For example, if the dominant soil unit is Haplic Arenosols and the associated soil is Gleyic Arenosols, this will be represented by the symbol ARh-ARg. Similarly, if the dominant soil unit is Orange Ferralic Arenosols and the associated soil is Yellow-orange Ferralic Arenosols, this will be represented by the symbol ARo(O)-ARo(Yo). If the dominant soil unit is Haplic Arenosols, the associated soil is Orange Ferralic Arenosols, and mixtures are Yellow-orange Ferralic Arenosols, this will be represented by the symbol ARh-ARo(O)-ARo(Yo).

Soil in the study area is mostly coarse-grained and the topography in the area is relatively gentle. Therefore, the symbol for soil texture and slope will be 1a. "-1a" is suffixed after the soil unit symbol. Because the soil texture and slope for the area are the same, the indication for the soil texture and slope has been omitted entirely.

(2) Distribution of soil type

The distribution of each soil type inside the areas where Mukusi forests are distributed is given below:

Orange Ferralic Arenosols (ARo(O)) A soil type which is the most widely distributed type inside the study area. This soil type is found in most parts of the Nalwama, Lwangula, Lonze, Kazu, Namena and Kalama forests in the Mulobezi and Machili zones in the northeast area, the Lumino forest in the central area, the Kateme, Katemazana and Zungubo Forests in the mid-west area, and the Samatela, Sisisi, Simungoma-West, Kasiki, and Monze Forests and Buhunda woodland in the southwest area. In some parts, this soil type is associated or mixed with Yellow-orange Ferralic Arenosols (ARo(Yo)).

Reddish Ferralic Arenosols (ARo(R)) are distributed in the study area in the Kanyanga and Nanga forests in the northeast area where elevation is relatively high, the Sijulu forest in the central area, the Kayumbwana, Lumbomba and Kangubu forests in the slightly lower part of the central area, and the Sichinga forest on the edge of the plateau in the southwest area.

Yellow-orange Ferralic Arenosols (ARo(Yo)) are distributed in the study area in the Mululwe forest, the Samatela woodland, the Sikubingwa and Simungoma-East forests bordering the distribution area of Orange Ferralic Arenosols in the mid-west and southwest areas. In some areas, this soil type is associated or mixed with Orange Ferralic Arenosols (ARo(O)) or Haplic Arenosols (ARh).

Haplic Arenosols (ARh) are distributed in this study area in the Situmpa forest in the Machili zone of the northeast and in the Nanyota and Malavwe forests bordering the distribution area of Yellow-orange Ferralic Arenosols and Orange Ferralic Arenosols in the mid-west and southwest areas. In some parts, this soil type is associated and mixed with Orange Ferraic Arenosols or Yellow-orange Ferralic Arenosols.

Albic Arenosols (ARa) are distributed in this study area in Dambos where Mukusi forests are not distributed or in grasslands in river channel areas. A typical soil profile of this soil type is the Namakwa Dambo in the mid-west area. Albic Arenosols are distributed in various parts of dambos and river channel areas. However, this soil type is associated in most of the areas with Gleyic Arenosols (ARg).

As in Albic Arenosols, Gleyic Arenosols (ARg) are distributed in grasslands in dambos, river channel areas, plains of wide lowlands and other areas. The typical soil profile of this soil type can be found in Kangubu plain in the central area. In some parts, this soil type is associated or mixed with Albic Arenosols, but is associated with Ferralic Arenosols or Haplic Arenosols around it.

2.2.6. Overall study of results of the soil survey

The soil survey of areas with Mukusi forests showed that the main soil types in the study area are Ferralic Arenosols and Haplic Arenosols. Furthermore, Ferralic Arenosols widely distributed in the area can be classified into three subtypes in accordance with the color of the subsoil. Soil maps have been prepared based on these criteria. The soil of Mukusi forests in the highlands is partially mixed in river channel areas, dambos and plains, which are lowland areas in the study area. However, Albic Arenosols and Gleyic Arenosols are mainly distributed in these lowland areas.

Mukusi remains as the dominant species in Mukusi forests, but forests in which Mukusi trees grow in concretions are few. Many Mukusi forests have become either extinct or degenerated due to cutting in the past or to burning. Although many Mukusi forests have become woodlands, Mukusi still remain in some parts of the study area and have regenerated. For this reason, the relation between the dominance of Mukusi on one hand and soil type distribution and soil profile characteristics on the other will be studied.

At present, Mukusi forests in which Mukusi remains and is growing to some extent in concretions are in the No. 17 Nanga forest, No. 10 Kalama forest and the Botanical Reserve Area in the No. 1 Malavwe forest. (Refer to the Soil Survey Plot.) Other Mukusi Forests in which Mukusi partially remains as the dominant tree are the No. 6 Lumino, No. 9 Kayumbwana, No. 12 Samatela, No. 14 Samatela, No. 15 Sisisi, No. 21 Namena East, No. 22 Kazu, No. 26 Sikubingwa, No. 27 Simungoma West, No. 31 Sumungoma East, No. 35 Kasiki, No. 36 Malavwe, No. 37 Nanyota and No. 38 Mululwe Forests. Those Mukusi forests in which Mukusi and other species are both dominant species are the No. 16 Kanyanga, No. 19 Situmpa (south), No. 20 Namena West, No. 28 Katemazana, No. 29 Zungubo and No. 30 Simungoma East forests. Mukusi forests which for the most part were burned with some trees still remaining and in which Mukusi is the dominant species are the No. 33 Monze, No. 34 Sichinga forest and No. 32 Buhunda woodlands. Those forests that are classified as Mukusi forests in which Mukusi is still remain but other species have become dominant species are No. 3 Kateme (now woodland), No. 5 Sijulu, No. 18 Situmpa (north), No. 23 Nalwama, No. 24 Lwangula forest, No. 4 Samatela and No. 13 Samatela woodlands.

Various types of soil are found in this forest land, in which Mukusi is dominant, but the correlation between the dominance of Mukusi and soil type is not clear. However, a correlation with the dominance of Mukusi can be recognized in terms of soil compactness. In particular, compact soil which is located within 50 cm from the soil surface, whose index on the soil hardness tester is higher than 25 mm and which has few coarse pores, can be found in forest land where species other than Mukusi are dominant. Soil is compact in some forest land where Mukusi is the dominant species and soil is compact in a subbase more than 100 cm below the surface. Soil in upper subbase which was compact could not be found. Mukusi remains as the dominant species in soft soils, in which entire layers are relatively coarse with an index on the soil hardness tester of 15 mm or less, and in soils which have coarse pores throughout.

During a dry season survey, compact soil with a very high soil compactness was found with an index of 28~30 mm on the soil hardness tester, at which plant root systems normally cannot grow. Soil of this nature has many capillary pores and is useful in retaining and supplying moisture during the dry season. However, roots cannot enter this soil and the growth of roots of Mukusi, which is a deep-rooting species, may be blocked. Mukusi and other deep-rooting species may be changed to shallow-rooting species or herbs.

Factors which make soil compact are believed to be migration and illuviation of fine grains (silt, clay, etc.) and minerals (iron, manganese, etc.) in the surface soil to subsoil due to progress in weathering caused by reductions in surface vegetation cover.

Observation of runoff and erosion of top soil on bare land (caused by rainfall during rainy season) as well as of fine grains containing surface humus flowing down to and illuviated on lowlands with strong force, and reddish brown sand grains being leached and changing from pale yellow to white, indicate a lowering of soil fertility, with the soil becoming infertile.

Haplic Aresonols and Yellow-orange Ferralic Arenosols are soil types that are found in Mukusi forests. Eluviation of minerals such as iron progress with these soil types. These have few soil colloids and have a low nutrition retention capability. Compared with them, iron and colloids, which are coated with sand grains of Orange Ferralic Arenosols and Reddish Ferralic Arenosols, have a nutrition retention capability that is rather high. However, soils with a high dominance of Mukusi have many coarse pores and are relatively soft and loose so that they are eroded easily by winds and water. Bare land resulting in destruction of surface vegetation degrades soil fertility. In addition to the runoff of soil nutrition and colloids, soil becomes compact due to migration and illuviation of iron and soil particles into the subsoil.

Continuous burning not only retards recovery of surface vegetation, but also deteriorates the soil, making it difficult for Mukusi to survive and regenerate.

Soil conservation should especially be taken into consideration in formulating the Forest Management Plan.

2.3. Forest Resources

The forest resources study is mainly aimed at grasping the distribution of Mukusi forests and the resources in them. Accordingly, lands subject to this study included whole areas in the Forest Estates directly managed by the forest department, in addition to the distribution of Mukusi forests. The Mukusi forest (in land-use vegetation map) and the amount of resources were defined with the preparation of the Forest Inventory Book, and these areas were taken as the subject of the study.

The area subject to the study totaled about 500,000/ ha. Although there are open woodlands, most of the tree species (excluding Mukusi) are widely distributed in closed woodlands. In the closed woodlands, some useful species such as Mukwa, Mutondo or Mubako have been utilized by fellers in the area, although on a small scale. Mukwa has a high utility value and is now designated as an important cutting tree. Also, to grasp the situation in this closed woodland, the management of future forest resources is necessary for the scope of the study.

2.3.1. Operating content of forest resources study

The operating procedures of the forest resources study are shown in the following flowchart.

To grasp the forest resources of an area of over 500,000 ha, photography interpretation and an effective use of on-site surveys are required.

The reasons for the on-site survey were two-fold: one was to measure the trunk shape so as to prepare a stand volume table; the other was to survey each circular plots/belts transect and to interpret the annual rings for data needed to prepare a crown-volume conversion table. The volume table provides the basis for the volume estimation of the forest stand for surveys at the site. The volume conversion table is used to convert the data obtained by the aerial photo interpretation into the stand volume.

In the aerial photo interpretation, the factors which made up the volume conversion table were prepared by an analysis of the data and were interpreted by using an on-site comparison to divide the different volume standing block. The results were transcribed on a mosaic photo and then on a topographic map. Using this topographic map, the areas in every block were measured and the stand volume in every block was obtained by multiplying by the stand volume per ha obtained from the volume conversion table.

After that, other block data were set aside to prepare the Forest Inventory Book. The total volume of forest resources was grasped by summing up each block volume. The map entered by block division was edited as an attached chart (a forest resources distribution map) of the Forest Inventory Book.

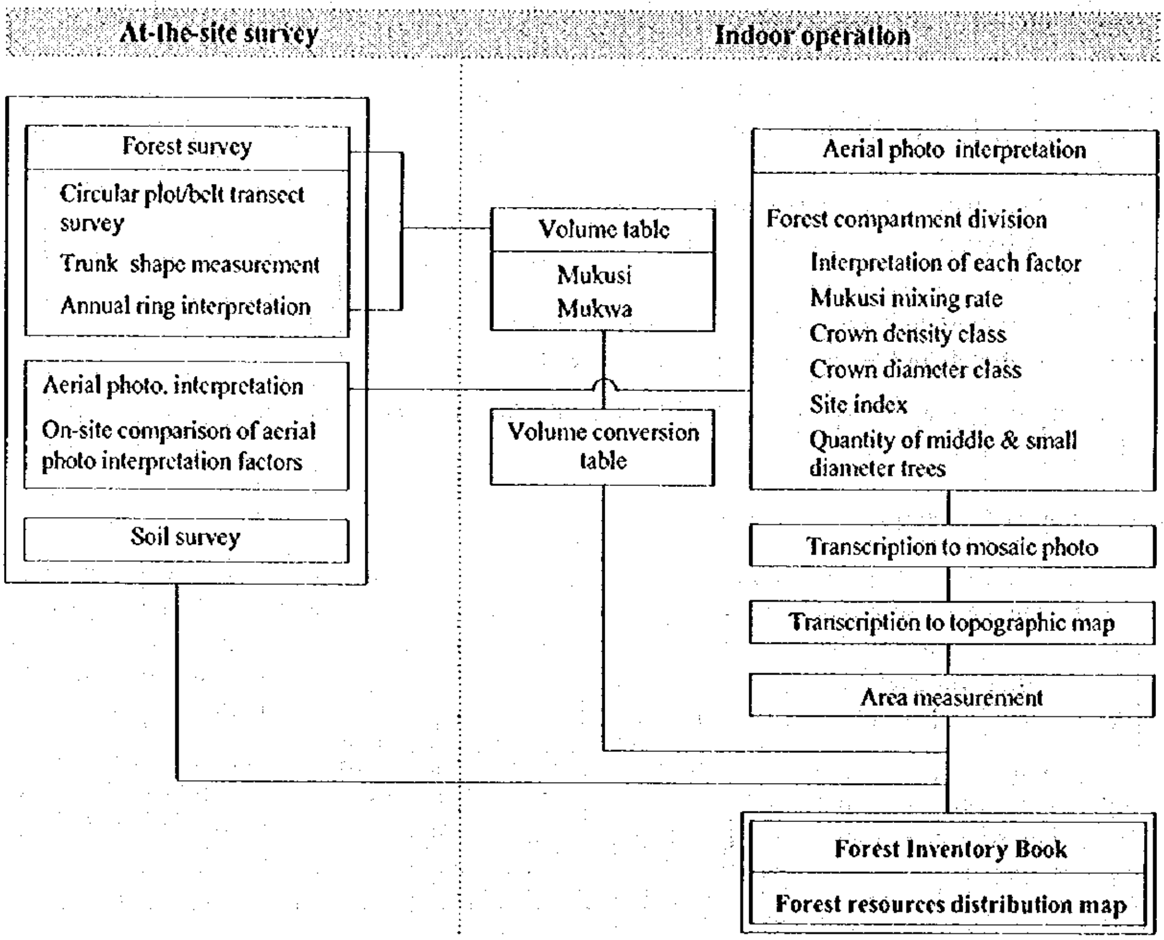


Figure 13 Flowchart of forest resources study

2.3.2. Forest survey

The conditions for setting the circular plot and belt transect are given in Table 17. For more details, refer to App. Table 8 (1), (2), (3) and to Figure 14 for study area position.

