is to prevent the spread of forest fires which do occur to the forests. In terms of hardware, mention may be made of improvement of fire-fighting equipment and machinery and establishment of fire breaks. These will be discussed in the next section.

4.8. Improvement of Infrastructure for Forest Management

To manage the growth and continuation of forests in a healthy state and make efficient utilisation of the same in a manner commensurate with modern society, it is necessary to improve the roads and machinery and equipment.

4.8.1. Transport vehicles and roads

To grow and cut trees in a Vast Forest Estate, it is necessary to have vehicles for transporting the equipment and personnel, vehicles for carrying the cut trees, and roads enabling passage by the vehicles.

The vehicles required are large-sized trucks for carrying the cut trees (logs) and small-sized (medium-sized) trucks for carrying equipment and personnel. Vehicles with wheels having large ground contact pressures are desired to enable driving through sand in the dry season and mud in the rainy season.

At the present time, the vehicles required for transporting the wood and for transporting personnel and equipment are provided by the sawmills. In the future, if forestation is conducted on a full-scale basis, the forest management organisations will also have to equip themselves with vehicles for transporting forestation equipment and personnel and vehicles for forest management. In concrete terms, if this project is to be realised, the vehicle type, number of vehicles, etc. will be required according to scale and need. Currently, there is a need for at least 1 or 2 jeeps.

Forest roads are established as roads having a constant high frequency of use, while work roads are established as roads used temporarily such as used only during cutting. Simple roads are mostly made by bulldozing away the root systems to clear the land, but usually in this case the surface of the roads become much lower than their surroundings. In locations which become wetlands in the rainy season, consideration may be given to constructing roads by digging up the surroundings and building up the roads in level.

When roads are not used for 2 or 3 years, shrubbery springs up to make the roads impassable. Accordingly, the 2 or 3 roads which have a very high usage frequency (total length of 50 km surrounding Mesese) are used as forest roads and are thus maintained. With regard to other forest roads, concrete plans and construction are put into effect when projects, such as silviculture, cutting, etc., are divided upon.

A road width of 5 m is considered to be suitable. Since this area has a level sandy stratum, public engineering works such as the building of asphalt and concrete roads, bridges, etc. are hardly required. Roads and can be constructed and repaired by bulldozers, so it is necessary that forest management organisations be provided with them.

4.8.2. Management roads also serving as firebreaks

When fires break out, or when a fire is strong in force, it may jump and spread over several dozen metres. In many cases, however, experience has shown that a firebreak of about 6 m width can probably stop the spread of a fire. Officially, burning is allowed in areas other than forests such as grasslands and tree plantations. This is considered in many cases to spread to the forest and cause forest fires. Accordingly, establishment of a firebreak along the boundary between the forest and other land so as to surround the forest could prevent the outbreak of forest fires.

A firebreak is a strip of no vegetation where the ground surface is exposed, so should take the same form as a road of a width of 6 m. Accordingly, if a management road of a width of 6 m is established around a forest and it is repaired every year so that bushes and herbs are prevented from encroaching upon it, it could be expected to serve as an excellent firebreak. Although the Forest Estate boundaries will be expanded by about 550 km, there is a dire need to expand by about 300 km near Sesheke and Masese.

It is desirable to introduce bulldozers as the machinery for the construction and repair of management roads serving also as firebreaks. Note that if the machinery is only for repair and management work, then use could be made of four-wheel drive vehicles to which ground scratching attachments can be affixed.

4.8.3. Forestry machinery and equipment

Ideally, high performance forestry machinery which can handle cutting, bucking, yarding, and other work all at once could be introduced, but at the present point of time there is a shortage of small forestry equipment such as hatchets, sickles, saws, axes, spades, and saw sharpeners, so these must first be augmented. Further, it is essential to first provide small sized forestry machinery such as bush cleaners and chain saws. In this region, in particular, there is marked growth of dangerous thorned bushes, so it is necessary to introduce long-handled bush cleaners to clear them away.

4.8.4. Seed storehouses

At the present time, the only technique for forest regeneration which is substantially perfected is reforestation by direct sowing. This technique has as a basic requirement the securing of good quality seeds. It is necessary to establish seed storehouses (with air-conditioning) for them.

4.8.5. Firefighting equipment

Common sense dictates that large mobile fire trucks etc. be provided, but when the area covered is vast and has no well developed road network, even a mechanically well equipped firefighting system could not be expected to function well. Effort should be concentrated in preventive measures as mentioned above.