Table 17 Information on reserched plots (Total)

Forest Name	Plot No.	Location	Area(m2)	Tree Numbers High	Middle	Low	Total
Sub-Total (Belt transect)	10 plots	Forest		132	132	132	132
	4 plots	Woodland		13	29	77	119
	8 plots		<1,000	65	66	144	275
	6 plots		=1,000	80	127	233	440
	14 plots	Total		145	193	377	715
Sub-Total (circle plots)	111 plots	Forest		941	998	1,365	3,304
	1 plots	Woodland		0	14	22	36
	83 plots		500	725	837	1,172	2,734
	29 plots		1,000	216	175	215	606
	112 plots	Total		941	1,012	1,387	3,340
Total	126 plots			1,086	1,205	1,764	4,055

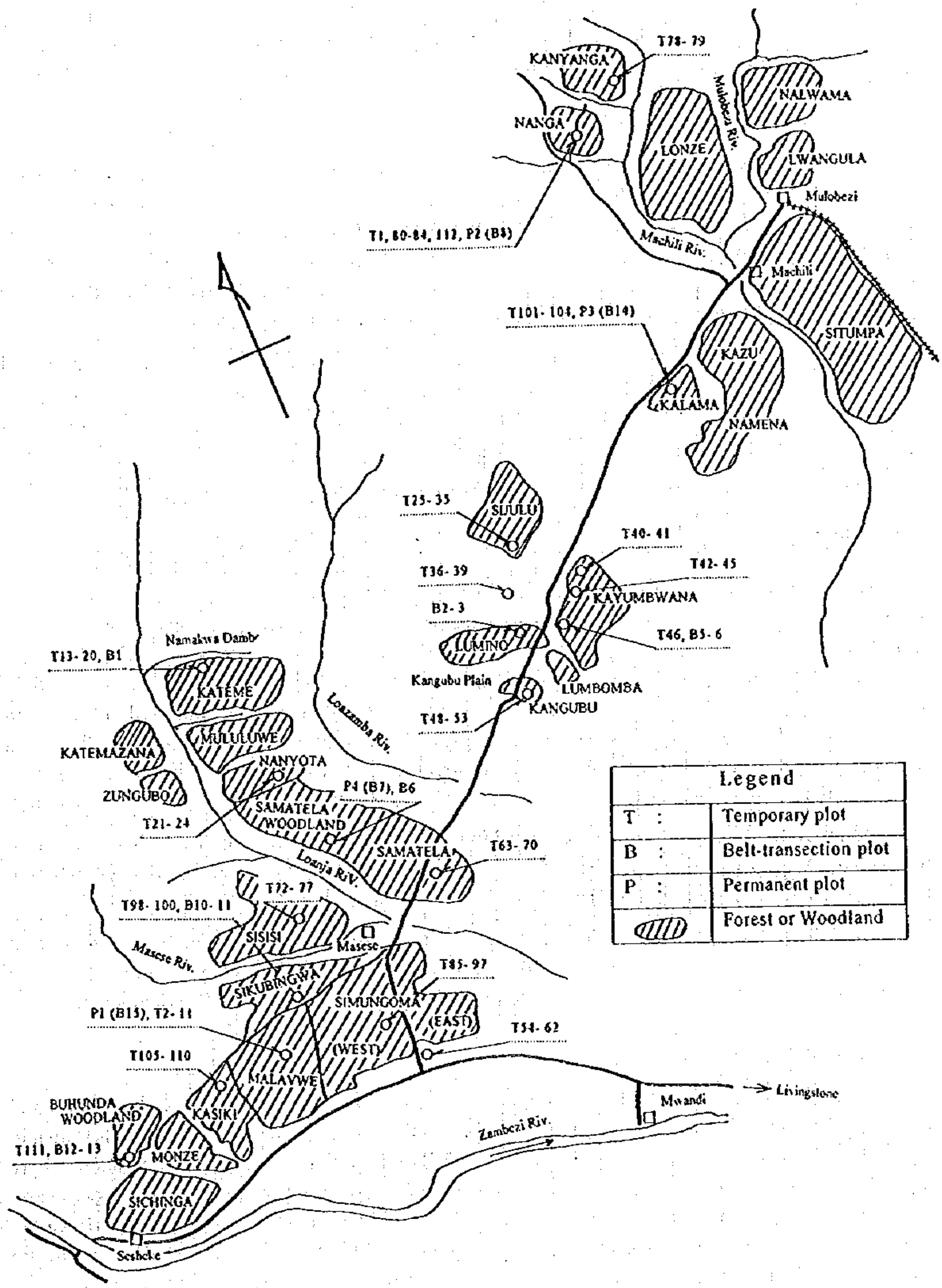


Figure 14 Plot survey areas

(1) Circular plot survey

The circular plot survey was conducted mainly to comprehend the Mukusi resources in the study area. The crown-volume conversion table is drawn up by analysing data obtained in this survey. Using this conversion table and factors for interpreting aerial photographs, the stand volume per ha for each compartment is estimated. The volume of Mukusi is estimated according to the mixing rate of Mukusi by interpreting the aerial photographs.

The target of this survey is all trees whose diameter at breast height is 6 cm or over. Included in the survey are the tree height, tree diameter at breast height, clear length, crown length, crown diameter, a sketch of the plane figure to show the standing tree position and tree crown projection, and remarks. The main tree species and number of trees were surveyed for undergrowth. The number of trees, tree height and diameter at breast height were surveyed especially for seedlings of Mukusi. The survey of seedlings would become an important element in formulating the resources management plan.

This survey was conducted in a field survey during Phases II and III. The survey was conducted at 54 plots in the first survey, 56 plots in the second survey and two plots in the third survey, totaling 112 plots. The areas of the plots were 500 m^2 (12.6 m radius) in typical forests and 1,000 m^2 (17.8 m radius) in open stands. Of the 112 plots in total, 500 m^2 plots totaled 83 and 1,000 m^2 plots, 29 plots.

App. Table 9, 10 and App. Figure 3 show an example of the circular plot survey.

(2) Belt-transect survey

The belt-transect survey was conducted to precisely determine the structure of each vegetation zone. The survey produces data, such as tree species, composition of each vegetation type, and composition of standing trees for each stratum. This data will enable a study of the succession and regeneration of Mukusi forests for use in formulating the resources management plan. During the field survey of Phases II (C) and III (A), Mukusi seedlings inside the plots were continuously observed to permit a study of the actual condition of regeneration and, the impact of burning and other factors on regeneration. The results of the belt-transect survey in forests can be used for the same purpose as those for data in the circular plot survey.

Basically, the survey items that were used in the circular plots were used here. However, new items were added in accordance with the additional purposes, such as tracing of the actual condition of regeneration and surveying of root systems.

The belt-transect survey was conducted during the field survey in Phases II and III. The number of survey plots in the belt-transect survey totaled eleven in the forests, four in woodlands and one in grasslands, totaling 16 plots. The size of the belts was 10 m in width and 30 to 100 m in length.

(3) Permanent plots

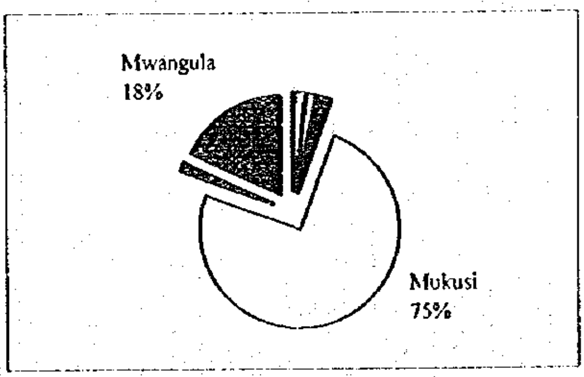
Plots B7, B8, B14, and B15 were set as permanent plots so that continuous observation and measurement could be carried out among belt transects. The setting condition of each plot is shown in App. Tables 11 to 14, App. Figure 4 and App. Figure 7. Plot B7 belt transect is set in woodlands where the Mukwa is dominant so that it can be compared with forests where the Mukusi is dominant. Seedlings can be seen in plots B8 and B14. In these plots a study of a continuously regenerated area can be made. However, B8 is the stand that has reached climax. B14 is a small stand along with tree height and breast height diameter. The regeneration condition of different stands of forest physiognomy can be traced. Plot B15 is set in a stand where trees of large diameter are numerous.

(4) Tree species and composition of stratum

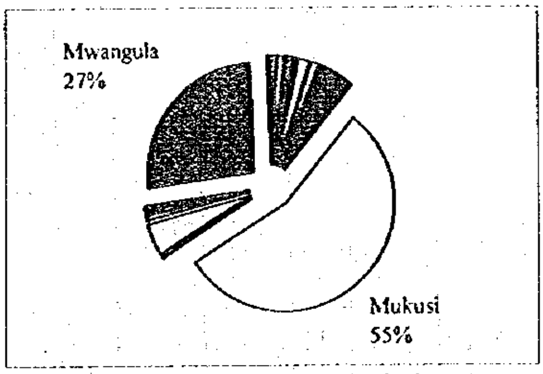
A total of 4,055 trees of 56 species in forests and woodlands were surveyed in the circular plots and belt-transect surveys. Of this total, 361 were dead trees. A total of 3,694 trees of 54 species were alive (App. Table 15).

When the forests/woodlands, dead/live trees and strata are classified, the above appears as shown in App. Table 16,17. Figures 15 and 16 show the number of live trees in the upper stratum and middle stratum, and the total number of respective forests and woodlands in graph form. The high stratum covers tree heights exceeding 12 m, the middle stratum heights exceeding 8 m (but below 12 m), and the low stratum below 8 m.

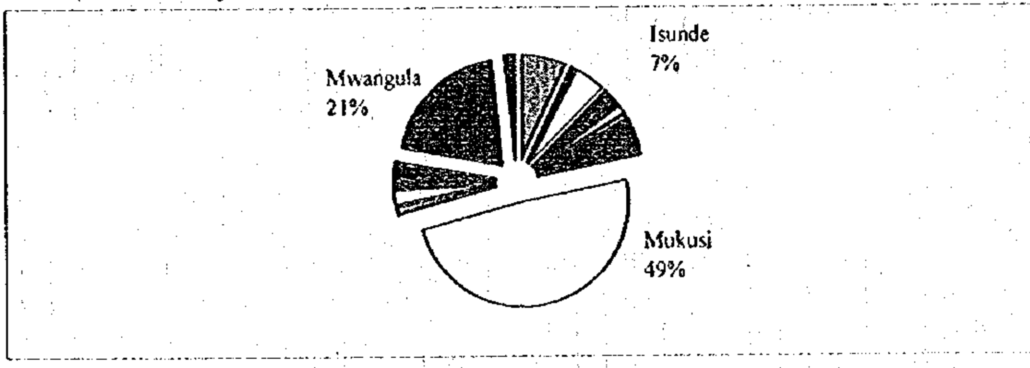
Of the live trees in forests, the Mukusi accounted for 49% (1,742 trees). When the Mwangula rate (730 trees) is added, these two species account for 70% of the total. They are followed by Isunde (250 trees, 7%) and Kangolo (173 trees, 5%) forming the lower stratum. In the woodlands, no tree species are prominently alive and Muzauli, Mukusi, Mububu, Mulya and Mukwa account for 18, 14, 9, 9 and 8%, respectively. In forests, tree species that form the high stratum are limited to two species, Mukusi and Mwangula. However, in the woodlands, various tree species are mixed. In forests, the number of trees counted is almost identical with the three strata. In woodlands, however, the number of trees counted in the lower stratum was approximately 70%, the middle stratum was 30% and the upper stratum only 10%. This indicates that overall tree heights in forests are taller than trees in woodlands.



(Live trees, high stratum, in forest)

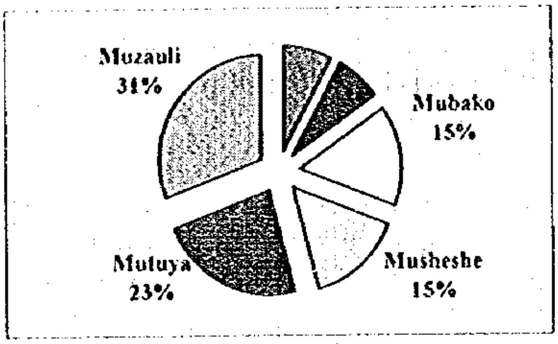


(Live trees, middle stratum, in forest)

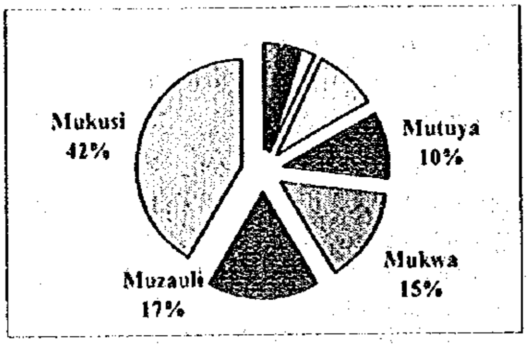


(Live trees, all strata, in forest)

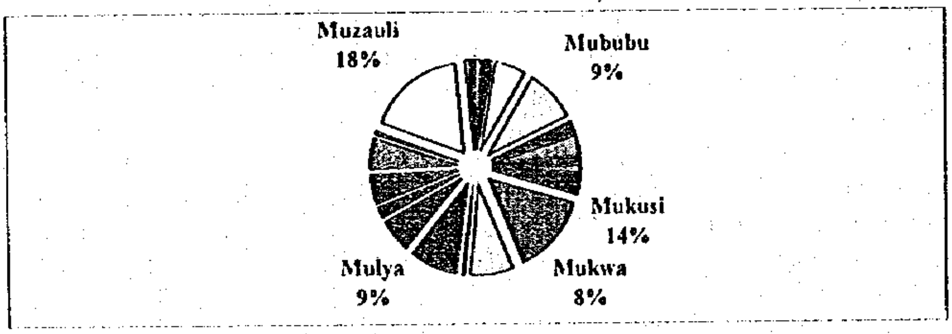
Figure 15 Number of trees according to species (Live trees in forest)



(Live trees, high stratum, in woodland)



(Live trees, middle stratum, in woodland)



(Live trees, all strata, in woodland)

Figure 16 Number of trees according to species (Live trees in woodland)

2.3.3. Preparation of volume table

A survey and analysis were conducted to prepare volume tables of useful tree species, especially Mukusi and Mukwa, and concrete numerical tables were prepared.

(1) Survey and measurement method

Generally, trees are felled and their trunks are analyzed. This was difficult with Mukusi and Mukwa, and the survey period for this analysis was short. Therefore, the analysis was made by the simple photogrammetry method.

In stem analysis, cross sections of trees that are cut to a specified length (2 m) to quantify not only the external forms, but also growth and trunk forms of the present and past (in growth stages) by measuring radii for individual tree age classes (age grade). One disadvantage with the photogrammetry method is that the stem form (external form) of only the present time can be measured. The volume and stem form coefficient at present can be calculated. However, past volumes and stem forms cannot be estimated because annual rings are not measured. Applicable forest trees have to be measured. In the case of Mukusi, interpretation of annual rings in forests is not possible and a felling analysis itself was inefficient.

1) Surveyed trees

Trees were widely selected from those forest trees which had different tree heights and different diameters at breast height. Approximately 100 Mukusi forest trees ranging 6 to 110 cm in diameter at breast height and 8 to 23 m in tree height were selected. Approximately 70 Mukwa forest trees ranging from 6 to 80 cm in diameter at breast height and 9 to 18 m in tree height were selected.

2) Photogrammetry method

A 10 m-high measurement stick was erected near a trunk and a 2 m pole was maintained horizontally, orthogonally crossing the stick at breast height. Photos were taken after setting the stick and pole to enable interpretation of the scale in photographs. Photographs were taken from a distance of approximately 30 m, and a full view of the trunk and branches is seen in one photograph. The diameter at breast height was also measured. A 35 mm AF camera with a focal distance of 38 to 135 mm was used.

3) Enlargement of photographs

The photos were enlarged to 203 x 254 mm or 254 x 305 mm on colour photographic paper. The trunk and branch diameters were measured using a micrometer by reading the graduations on the measurement stick. The photographs were taken of flat ground and the diameters of the upper parts of trees near the tree tops were measured minutely. However, measurement values were adjusted using vertical variation of the measurement stick graduation as a reference. If a silhouette floating in midair could be obtained, measurement using monochrome photographs was possible. If dark-green spaces inside the forest or canopy were found in the background, trunks could not be identified so colour photos were used.

4) Measurement

As shown in Figure 17, the diameter was measured at cross sections at every meter in the upper tree parts (G_1, G_2, G_3, G_4 ... G_n) using the base section area of DBH (G_1) (diameter) as a reference. In the case of broad-leaved trees, the tree branches into many stalks in the upper part of it.

Diameters of cross sections of these stalks located at the same distance from the breast height were also measured.

The same places can be measured in the case of a standing tree by using a diameter gauge to measure the DBH as high as the hand can reach. To measure the tree at higher levels, a memory that crossed the measurement stick orthogonally at 40 cm intervals was used. By this means, the diameter at each height was measured.

The cross section area including bark (G_b) of various cross sections were calculated based on the diameter at breast height including bark (D_b).

$$G_b = \pi \ (D_b/2)^2$$

Cross section areas of branches (for example G_{b51}, G_{b52}, G_{b53}, ... G_{b5n}) located at the same distance from the breast height G_{b1} are calculated for branch stalks. These cross section areas were totaled to calculate the equivalent cross section area (G_{b5}) and equivalent diameter (D_{b5}).

$$G_{b5} = G_{b1} + G_{b2} + G_{b3} + G_{b4} + ...$$

$$D_{b5} = 2 \ (G_{b5}/\pi)^{05}$$

The trunk volume including bark (v_b) was calculated using the sum of products obtained by multiplying the trunk cross section area (equivalent cross section area for branch) (m^2) by a unit trunk length (Δ L:1m).

$$v_b = 1.7\,G_{b1} + (G_{b2}+G_{b3}+G_{b4} + ... + G_{bn})\,\Delta L$$

If cross section areas G_1, G_2, G_3 .... Gn can be obtained after removing bark using felled trees or by other means, the true trunk volume (v) of wood after removing bark would be calculated.

$$v = 1.7\,G_1 + (G_2+G_3+G_4 + ... + G_n)\,\Delta L$$

5) **Form factor at breast height**

The basic section area of DBH including bark (G_{b1}) is calculated using the diameter at breast height including bark (D_{b1}) to calculate the basic section area of DBH of a cylinder including bark (H-G_{b1}). The breast height form factor including bark (f_b) is calculated by the ratio between the cylindrical cubic volume and the volume including bark v_b. The breast height form factor (f) is calculated by the ratio between the volume v excluding bark.

$$f_b = v_b / HG_{b1} = v_b / \pi H (D_{b1}/2)^2$$

$$f = v / HG_1 = v / \pi H (D_1/2)^2$$

If v is not available, the following relation appears to establish approximately:

$$f \fallingdotseq f_b (D_1 / D_{b1})^2$$

By minutely studying the distribution of bark thickness on trunks, the trend of $f < f_b(D_1/D_{b1})^2$ can be noticed. However, this trend was not taken into consideration in these calculations.

(2) **Estimation of volume formula**

Let us consider estimating a volume by estimating the breast height form factor (f).

1) **Form factor at breast height for Japanese forest trees**

(Examples - See Figure 18.)

A study of the breast height form factor of Japanese tree species was made to obtain a reference for the study.

Cryptomeria japonica

The form factor at breast height is affected solely by the diameter at breast height (form factor at breast height decreases as the diameter increases at breast height) but changes are not related to tree height.

Warm-temperature broad-leaved trees

The form factor at breast height is affected not only by the diameter at breast height, but also by the tree height.

The form factor decreases as the diameter at breast height increases. When the diameter becomes large (50 cm or larger), the tree height is also affected, i.e., and the form factor at breast height decreases the taller the tree height becomes.

2) **Form factor at breast height and volume formula of Mukusi**

When the breast height form factor is plotted on a graph, the form factor generally varies according to the diameter at the breast height, unlike the Japanese example of broad-leaved trees as shown in Figure 18. This can be explained by Eqs. (2) and (3). The form factor at breast height is small (0.43 ~ 0.53) with immature trees and reaches maximum, 0.6 or more, when the diameter at breast height is 25 to 30 cm. The form factor at breast height conversely decreases if the diameter increases further, reaching approximately 0.53 when the diameter is 55 cm. The coefficient drops below 0.45 with large-diameter trees that are more than 100 cm in diameter. Because of these characteristics, it was deemed necessary to consider a mathematical expression entirely different from that of the Japanese volume expression. After some trial and error execution on a graph, the following assumption was devised:

$$v = fH\pi(D_{b1}/200)^2 = fHG_{b1} \quad (1)$$

v : Volume of tree stem (m^3), H : height of tree (m)

D_{b1} : Diameter breast height (including bark) (cm)

G_{b1} : Base area of stem at breast height (including bark)

$$f = 0.53 + 0.1 \sin\{66(D_1 - 9)^{0.37} - 90\} \quad (2)$$

$\sin\theta$ is caluculated by degree (°)

If D is less than 9, the same value as that in "9" will result. If D is larger than 110, the same value as that in "110" will result.

App. Table 18(1),(2),(3) shows the volume table that was calculated using Eqs. (1) and (2).

By studying the wood form while taking the equivalent cross section into consideration, the form factor at breast height is large. It is assumed that trees grow at an equal level from their stumps to the top, compared with broad-leaved trees in Japan.

3) Form factor at breast height and volume formula for Mukwa

Figure 18 shows the relation between the form factor at breast height and diameter at breast height of Mukwa. As with the Mukusi, the form factor at breast height tends to be lower with immature forest trees, becoming larger with mature forest trees and again lower with overmature forest trees. Compared with Mukusi, the form factor values are generally large, with the maximum value nearing 45 cm. After some trial and error execution, the following volume assumption was obtained:

$$v = fH\pi(D_{b1}/200)^2 \quad (3)$$

$$f = 0.55 + 0.1 \sin\{14.4(D-10)^{0.7} - 90\} \quad (4)$$

$\sin\theta$ is caluculated by degree (°)

App. Table 19(1), (2), (3) shows the volume table calculated using Eqs. (3) and (4).

(3) Effective volume

At present, trees larger than 20 cm at the top (22 cm or more including bark) are used as wood. The volume of trunk wood with a larger diameter was calculated and the relation with the foregoing volume values was studied.

Available timber volume ratio = stem volume of trees larger than 20 cm in diameter/stand volume

Figure 19 shows the relation between the breast height diameter and utilisation rate of Mukusi. The two items have a very close relation, because the larger the diameter of the tree trunk, the higher the utilisation rate (80% or more) in the yield of lumber.

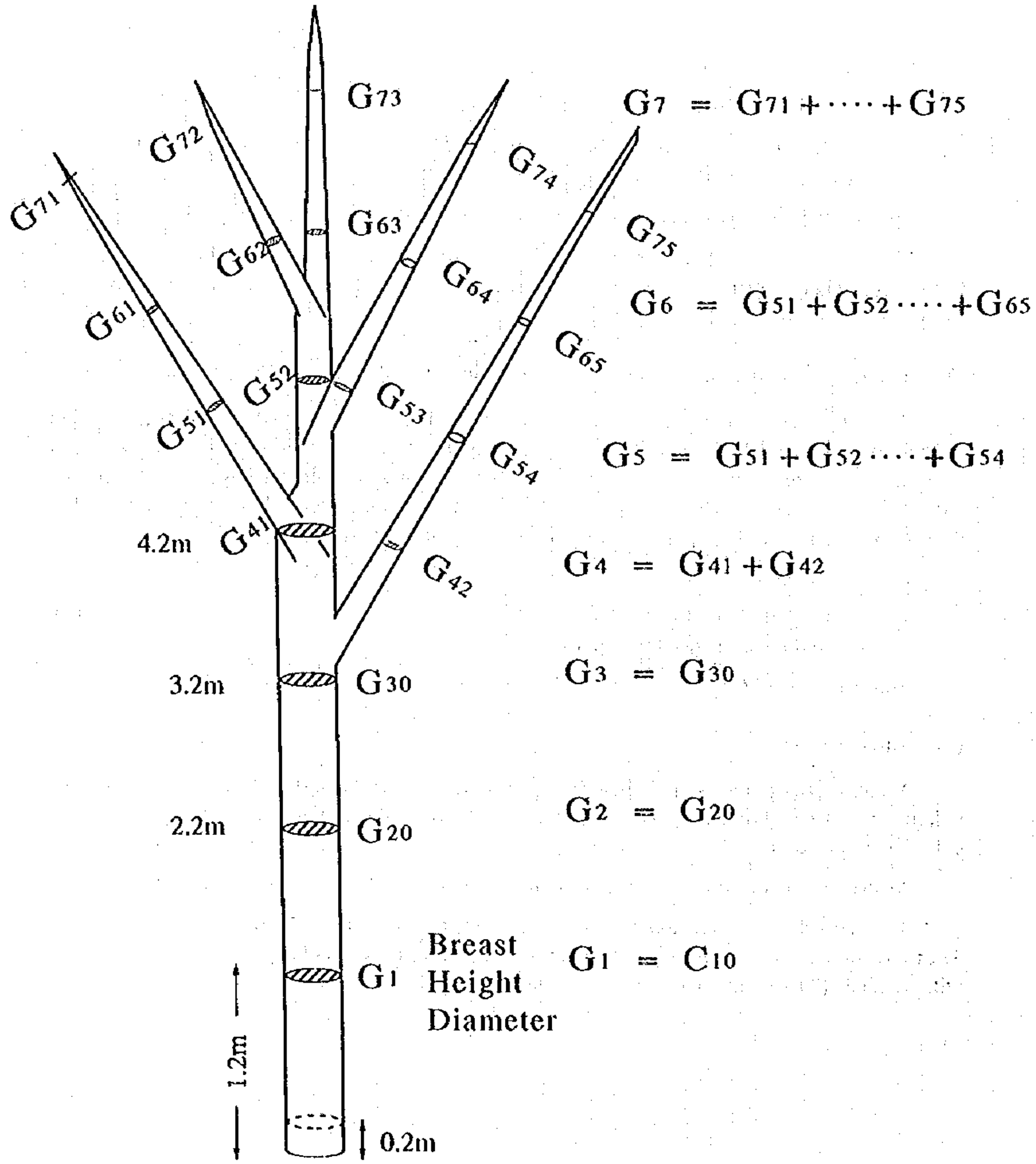


Figure 17 Measuring cross section of stem

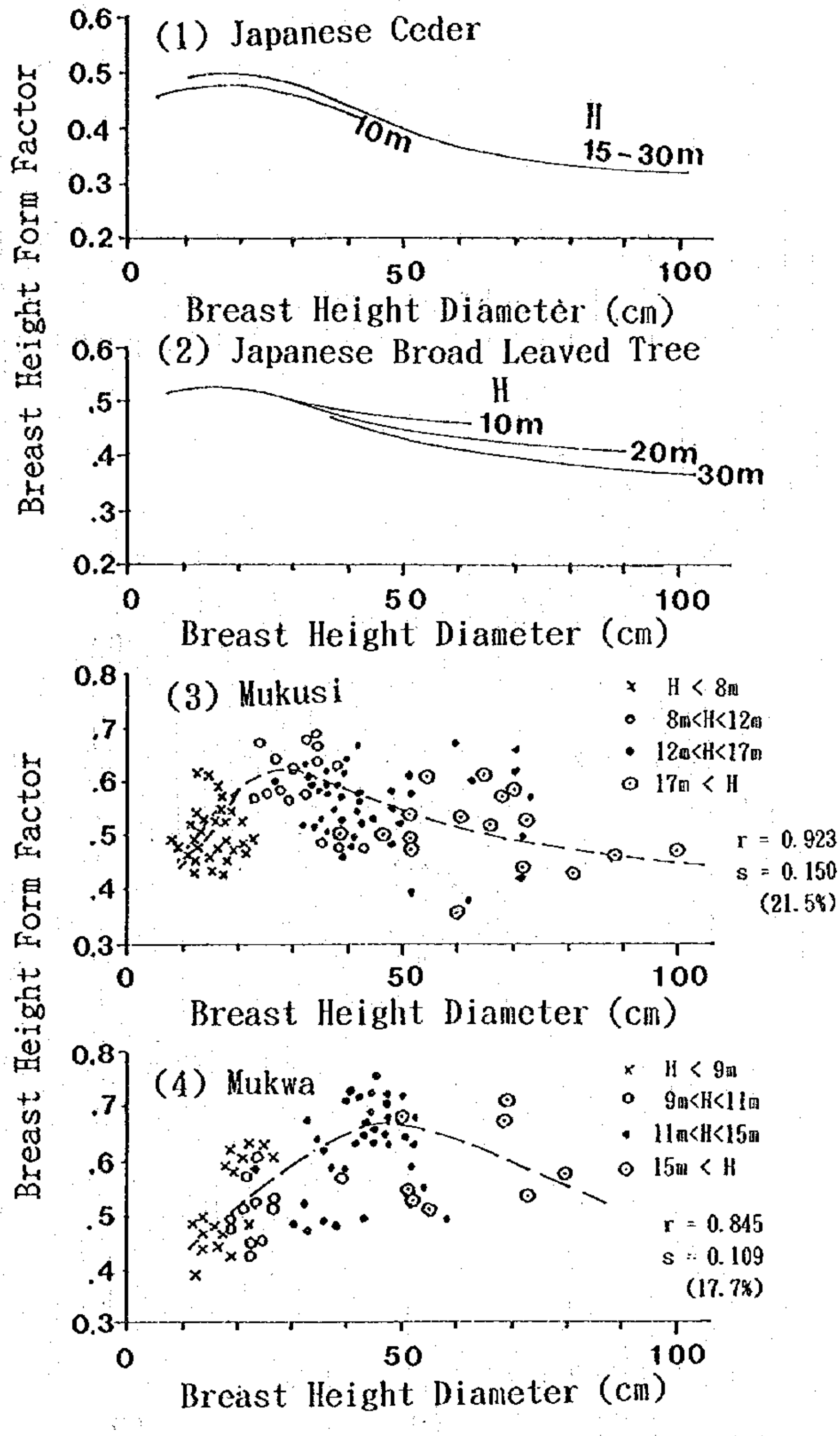
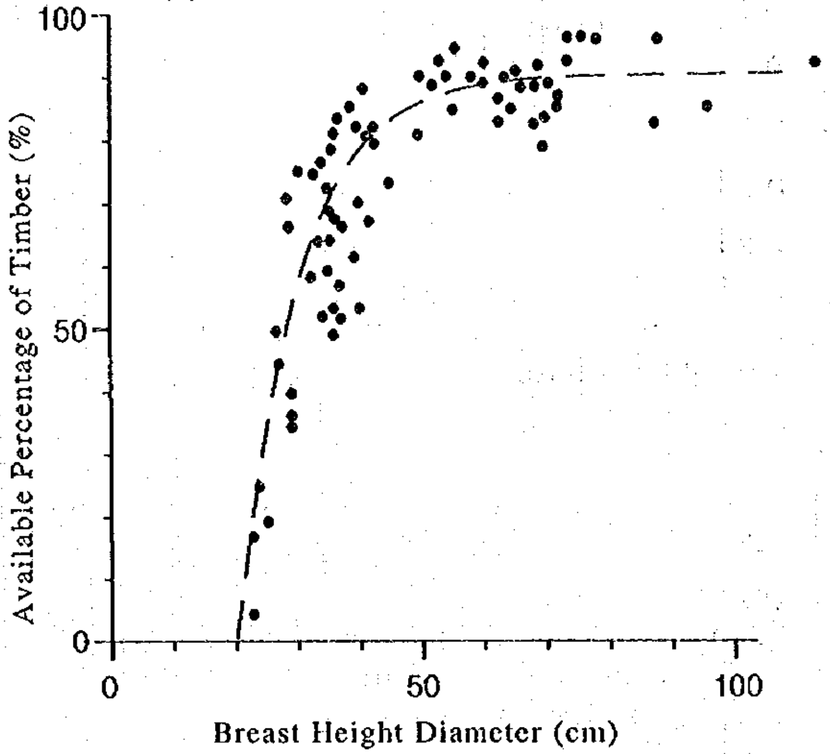


Figure 18

Relation between height of tree and breast height form factor classified by DBH

(1) Mukusi



(2) Mukwa

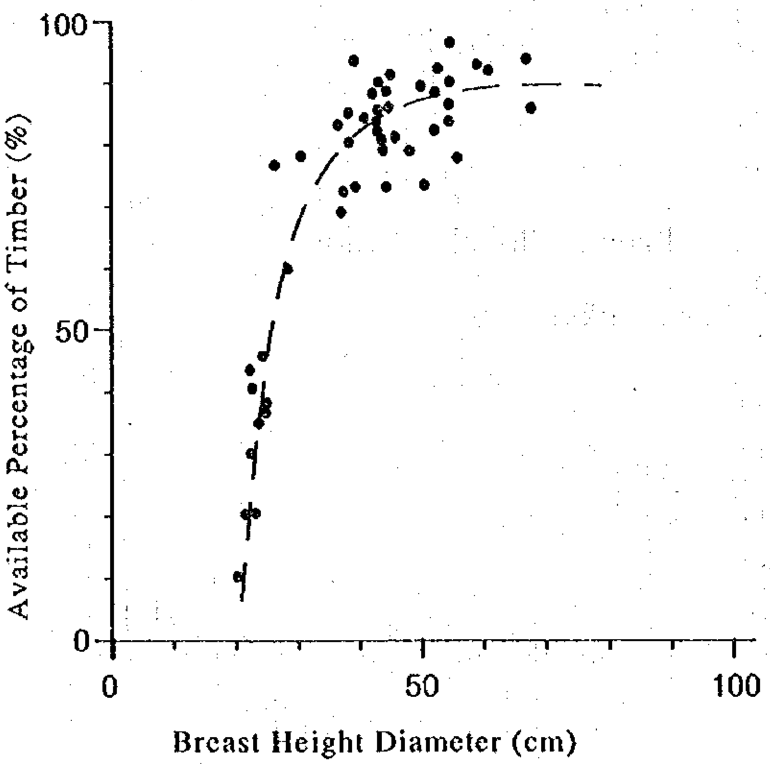


Figure 19

Relation between available ratio of timber and DBH

Conversion table from crown projection area ratio to canopy closure

2.3.4. Estimation of stand volume by crown closure composition

(1) Approach

The survey of forest resources in south-western Zambia must be performed using aerial photographs. The factors that are measured and interpreted using aerial photographs are the canopy closure, sizes of crowns making up canopies, crown density (for open forest) and other canopy (crown) factors, as well as decision of relative tree height (used in site index and forest age decisions). Compared with this, the factors that are needed in calculating forest resources (stand volume) are the tree height, diameter at breast height, mixing composition, stand density, site index and other factors. All of them cannot be read directly from aerial photographs.

To quantitatively estimate a stand volume, the relation between canopy and crown factors and forest-tree and stem factors is calculated separately by ground surveys.

Using this relation, indirect estimation from the aerial photograph information must be made.

(2) Relation between forest tree crown and stem growth

Trees grow by optical synthesis of leaves forming crowns. The amount of light reaching the leaves seems to regulate the growth. On the other hand, leaves at crowns of broad-leaved trees are made to cover surfaces of crowns with a certain thickness. It can be concluded that the quantity of leaves varies in proportion to the surface area of a crown. Crowns of broad-leaved trees, whose crowns tend to spread flatly, have a high probability of the surface area of a crown varying in proportion to the projected cross section of a crown. Therefore, the amount of light reaching the leaves, namely, growth, varies in proportion to the projected section area (plenary area) of a crown. (Takeshita, 1985)

Aside from this, in Mukusi, the relation between diameter growth and age is linear and the diameter growth of stem under natural conditions varies in proportion to the circumference of a stem.

$$\Delta G = \pi (r + \Delta r)^2 - \pi r^2 = 2\pi r \cdot \Delta r$$

G : Base area breast height
ΔG : Growth of base area per year
D : Breast height diameter
r : Breast height radius
Δr : Growth of radius : constant

Therefore, the annual increment approximately varies in proportion to the plane area of a crown.

$$2\pi r \cdot \Delta r \fallingdotseq k\,\pi C r^2$$

The base section area (πr^2) of DBH as an integrated value of the annual increment also has a close correlative relation with the crown projection area and a close correlative relation (probably an exponential curve relation near linear) with volume ($f \pi r^2 H$) has also been suggested.

The survey was conducted under this approach and the relation between the volume and crown-projection cross section area of forest trees was calculated.

Figure 20 shows a relational graph as a result of these calculations. A close correlative relation sufficient to confirm the foregoing forecast is found. A curve relation of the base section area of DBH delicately changing if the trend leave and crown in the diagram is small. If the crown scale is larger than 80 to 100 m², (crown diameter 10 to 11 m), a simple linear relation is suggested. Therefore, crown interpretation using aerial photographs needs be studied by fractionating below 100 m².

Specifically, the following three divisions were set noticing the size of the crown diameters:

	C_1	C_2	C_3
Crown diameter	1 ~ 6 m	~ 10 m	≥ 10.5 m
Crown base area	~ 18 m²	~ 80 m²	≥ 85 m²

(3) Total of crown areas and stand volume

The foregoing explanation indicates that a close correlation can be expected between the crown projection area and forest tree volume. Thus, it is possible that a close relation exists between the total crown projection area rate per unit area and forest stand volume inside the area. The total crown projection area rate per ha and stand volume was calculated for each survey plot and the relation between the two was analysed. Figure 21 plots the correlation between the total crown section area and forest stand volume.

Each point in the graph was identified as a high layer tree (H > 12 m), middle layer tree (12 m > H > 8 m) or low layer tree (8 m > H) in accordance with the height of the crown layer.

The high layer trees were divided into Site Classes I and II in accordance with their site class. A close correlation exists between these site classes. The following criterion was used in deciding the site class:

Height of a tree approximately 40 years old: Site class I > 14 to 15 m tree height > site class II

1) Conversion of total crown area to canopy closure

The crown projection area ratio is higher than 150% in the graph shown in Figure 21. It is inconceivable that the real canopy closure area ratio integrating them will exceed 100%. We are trying to estimate stem composition in a stand based on the canopy closure area ratio measured and interpreted using aerial photographs. This will require an adjustment between the canopy closure area ratio and total crown area ratio.

The reason why the total crown projection area ratio becomes large (exceeding 100%) can be explained by errors in measuring crowns, on the ground. The largest reason is that actually crowns overlap considerably vertically. According to field observation, overlapped crowns can rarely been seen in open forest stands with a canopy closure area ratio of less than 50%. If this ratio exceeds 50%, overlapped crowns start to appear in stands. The frequency of crowns overlapping is known to become high in stands with more than 70% of this ratio. It will not be rare to have values higher than 100% if crowns for individual trees are simply totaled in stands which have a high crown density.

The following conversion was made with total crown projection area ratio per ha to estimate the canopy closure area ratio.

Total crown projection area ratio by stratum : $\sum Cr = \sum \pi C m^2 / 100$ (%)

$\sum \pi C m^2$ (m²/ha) Cm : Single forest tree crown radius

Canopy closure Cc (%)

Total forest-tree crown area ratio Below 50% (Area less than 5,000 m²/ ha)

$$Cc = \sum \pi Cr / 100 \qquad (1)$$

Total forest-tree crown area ratio 50 to 150% (5,000 to 15,000 m²/ha)

$$Cc = 50 + (\sum Cr - 50)^{0.85} \quad (2)$$

Total forest-tree crown area ratio 150% or higher(15,000 m²/ha or higher)

$$Cc = 100$$

Conversion Table from Crown Projection Area Ratio to Canopy Closure

Crown projection area ratio (%)	0~40	50	60	70	80	90	100	110	120	130	140	150	160	.....
Canopy closure (%)	0~40	50	57	63	68	73	78	83	87	92	96	100	100	100

2) Estimation of stand volume by canopy closure area ratio

Eqs. (1) and (2) enable a conversion of the relation between the total crown projection area ratio and stand volume shown in Figure 21 into the relation between the canopy closure area ratio and stand volume. The relation shown in Figure 22 could be obtained by converting the correlative curves shown on the graph. The relation between them can be summarised as shown below. Using these relational formulas (3) to (6), the stand volumes were estimated based on the canopy closure area ratio measured using the aerial photographs.

(1) High layer forest trees

(1)-1 Site class I

Canopy closure 50% or less $V = 1.8C$

Canopy closure 50 to 100% $V = 90 + (1.8C - 90)^{1.125}$ (3)

V : Forest stand volume (m³/ha)
C : Canopy closure measured using aerial photographs (%)

(1)-2 Site Class II

Canopy closure 50% or less $V = 1.2C$

Canopy closure 50 to 100% $V = 60 + (1.2C - 60)^{1.16}$ (4)

(2) Middle layer tree

$$V = C \quad (5)$$

(3) Low layer tree

$$V = C^{0.8} \quad (6)$$

Table 18 summarises these relations in a table.

Table 18 Crown-volume conversion table

Crown Density %	0~5	~10	~15	~20	~25	~30	~35	~40	~45	~50	~55	~60	~65	~70	~75	~80	~85	~90	~95	~100
High Layer C3	9	18	27	36	45	54	63	72	81	90	102	116	131	146	162	179	196	213	230	248
site class I		18					63					116					196			
High Layer C3	6	12	18	24	30	36	42	48	54	60	68	78	89	100	112	124	136	149	162	176
site class II		12					42					77					136			
Middle Layer C2	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
		10					35					60					85			
Low Layer C1	4	6	9	11	13	15	17	19	21	23	25	26	28	30	32	33	35	37	38	40
		6					17					26					35			

3) Mukusi only

Using Figure 21 as a reference, the relation was calculated when Mukusi was the only species (Figure 23). Compared with the case for all tree species, the stand volume has decreased slightly from 85% to 90%. It suggests that the volume would be small for forests which are almost pure forests of Mukusi if only Mukusi is noticed.

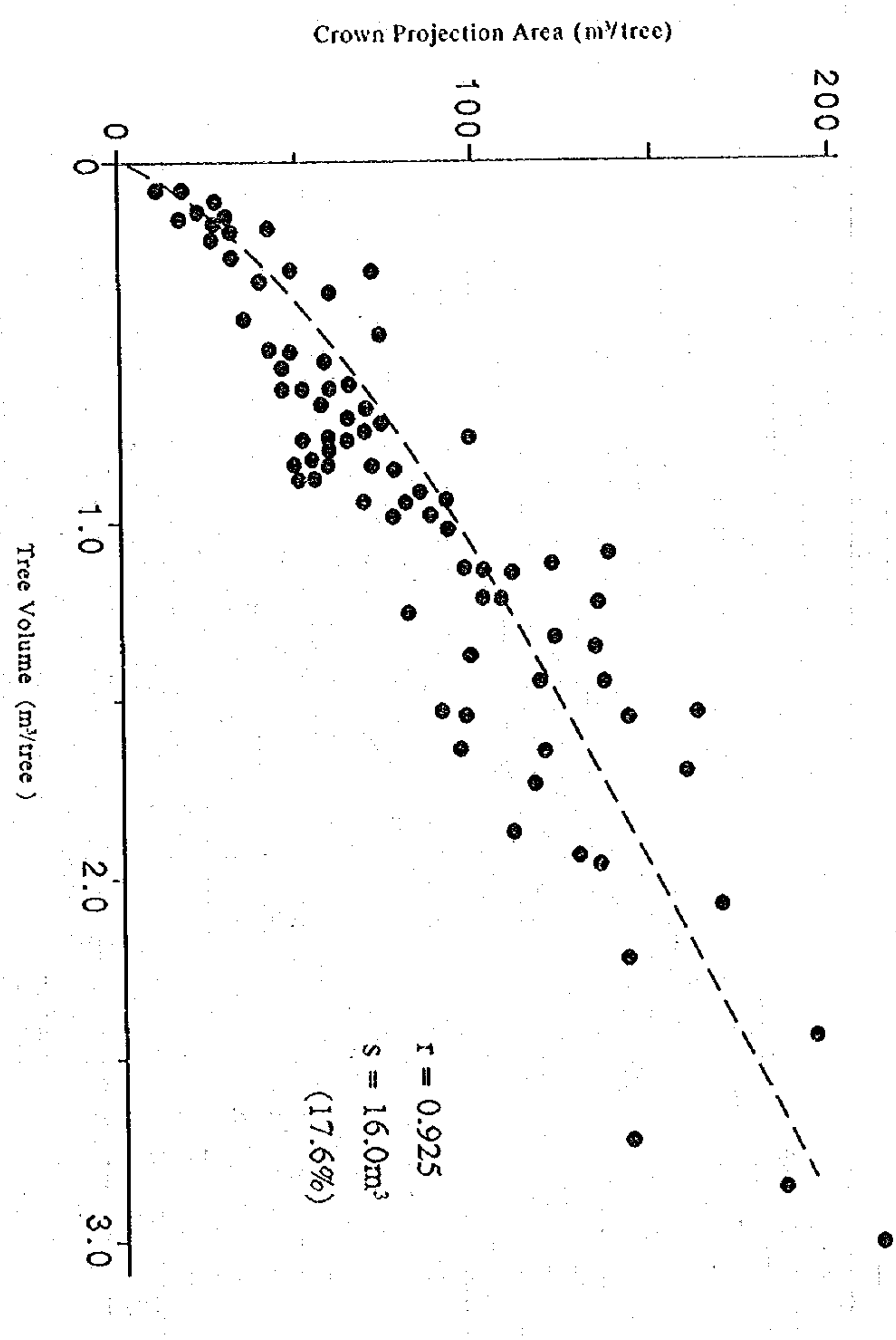


Figure 20 Relation between crown projection area and volume of tree
$r = 0.925$, $s = 16{,}0\ m^3$, (17.6%)

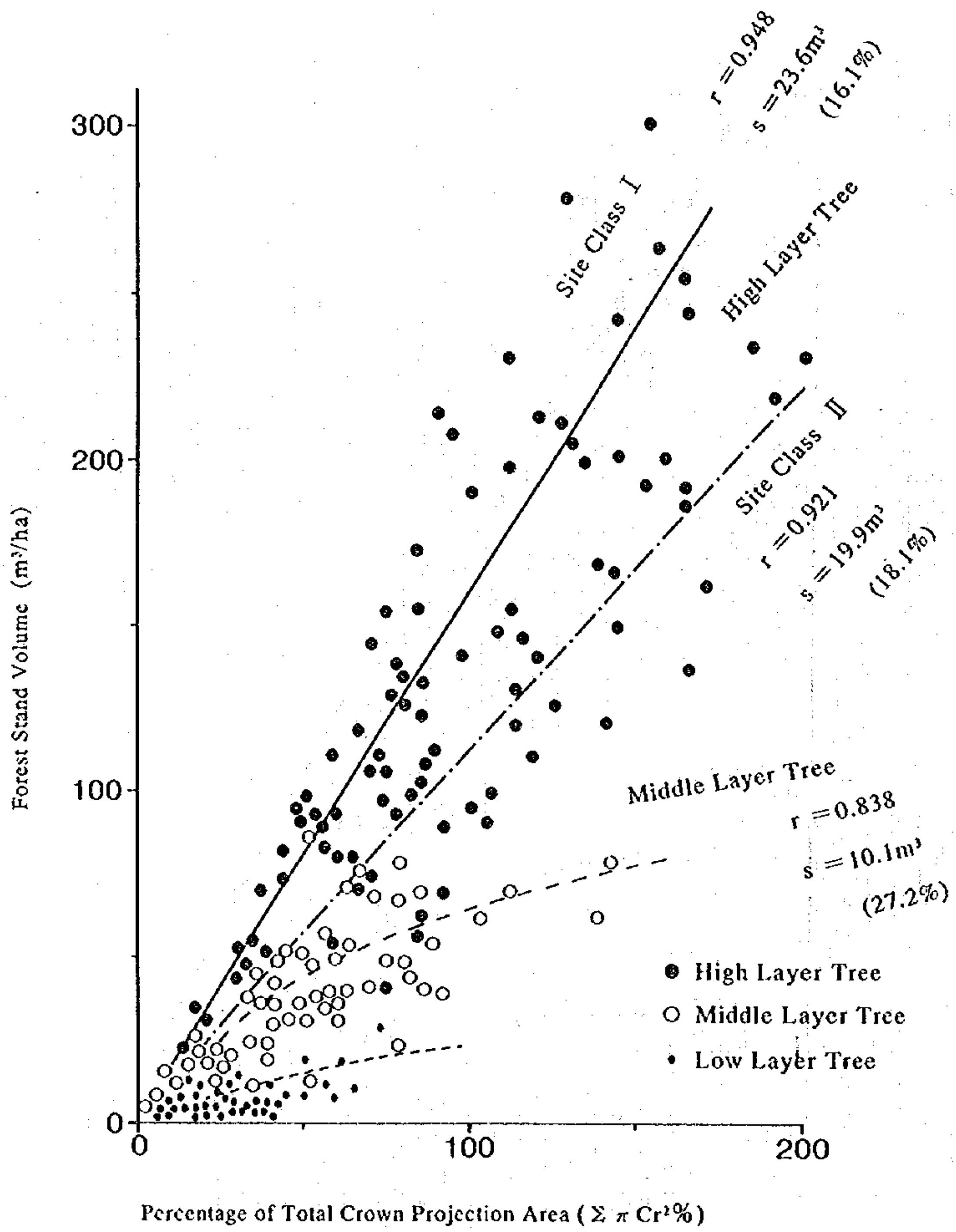


Figure 21 Relation between forest stand volume and forest crown closure

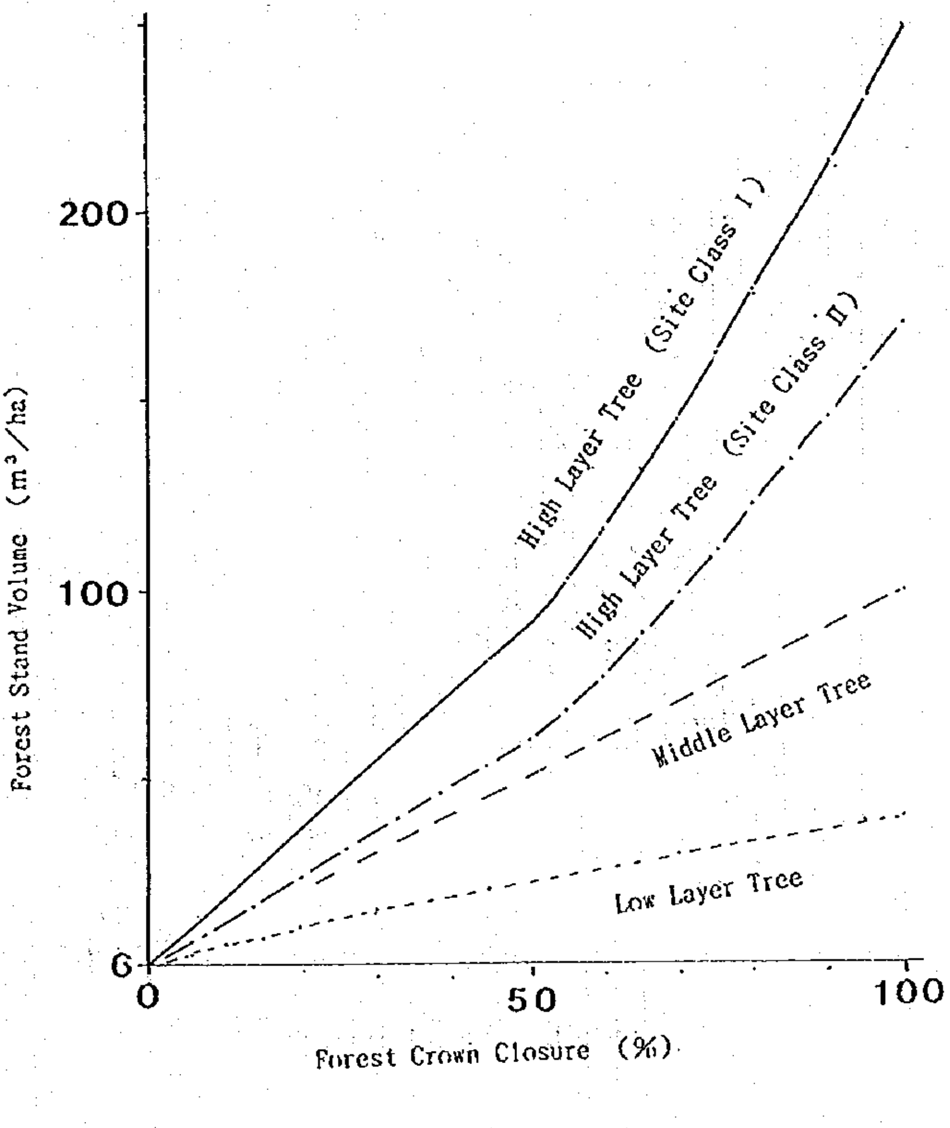


Figure 22 Conversion relation between forest crown closure and stand volume

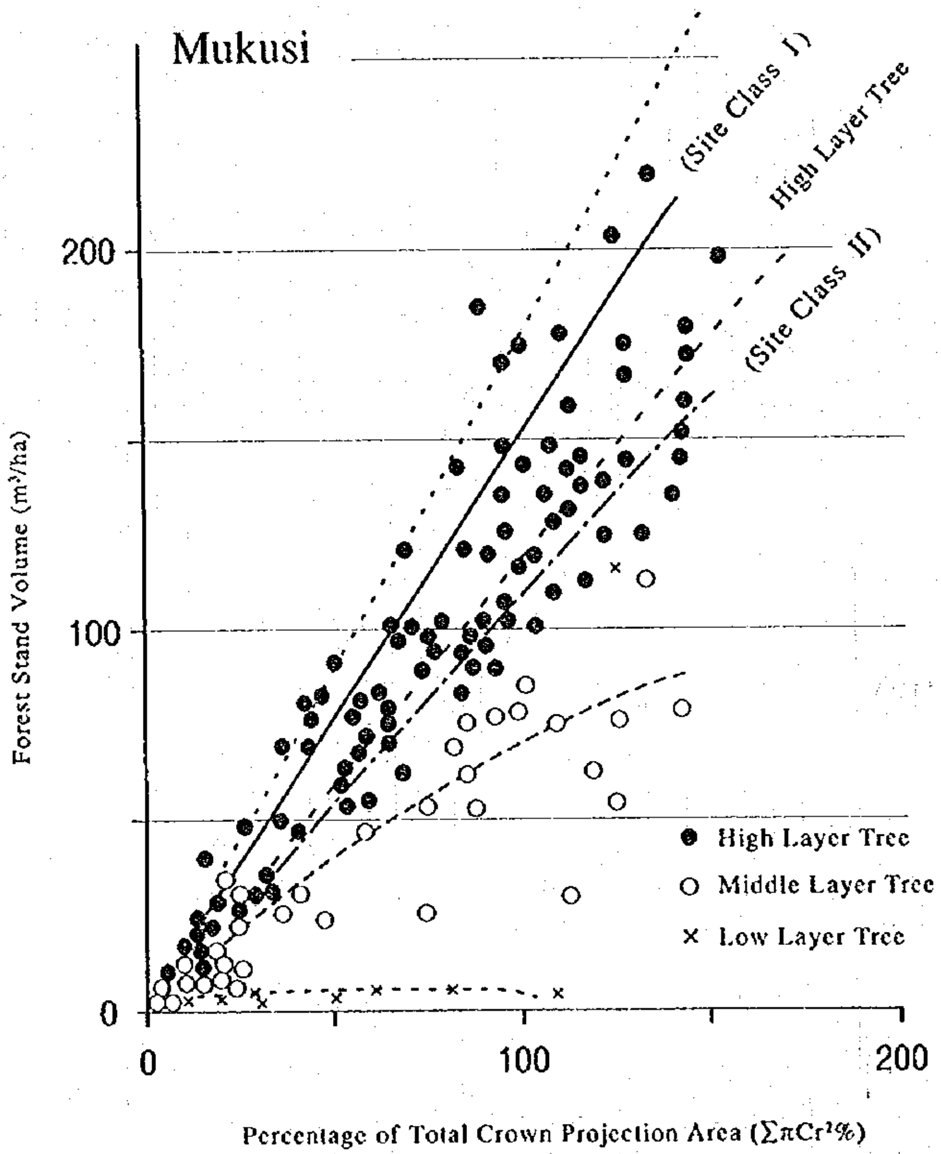


Figure 23 Relation between Mukusi forest stand volume and total crown projection area

2.3.5. Interpretation of aerial photographs

As was clarified in the preceding section, the stand volume of forests may be estimated by interpreting each factor to index such volumes by utilising aerial photographs. To be specific, the following factors of forests and closed woodland, established through land-use vegetation surveys, were interpreted by using aerial photographs, measured, and subdivided into small compartments. The interpretation criteria indicated in categories b to e are the factors to index the stand volumes proposed in the preceding paragraph.

Moreover, in order to estimate the volume of Mukusi, the determination of tree species by utilising aerial photographs was examined. According to the results of forest surveys, the tree species mainly constituting the tree layer of Mukusi forest as well as representing its characteristics were Mukusi and Mwangula mixed with small quantities of Muhoto, Muhonono and Mukololo. Although Muhoto and Muhonono are dominant species in some cases, they are often distributed only in small areas. As a result of interpretation using aerial photographs and field inquiries performed on various species growing either as a single tree or a pure forest, Mukusi was distinguished rather easily from other tree species.

For this reason, it was decided to classify the tree species in each compartment into two groups, i.e., Mukusi and species other than Mukusi, and then interpret the Mukusi mixing rate for each compartment applying the criteria indicated in category a.:

The data obtained from interpretation were entered in the Forest Inventory Book, using the symbols assigned to each of the following criteria:

a. Mukusi mixing rate

- M0: 0 - 5%
- M1: 5 - 25%
- M2: 25 - 50%
- M3: 50 - 75%
- M4: 75 -100%

b. Crown density class

- D1: 20 - 45%
- D2: 45 - 70%
- D3: 70 -100%

c. Crown diameter class

- C1: 1 - 6 m
- C2: 6.5 - 10 m
- C3: Exceeding 10 m

d. Site index

- H1 (Index I): Tree ht. 15 m and up
- H2 (Index II): Tree ht. 14 m and under

e. Quantity of middle layer trees

- S1: Few - less than 50%
- S2: Many - 50% or more

2.3.6 Preparation of Forest Inventory Book

(1) Forest blocking methods and compartments

Forest Estates are blocks of Mukusi forests directly managed by the Forest Department at present where Mukusi grows intensively. They are blocked mainly by rivers (rivers, dambos, plains) as well as by main felling roads. Therefore, having decided to treat a Forest Estate as a fixed unit of blocks, we specified the same in topographic maps.

Table 19 Example of Forest Inventory Book

FOREST INVENTORY BOOK

Forest Name	Total area(ha)
Zungubo forest	950

No.

Compart-ment No.	Area (ha)							Forest condition: By aerial photographs					Forest condition: Volume			Site condition	Remarks
								Mukusi mixing rate	Crown density class	Crown diameter class	Site index	Middle layer tree	Volume per ha	Total Volume	Mukusi Volume	Soil type	
	F	CW	OW	NTG	ATG	NG	FL	M_0-M_4	$D_1D_2D_3$	$C_1C_2C_3$	H_1H_2	S_1S_2	m^3/ha	m^3	m^3		
1	20							1	1	3	1	1	63	1,260	189	ARo-O	
2	24							0	1	2	2	1	35	840	0	ARo-O	
3	107							1	3	3	2	2	136	14,552	2,183	ARo-O	
4	40							1	1	2	2	1	35	1,400	210	ARo-O	
CW1		12						0	1	3	2	1	42	504	0	ARo-O	
CW2		53						0	1	3	2	1	42	2,226	0	ARo-O	
ATG1					694											ARo-O	
Total	191	65	0	0	694	0	0							20,782	2,582		

Although the chiefs control areas outside the Forest Estates, no clear territorial boundaries have been established, so it was difficult to classify such areas in topographical maps. Thus no fixed blocks were specified.

Forest Estates were first classified per land-use and vegetation types. Then, the forests and closed woodlands in the Forest Estates were subdivided by means of interpretation using aerial photographs. The compartments in the Forest Estates were thus established, and a number was assigned to each of them.

With regard to forests and closed woodlands outside the Forest Estates, those were subdivided by means of interpretation using aerial photographs and classified according to the vegetation type.

The handling of forests is determined according to each of the compartments under different forest conditions. However, depending on the variation in felling policies and forestry achievements so far obtained, the state of individual compartments is subject to changes.

(2) Forest resources distribution maps

The condition of quantitative distribution of forest resources was determined by taking into consideration the convenience in forestry management, and forest resources distribution maps were prepared as being directly associated with the Forest Inventory Book.

Preparation of forest resources distribution maps was attempted by transferring the portions for forests and closed woodlands out of the divisions established per land-use and vegetation types onto topographic maps. Then the boundaries between the regions of compartments and forest estates were entered in the topographic maps. In short, the map, which may be called a map of compartment locations, is to be used in conjunction with the Forest Inventory Book.

The compartment number and growing stock per ha were indicated for each compartment so that the conditions for resources distribution might be clarified. Referring to the area of each compartment indicated in the forest resources distribution maps, the area of each compartment was measured, and the results obtained were entered in the Forest Inventory Book.

(3) Forest Inventory Book

The style of the Forest Inventory Book is as indicated in Table 19, and various contents are given for each forest block. If we see a part of a specific compartment in the Forest Inventory Book, a variety of information on the relevant compartment may be acquired.

The total growing stock of the area surveyed may be calculated by adding the growing stocks of each compartment indicated in the Forest Inventory Book.

a. Forest division

In summing up the Forest Estates managed by the Forest Department, the name of each Forest Estate was entered. Forests and closed woodlands outside the Forest Estates were compiled as per sheet of topographical paper.

While consecutive numbers were assigned as compartment numbers to forests, abbreviations of the divisions established per vegetation type and followed by consecutive numbers were assigned to the compartments of other vegetation types. (For example, CW1 represents the No. 1 compartment of a closed woodland.)

b. Area

Compartment areas were entered for each division of vegetation type.

c. Forest conditions

As forest conditions, entered were the results of interpretation using aerial photographs in accordance with the criteria indicated in the above categories a. to d., the stand volume per ha obtained from the crown-volume conversion table (the table of crown diameter classes, crown density classes, and site indices from which volume per ha will be found), as well as the total stand volume of the relevant compartment, and the total stand volume of Mukusi.

The total stand volume was calculated by multiplying the volume per ha by the area of the compartment area, while the stand volume of Mukusi was calculated by multiplying the total stand volume by the Mukusi mixing rate interpreted.

d. Land description

As land description, topographic conditions and soil types are usually stated. However, since the area surveyed was mostly even without any topographic differences involved, only soil types were entered. A statement concerning dambo was included in the Remarks column.

2.3.7. Present conditions of forest resources

In the compilation in the Forest Inventory Book, the area of each forest and closed woodland, the growing stocks of all the forest trees, the volume of Mukusi, and the growing stock per ha were entered for each Forest Estate as well as for each topographic map sheet. Refer to Table 20 for details.

In the entire study area of approximately 500,000 ha, the forest area of 86,021 ha (17%) was included with its growing stock being 8,201,580 m^3 (95 m^3/ha). On the other hand, since closed woodland was distributed to cover 153,152 ha (30%), with its growing stock of 7,978,255 m^3 (52 m^3/ha), the growing stock per ha is only 50% of the forests.

(1) Land description within the Forest Estate

The study area contained 25 Forest Estates with a total area of 125,943 ha. The Mukusi forests included in these Forest Estates had decreased to 61,670 ha, which accounted for 49% of the total area. As mentioned in the section related to land-use and vegetation surveys, most of the vegetation-type divisions other than that of Mukusi forests were tree grassland degraded from Mukusi forests, and its area was confirmed to have decreased considerably. Further, the closed woodland was distributed in a small area, accounting for only 2% to the total area.

Next, with regard to the area rate of forests per each Forest Estate, while the forest rate of the lots surrounding Mulobezi (Kazu-Namena to Kanyanga Forest) was 70%, the average forest rate of the forest estates located in the south was only 40%. In particular, the low forest rates of Sichinga (20%) and Monze Forest (13%) were remarkable. This was not caused by forest cutting. Rather, it was due to the expansion of tree grassland caused by large-scale fires from burnings having taken place disorderly.

Next, the total growing stock (Table 20) of the forest estates and that of Mukusi forests were 6,663,075 m^3 (104 m^3/ha) and 3,234,215 m^3, accounting for 49% to the total growing stocks, respectively.

Although the stands of some plots surveyed were found to be in excess of 200 m^3/ha, the only plot with its average stand being kept in a rank near to above was Nanga Forest (171 m^3/ha). The plots which were found to have maintained both the average and total growing stocks (with forest rates being 70% or more) were Simungoma east, Simungoma west, Kanyanga, Lonze, Situmpa forests, etc. However, even in these cases, the growing stocks were around 120~130 m^3/ha.

(2) Forests outside the Forest Estates

The total area of forests which were outside the Forest Estates was 24,351 ha. In many cases such forests were distributed in small quantities in tree grasslands. Relatively large forest land consolidations, which were distributed around Forest Estates with stands mixed with Mukusi, were released to residents. However, as a matter of fact, a considerable number of forests were included in the forests outside the Forest Estates where tree species other than Mukusi were dominant. Their Mukusi mixing rate of 24% was around half compared with the Mukusi mixing rate of forests within forest estates.

Most of the closed woodlands, where useful tree species such as Mukwa, Muzauli, etc. were growing, were widely distributed outside the Forest Estates, with the total area amounting to 150,753 ha.

The growing stock of forests was estimated as 1,634,317 m^3, and the average growing stock per ha was 67 m^3, which was only approximately 60% of the total growing stock of forests within the Forest Estates (106 m^3/ha). On the other hand, the average growing stock of closed woodlands was 52 m^3/ha. However, since the total area was wide, the total growing stock was established as 7,882,443 m^3. Although Mukusi was mixed in the growing stock of closed woodlands, its ratio of approximately 6% was very small.

(3) Condition for each stand type

Calculation of stand volumes was based on the crown-volume conversion table as per Table 18. The total area, growing stock, etc. calculated in accordance with the table for individual divisions per type are indicated in Table 21. The values in the table calculated for forests and closed woodlands clearly indicate a difference in the content of the growing stocks.

Out of the total area, i.e., of the 86,021 ha of forests, 58,107 ha constituted 70% of the total, mainly consisting of trees with large diameters (Site I and C3 of Site II), with their growing stocks being 6,955,625 m^3 or 85% of the total. Although the Site I D3C3 stand was calculated as having an average of 196 m^3/ha, in a stand of this type, the crown density exceeded 90%. Such a stand exceeds 210 m^3/ha (see Table 18).

On the other hand, in closed woodlands, the area whose growing stock of more than 100 m^3/ha was 3,363 ha, accounting for only around 2% of the total area of 153,152 ha. Also among the areas occupied by trees with large diameters, those with a low growing stock of 63 m^3/ha accounts for about 60% of the total area.

In closed woodlands, useful tree species including Mukwa, Mutonndo, Mubako, etc. were felled by pit sawyers. In view of the low average growing stocks, in cutting them it is necessary to pay careful attention so that a possible change for the worst in forest physiognomy may be avoided.

Table 20 Present condition of forest resources

No.	Forest estate	Total area(ha)	Forest						Closed Woodland						Total					
			Area		Stand volume(m^3)			Mukusi rate	Area		Stand volume(m^3)			Mukusi rate	Area		Stand volume(m^3)			Mukusi rate
			(ha)	Rate (%)	Per ha	All trees	Mukusi	(%)	(ha)	Rate (%)	Per ha	All trees	Mukusi	(%)	(ha)	Rate (%)	Per ha	All trees	Mukusi	(%)
1	Masese group of forest	54,933	25,228	46	103	2,605,836	1,688,323	65	612	1	33	20,404	0	0	25,840	47	102	2,626,240	1,688,323	64
a	Sichinga	5,974	1,220	20	41	50,281	17,339	34	137	2	25	3,373	0	0	1,357	23	40	53,654	17,339	32
b	Monze	6,083	769	13	52	39,614	13,282	34	0						769	13	52	39,614	13,282	34
c	Kasiki	5,540	2,022	36	96	194,544	110,289	57	0						2,022	36	96	194,544	110,289	57
d	Malavwe	5,681	2,291	40	71	163,366	81,735	50	0						2,291	40	71	163,366	81,735	50
e	Simungoma west	7,990	5,734	72	125	717,222	435,337	61	0						5,734	72	125	717,222	435,337	61
f	Simungoma east	8,540	6,237	73	129	801,522	621,779	78	0						6,237	73	129	801,522	621,779	78
g	Sikubingwa	5,385	3,391	63	96	326,354	222,470	68	279	5	36	10,171	0	0	3,670	68	92	336,525	222,470	66
h	Sisisi	9,740	3,564	37	88	312,933	186,092	59	196	2	35	6,860	0	0	3,760	39	85	319,793	186,092	58
2	Zungubo	950	191	20	95	18,052	2,582	14	65	7	42	2,730	0	0	256	27	81	20,782	2,582	12
3	Kateme	2,560	1,043	41	108	112,252	31,386	28	132	5	17	2,244	0	0	1,175	46	97	114,496	31,386	27
4	Mululwe	7,276	899	12	57	51,475	11,046	21	127	2	63	8,001	1,200	15	1,026	14	58	59,476	12,246	21
5	Nanyota	3,432	763	22	70	53,136	29,638	56	212	6	63	13,356	2,003	15	975	28	68	66,492	31,641	48
6	Samatela	6,485	1,389	21	64	88,293	27,669	31	1,062	16	35	37,170	11,805	32	2,451	38	51	125,463	39,474	31
7	Lumino	4,000	1,742	44	116	201,580	85,369	42	32	1	63	2,016	0	0	1,774	44	115	203,596	85,369	42
8	Kayumbwana	3,575	1,919	54	109	208,394	81,000	39	0						1,919	54	109	208,394	81,000	39
9	Nangombe	2,380	855	36	111	94,768	13,959	15	0						855	36	111	94,768	13,959	15
10	Sijulu	2,770	1,731	62	127	219,776	76,888	35	77	3	63	4,851	0	0	1,808	65	124	224,627	76,888	34
11	Kalama	1,006	302	30	53	16,070	3,968	25	0						302	30	53	16,070	3,968	25
12	Kazu-Namena	7,860	5,287	67	100	528,468	134,219	25	23	0	63	1,449	217	15	5,310	68	100	529,917	134,436	25
13	Nanga	1,450	1,149	79	171	197,002	114,580	58	0						1,149	79	171	197,002	114,580	58
14	Kanyanga	1,980	1,337	68	99	132,599	58,792	44	57	3	63	3,591	0	0	1,394	70	98	136,190	58,792	43
15	Lonze	9,295	6,519	70	114	742,353	351,576	47	0						6,519	70	114	742,353	351,576	47
16	Nalwamu	3,340	2,084	62	77	161,167	64,613	40	0						2,084	62	77	161,167	64,613	40
17	Lwangula	2,131	1,212	57	98	118,641	32,507	27	0						1,212	57	98	118,641	32,507	27
18	Situmpa	10,520	8,020	76	127	1,017,401	410,875	40	0						8,020	76	127	1,017,401	410,875	40
	Subtotal(Forest estate	125,943	61,670	49	106	6,567,263	3,218,990	49	2,399	2	40	95,812	15,225	16	64,069	51	104	6,663,075	3,234,215	49
Sheet No. of Topographic map															0					
	1724A2	42,570	418	1	50	20,782	2,532	12	31,283	73	51	1,606,146		0	31,701	74	51	1,626,928	2,532	0
	1724A4	36,703	2,009	5	51	103,027	5,360	5	9,229	25	45	415,542	12,665	3	11,238	31	46	518,569	18,025	3
	1724B1	46,663	1,935	4	58	112,689	38,593	34	26,280	56	61	1,611,690	230,774	14	28,215	60	61	1,724,379	269,367	16
	1724B2	55,398	5,072	9	79	400,235	128,080	32	10,107	18	48	481,668	8,538	2	15,179	27	58	881,903	136,618	15
	1724B3	19,635	3,643	19	61	222,303	68,937	31	1,369	7	49	66,454	9,492	14	5,012	26	58	288,757	78,429	27
	1725A1	20,306	3,100	15	60	185,157	66,083	36	0						3,100	15	60	185,157	66,083	36
	1624D3	37,943	687	2	82	56,533	3,554	6	28,522	75	51	1,453,263	88,452	6	29,209	77	52	1,509,796	92,006	6
	1624D4	33,648	1,656	5	70	115,932	3,795	3	20,071	60	43	869,673	10,742	1	21,727	65	45	985,605	14,537	1
	1625C1	34,848	1,065	3	65	68,876	27,162	39	16,413	47	58	954,395	12,172	1	17,478	50	59	1,023,271	39,334	4
	1625C3	38,234	4,657	12	74	342,498	49,030	14	7,479	20	57	423,612	61,428	15	12,136	32	63	766,110	110,458	14
	1625C4	9,013	109	1	58	6,285	79	1	0						109	1	58	6,285	79	1
	Subtotal(Sheet)	374,961	24,351	6	67	1,634,317	393,205	24	150,753	40	52	7,882,443	434,263	6	175,104	47	54	9,516,760	827,468	9
	Total	500,904	86,021	17	95	8,201,580	3,612,195	44	153,152	31	52	7,978,255	449,488	6	239,173	48	68	16,179,835	4,061,683	25

Table 21 Totaling forest stock according to each forest type (forests and closed woodlands)

Forest in the study area

Crown diameter class \ Forest crown closure		D1 20%<Cc<45% Σm³ / Σha	m³/ha	D2 45%<Cc<70% Σm³ / Σha	m³/ha	D3 70%<Cc Σm³ / Σha	m³/ha	Total Σm³ / Σha	m³/ha
Site I /C3 Cd>10m	All tree	1,174,509	63	2,140,664	116	3,429,412	196	6,744,585	124
	Mukusi	480,961	26	1,115,530	60	1,756,468	100	3,352,959	61
	Area(ha)	18,643		18,454		17,497		54,594	
Site II /C3 Cd>10m	All tree	96,558	42	66,066	77	48,416	136	211,040	60
	Mukusi	38,809	17	17,904	21	7,453	21	64,166	18
	Area(ha)	2,299		858		356		3,513	
Site II /C2 6<Cd<10m	All tree	352,765	35	361,020	60	347,650	85	1,061,435	53
	Mukusi	76,836	8	57,312	10	52,518	13	186,666	9
	Area(ha)	10,079		6,017		4,090		20,186	
Site II /C1 Cd<6m	All tree	53,329	17	78,936	26	52,255	34	184,520	24
	Mukusi	4,221	1	1,408	0	2,775	2	8,404	1
	Area(ha)	3,137		3,036		1,555		7,728	
Total	All tree	1,677,161	48	2,646,686	93	3,877,733	165	8,201,580	95
	Mukusi	600,827	18	1,192,154	42	1,819,214	77	3,612,195	42
	Area(ha)	34,158		28,365		23,498		86,021	

Closed woodland in the study area

Crown diameter class \ Forest crown closure		D1 20%<Cc<45% Σm³ / Σha	m³/ha	D2 45%<Cc<70% Σm³ / Σha	m³/ha	D3 70%<Cc Σm³ / Σha	m³/ha	Total Σm³ / Σha	m³/ha
Site I /C3 Cd>10m	All tree	5,524,659	63	390,108	116	0	0	5,914,767	65
	Mukusi	365,811	4	50,007	15	0	0	415,818	5
	Area(ha)	87,693		3,363		0		91,056	
Site II /C3 Cd>10m	All tree	721,770	42	0	0	0	0	721,770	42
	Mukusi	2,948	0	0	0	0	0	2,948	0
	Area(ha)	17,185		0		0		17,185	
Site II /C2 6<Cd<10m	All tree	1,054,690	35	49,980	60	0	0	1,104,670	36
	Mukusi	23,225	1	7,497	9	0	0	30,722	1
	Area(ha)	30,134		833		0		30,967	
Site II /C1 Cd<6m	All tree	237,048	17	0	0	0	0	237,048	17
	Mukusi	0	0	0	0	0	0	0	0
	Area(ha)	13,944		0		0		13,944	
Total	All tree	7,538,167	51	440,088	105	0	0	7,978,255	52
	Mukusi	391,984	3	57,504	14	0	0	449,488	3
	Area(ha)	148,956		4,196		0		153,152	

3. SURVEY FOR FORMULATING FOREST MANAGEMENT PLAN

3.1. Yield Table and Resources Management Based on It

Forests are considered to be endless resources in that they are eventually restored even after harvesting. However, unless an appropriate yield volume is established and logging is conducted accordingly, the forests may be destroyed and a sustained yield not realized. From this viewpoint, a study was made to grasp the structure and properties of the Mukusi forest and, based on the findings, establish an appropriate yield volume, with the aim of preserving the said forests located in south-western Zambia. A yield table based on the quantitative results is shown below.

3.1.1. Basis for preparation of yield table

Trees which comprise natural forests grow every year and, in the process, competition among the adjacent trees starts. The dominant trees survive as members of the forest, while the dominated trees stop growing and eventually die. A reduction in the density of forest trees as a result of competition during the growth of forest trees is called natural thinning. Even if trees, which are destined to die off from natural thinning within a certain period of time, are harvested before they wither, the growth of the forest as a whole should not be impeded. The table quantitatively describing changes in the stand compositions so that the growth of forests can be maintained even if trees are harvested at a certain predetermined cycle is called the yield table. In concrete terms, it describes the stand composition that changes with the forest's age (tree height, diameter, volume of single tree, stand density, stand volume), the possible yield (harvest volume that should not hinder the sound growth of the forest stand: number and volume of the overmatured trees, dominated trees, minus trees, etc.).

Natural thinning is executed under critical conditions that determine survival or death, so that the stand density which triggers natural thinning is called full density. Most of the natural forests are maintained in this full density state, but the forest itself has a capacity to adapt to a wider variety of conditions and, therefore, it is not necessary to strictly observe the full density condition when selectively felling forest trees. In other words, forests can be preserved even if they are controlled at a density lower than full density.

Forest trees grow by means of photosynthesis. A single tree having a wider crown receives a greater amount of light and grows larger. The same concept is adopted for a forest stand which has a cluster of single trees; as the covering of the forest canopy increases, the forest stand maintains higher growth, and the smaller the covering, the lower the growth in the forest stand will be. Individual trees have the capacity to adapt flexibly to the sizes of the crowns. Even if there are some differences in the size (within a certain limit) among the trees that comprise the forest canopy, and even if the stand density varies slightly, the same forest canopy closure can be secured. In other words, forest trees show flexible changes; for example, when the density is high, the crown of each tree provides a smaller shaded area and when the density is low, it provides a larger shaded area. Unless the density is extremely low, the forest maintains the closed forest canopy (almost uniform forest canopy closure). On the other hand, if the forest canopy closure is the same, the amount of solar rays received by the forest stand as a whole, and also the growth rate, should remain unchanged. Therefore, a forest stand whose density is somewhat lower than that of natural thinning (full density) should maintain a closed canopy and attain the same growth rate. In other words, even if trees are cut to excess during selective cutting or thinning, the forest canopy will be maintained in a sound state. This indicates that even if slightly excessive thinning or selective cutting is exercised in density control, there should be no hindrance to growth of the forest stand.

When the forest density is reduced and the size of a crown of individual trees is increased, the diameter increment of the trees increases so that timber of larger diameter can be produced. Therefore, in a man-made forest whose objective is to produce large-diameter timber for board materials, the stand density is often kept significantly lower than that achieved by natural thinning. Often the stand density is kept below 50% and the stand volume is maintained equal to or better than that obtained at the higher density. In the semi-arid tropical regions with little precipitation, the competition for water is keener than that for solar rays; therefore, the emphasis should be placed on the spread of crowns rather than the spread of the root system. However, the root system conditions are invisible and therefore the crown structure is reviewed as a parameter.

In an arid region such as the southwest district of Zambia, a complete closure of the forest canopy cannot be expected because of climatic conditions. If the stand density is reduced by as much as 50%, as in the case of a humid region, the closure of the forest canopy cannot be expected. Nevertheless, it seems that the canopy temporarily opens widely but eventually recovers the closure if the stand density is reduced by 30~35%.

In the natural forests in the southwest district of Zambia, positive control of the trunk number (diameter control) is not feasible. Therefore, it is appropriate to consider a stand composition akin to that by natural thinning, rather than the low density stand composition often seen in man-made forests. However, forest trees harvested after they withered are useless as a resource. Therefore, it was decided to prepare a yield table on the assumption that the decay and mortality of trees in forest rotation is predicted and the trees are harvested before they are dead.

As mentioned above, in preparing the yield table, it is necessary to quantitatively grasp the relation among the stand composition factors, such as the forest age (tree age), tree height, diameter at breast height, single tree volume, stand density, stand volume, etc. However, it was difficult to estimate the forest age of Mukusi, which is the major target species at this time, without felling it so that, in the forest survey at the site, it was decided to obtain the relation between the diameter at breast height or the base area and other stand composition factors as a substitute for the forest age. In the case of a forest stand in Japan, the base area has an almost linear correlation with the tree age. Therefore, initially for Mukusi, too, the relation between the base area and the tree height, density, volume, etc. was obtained. However, after having examined the annual rings of Mukusi wood felled at the site, it was found that there is a simple, almost linear, relation (approximation in direct proportion) between the diameter at breast height and the age (number of annual rings). (Figure 24)

The forest age can be calculated easily from the diameter at breast height using this linear correlation. So, we thought that if the relation between the diameter at breast height and the various stand composition factors are obtained, it would be possible to substitute them with the relation with the forest age. Based on this concept, we obtained the relation between the diameter at breast height and the stand composition factors shown below that may be required for formulation of the yield table and review of forest management.

Relation between the diameter at breast height and the tree height (dominant trees) (App. Figure 8)

Relation between the diameter at breast height and stand density (App. Figure 9)

Relation between the diameter at breast height and forest stand volume by layer (high, middle and lower layers) (App. Figure 10)

Relation between the diameter at breast height (dominant tree) and the forest stand volume of the middle layer tree (App. Figure 11)

Using Figure 24, the relation between the diameter at breast height and forest age was rearranged into a smooth curve by site class (nearly linear) (site classes I and II), and the relation as shown in Figure 25 was obtained. Using this relation as a medium and substituting the relation with the diameter at the breast height by the relation with the forest age, the relation between the forest age and the following factors was analysed.

The following are shown along with the above:

Relation between the tree height and forest age (Figure 25)

Relation between the stand density and forest age (Figure 26)

Volume growth curve plotted and based on the tree height growing curve and growing curve for diameters at breast height (Figure 27)

Relation between forest stand volume and forest age by layer (Figure 28)

The yield table for the dominant trees for a period of 20 years was prepared using these relational diagrams. Concerning the secondary forest trees (dominated trees: yield prediction index), it was assumed that 65% of them may be harvested, considering that some of the forest trees may be withered and dead without being harvested in the time span of 20 years. In concrete terms, after taking into account the number of trees that already were dominated at the time of felling, it was estimated that 35% of the total volume of major and secondary trees, as the volume of currently existing secondary forest trees (for the first term), and about 30% of the existing major tree volume (for the second term) were trees that are expected to be dominated. These can be harvested in the future. The harvest volume (merchantable volume) was calculated by multiplying this number of trees by 80% of the average single tree volume of the forest age (m^3/forest age) (for older trees: 85~95%).

3.1.2. Yield table (forest age grade and composition of major and secondary trees)

First, the process that the forest stand grows old from its infant period to old stage was estimated. In concrete terms, the yield table was prepared as shown in Table 22 with the focus on the relation plotted in Figure 28. Although the data on the young and immature forests below 40 years are lacking because the forests at the site of the survey are mainly natural forests, the table was compiled using the available data and the estimated values.

(1) Characteristics

The following characteristics could be perceived during the process of compiling the yield table.

- Maximum stand volume can be achieved in mature forests aged 60 to 80 years old. After 100 years, the stand volume will decrease, probably due to old age.
- Trees in young forests below 40 years are lost due to forest fires. For this reason, the stand volume shown in Figure 28 is small. The yield table adjusts this situation by providing it as observation in presenting a proper stand volume.
- The yield table shows the composition of natural forests going through an almost ideal growth process. The actual condition is poorer than this composition.

(2) Growth and yield implied by Yield Table I

A high growth is maintained even by overmatured forests older than mature forests in the growth of single dominant trees (Figure 27). Based on this observation, the relation between the forest age and forest stand volume seemed to maintain an increased trend after mature forests also. Nevertheless, competition among forest trees is keen and dominant trees maintain an active growth. Once trees become dominated trees, their growth is stunted and they quickly become weak and wither. For this reason, the number of surviving trees has decreased approximately 20% or more in the past 20 years. In many cases, these dead trees reduce the overall stand volume and the growth trends for entire forest stands show a decrease, even through surviving trees grow at a high level. In fact, the forest stand volume tends to decrease after the forest age passes the mature forest age of 60 to 80 years.

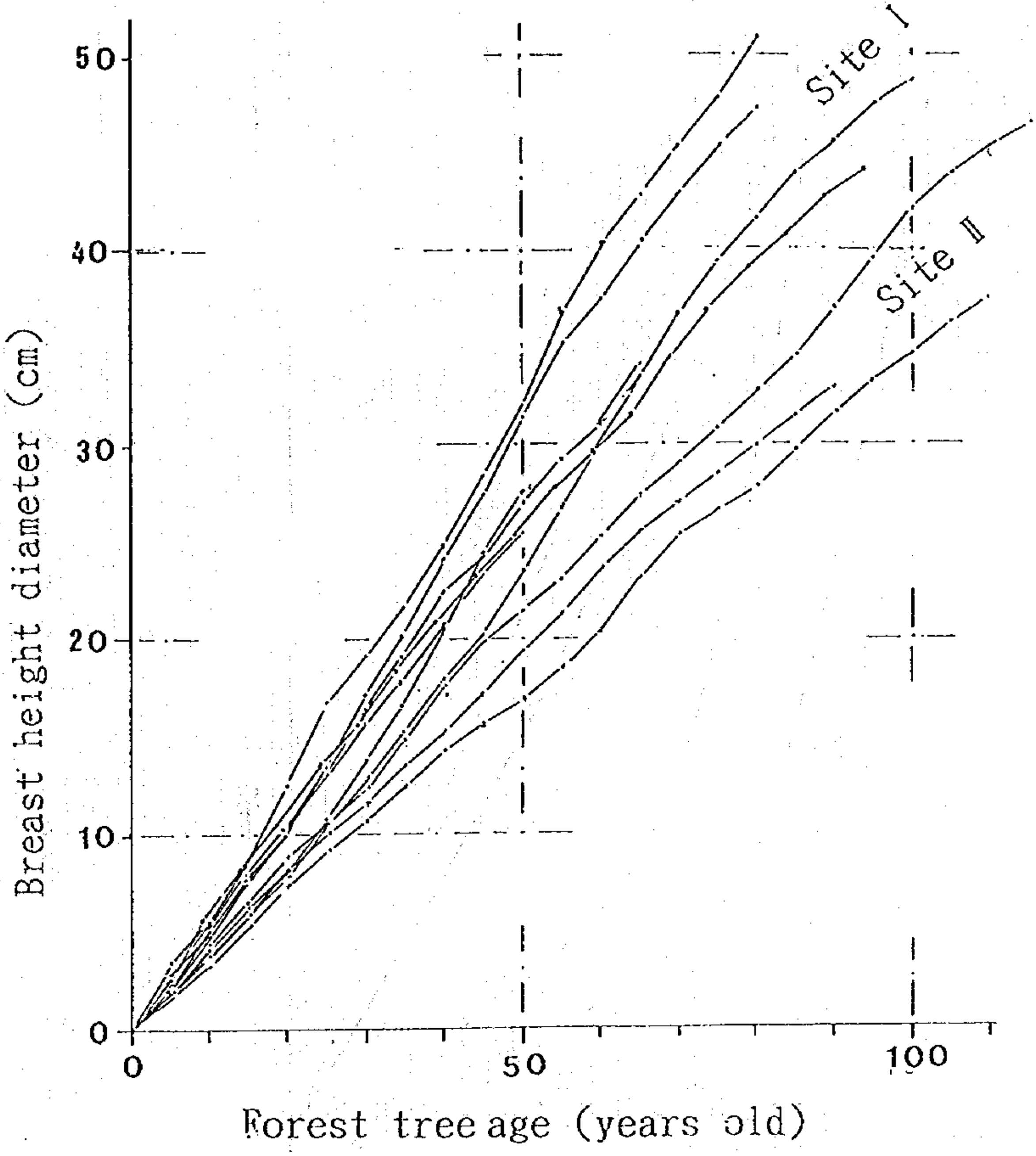

50
40
30
20
10
0
Breast height diameter (cm)
0
50
100
Forest tree age (years old)
Site I
Site II

Figure 24

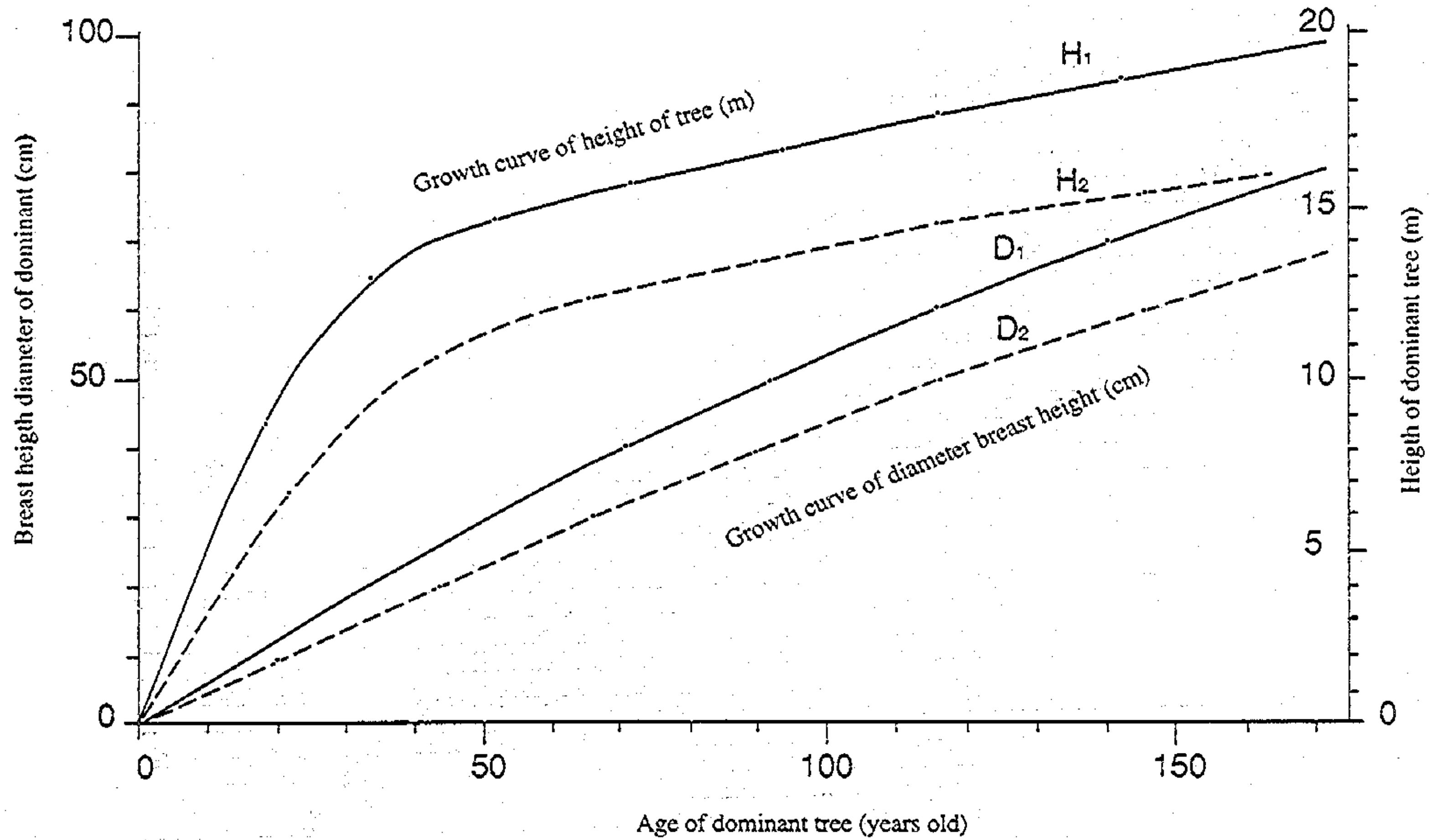


Figure 25 Relation between the tree height and forest age

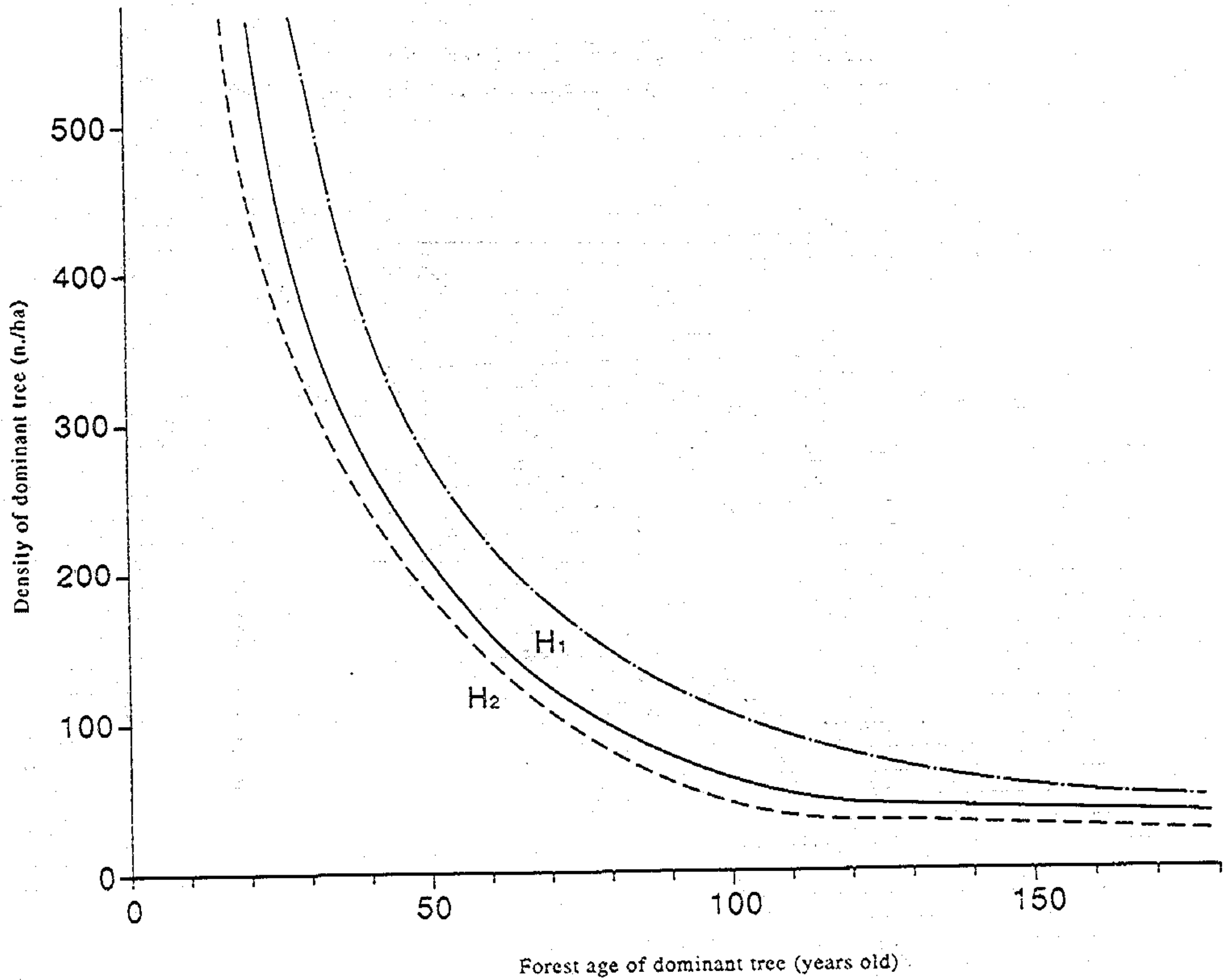


Figure 26 Relation between the stand density and forest age

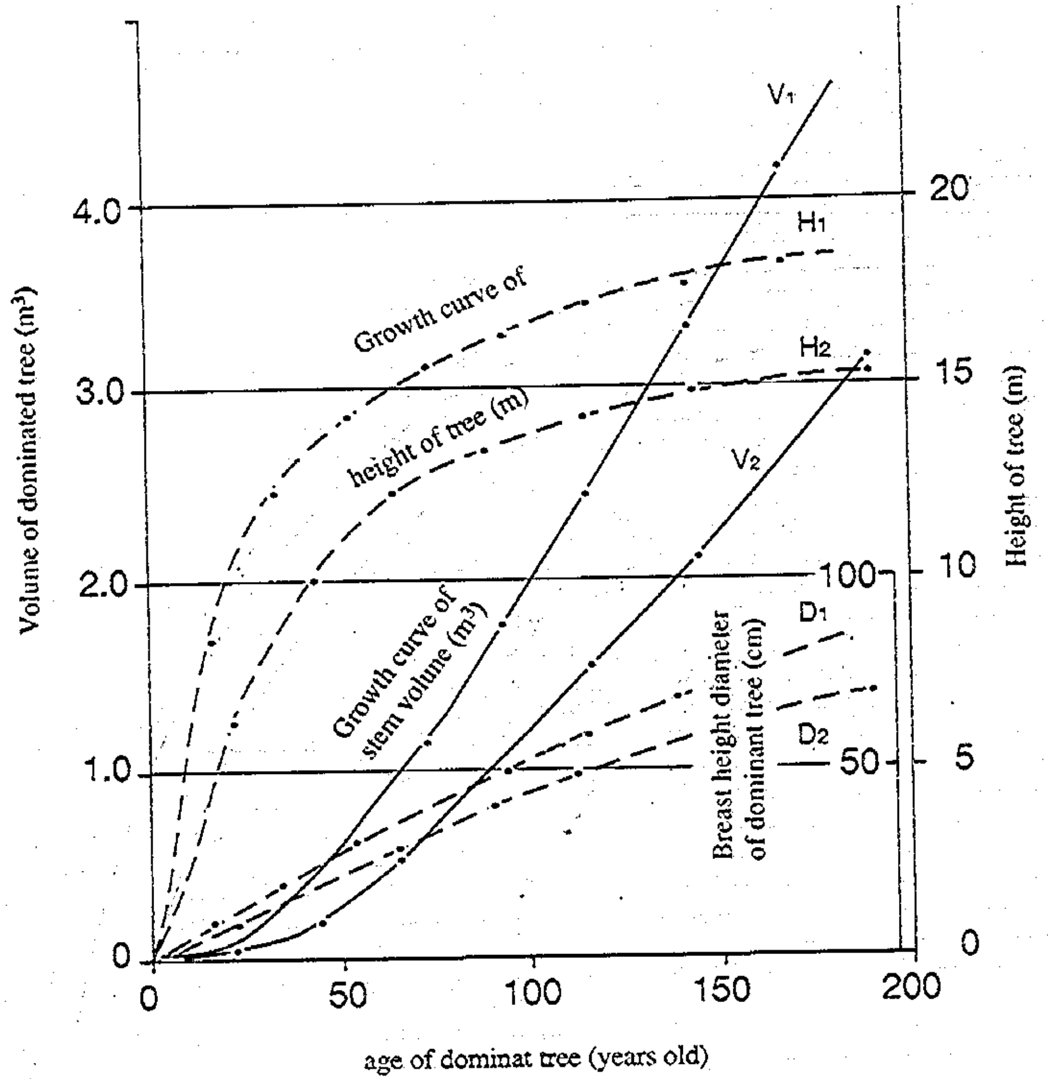


Figure 27 **Volume growth curve plotted and based on the tree height growing curve and growing curve for diameters at breast height**

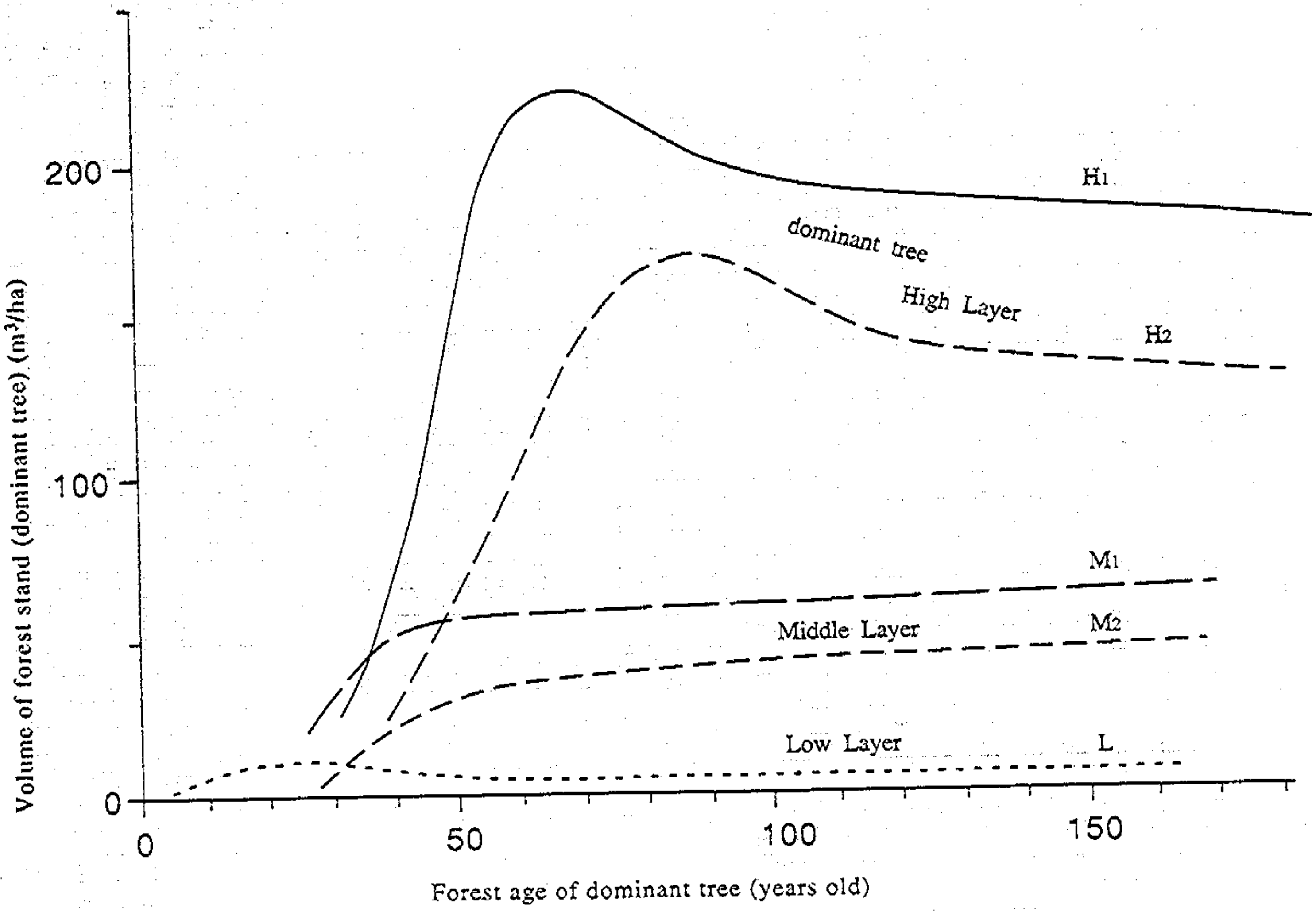


Figure 28 Relation between forest stand volume and forest age by layer

Table 22 Yield Table I (Mukusi forest stand) Forest age and stand volume

Site Class I

Forest	All of tree					Dominated		Middle
Age	H	DBH	v	N	V	Ni	Vi	Vm
	(m)	(cm)	(m^3)	(n/ha)	(m^3/ha)	(n/ha)	(m^3/ha)	(m^3/ha)
20	8.8	12.0	0.054	550	30			
40	12.5	22.5	0.312	420	131	92	23 (18%)	50
60	14.4	33.0	0.754	276	221	77	46 (21)	56
80	15.7	43.5	1.353	154	209	58	63 (30)	58
100	16.7	53.0	1.875	105	196	29	44 (23)	59
120	17.6	62.0	2.656	70	187	17	36 (19)	60
140	18.4	70.5	3.424	54	184	10	27 (15)	61
160	19.0	76.5	4.021	45	182	7	22 (12)	62

Site Class II

Forest	All of tree					Dominated		Middle
Age	H	DBH	v	N	V	Ni	Vi	Vm
(y)	(m)	(cm)	(m^3)	(n/ha)	(m^3/ha)	(n/ha)	(m^3/ha)	(m^3/ha)
20	6.0	8.0	0.013	750	10			
40	9.3	17.5	0.134	460	62	145	16(26%)	20
60	11.9	26.5	0.411	304	125	82	27(22)	32
80	13.0	35.0	0.759	213	162	56	34(21)	36
100	13.8	43.5	1.176	134	157	41	39(25)	38
120	14.4	51.0	1.600	91	146	23	29(20)	40
140	15.0	58.0	2.041	68	138	14	23(17)	42
160	15.5	64.0	2.470	53	132	9	18(14)	43

The forest stand volume and the degree of growth (growth rate) differ for each age period, namely, the period of the young forest age when the forest stand volume increases, the period of the mature forest age (60 to 80 years old) that reaches the maximum stand volume, the period of the overmatured age when the stand volume decreases and the period when the stand volume decreases slightly or is maintained constant. Therefore, it is difficult to uniformly forecast the degree of growth (growth rate) that corresponds to the volume (rate) of allowable cutting. However, if a cutting rate (volume rate of the secondary forest trees) with an eye on sustained yield is to be presented on the assumption that the trees are 90~110 years old for Site I and 100~120 years old for Site II, the logical rate would be approximately 20 to 25% with the 20-year selective cutting cycle.

The yield table was prepared by keeping in mind the selective cutting cycle of 20 years. If the cutting cycle is reduced to 10 years, the cutting rate for one time becomes as small as 15%. However, since the mortality (the nonmerchantable volume ratio) of the dominated trees during the cutting period decreases, the total harvest volume should increase. The 10-year selective cutting cycle is preferable in such places where the transportation means are readily available, and intensive cutting and harvesting are possible. However, the harvesting rate of Mukusi for one time would decrease to 7~10% or under and, therefore, it is highly likely that the operational efficiency may drop. Therefore, it was determined that the 20-year cutting cycle would be appropriate under the present situation.

3.1.3. Yield Table II (standard stand composition of old age natural forest)

(1) Preparation of Yield Table II

In Yield Table I, the changes in the forest stand composition with the lapse of time and the harvesting volume obtainable in the 20-year cutting cycle are shown, assuming that the forestation is uniform like in a man-made forest. However, in reality, a natural forest is a community comprised of various kinds of trees whose species, tree size class, tree height are different. Therefore, in order to achieve harvesting by taking into account the sustained yield under such conditions, it is essential to forecast how many dominated trees will be produced during 20 years for each diameter class or tree height class.

Thus, the frequency of appearance of each diameter class for each forest stand survey plot was calculated and, using the average value, the number of trees (Nt) for each diameter class in the standard forest stand in this region (not subjected to forest fires) was estimated. On this occasion, since almost all the trees 30 years old or under were damaged, the frequency of appearance of the trees of such small diameter class was separately estimated with reference to the values measured for the small sound forest stand, instead of using the simple average value. The volume (Vt) of each diameter class was obtained by multiplying the number of trees for each diameter class by the single tree volume. The forest stand volume was calculated by adding all of the obtained values.

In an attempt to grasp the current situation and the state of Mukusi, the target tree species, the number of trees for each diameter class estimated using the actual frequency of appearance, was shown as Ntp, and the volume corresponding to it was calculated and shown as Vtp. Similarly, for Mukusi that appears in the forest stand, the number of trees (Nm: standard), (Nmp: practical), and the volume (Vm: standard), (Vmp: practical) for each diameter class were calculated.

When the simple average composition was obtained, the forest stand volume was high: 220 m^3/ha (Site I, the forest age: 80 years old). However, in reality, the forest stands having such high growing stock are rare, so that an adjustment was made to reduce the number of trees and, as a result, the standard forest volumes were estimated to be 198 m^3/ha (forest age: 100 years old) for Site I and 145 m^3/ha (forest age: 120 years old) for Site II. Yield Table II (Table 23 (1), (2)) was prepared based on the forest stand composition under these conditions.

Table 23 (1) Yield Table II (Mukusi forest stand)

Standard structure of stand: Number of trees and volume classified by DBH

(1) Site Class I

DBH	H	v	N: stand density					V: stand volume				(age)
cm	m	m^3	Nt	ΔNt	Ntp	Nm	Nmp	Vt	ΔVt	Vm	Vmp	y
6 ~ 10	6	0.013	120	--	100.	72.0	11.0	1.56	--	0.94	0.21	10
~ 15	8	0.059	98.0	22	80.0	64.0	13.0	5.78	1.30	3.78	0.77	20
~ 20	10	0.147	68.0	17	41.0	45.0	14.0	10.00	2.50	6.61	2.06	30
~ 25	11.6	0.298	52.0	8	32.0	39.0	18.0	15.50	2.38	11.62	5.36	40
~ 30	13	0.484	40.0	7	26.0	32.0	19.0	19.36	3.39	15.48	9.20	50
~ 35	14	0.714	31.0	5.9	28.0	26.0	23.0	22.13	4.21	18.56	16.42	60
~ 40	14.8	0.984	23.0	5.1	26.0	19.0	24.0	22.63	5.02	18.70	23.62	70
~ 45	15.5	1.289	16.0	3.9	21.0	14.0	20.0	20.62	5.03	18.05	25.78	80
~ 50	16.2	1.596	12.0	2.7	10.0	10.0	10.0	19.15	4.31	15.96	15.96	90
~ 55	16.7	1.936	8.4	2.0	10.0	7.0	10.0	16.26	3.87	13.55	19.36	100
~ 60	17.2	2.293	5.2	1.3	5.7	4.5	4.5	11.92	2.98	10.32	10.32	110
~ 65	17.6	2.698	3.8	0.9	4.4	3.6	3.6	10.25	2.43	9.71	9.71	120
~ 70	18.0	3.114	2.8	0.7	3.2	2.6	2.4	8.72	2.18	8.10	7.47	130
~ 75	18.3	3.556	1.9	0.6	1.6	1.9	0.4	6.76	2.13	6.76	1.42	140
~ 80	18.6	4.030	1.2	0.5	1.3	1.3	0.8	4.83	2.02	5.24	3.22	151
~ 85	18.9	4.583	0.6	0.3	0.8	0.6	0.8	2.75	1.37	2.75	3.67	163
~ 90	19.2	5.096	0	0	0	0	0	0	0	0	0	176
			484.	78.	391.	343.	175.	198.2	45.1	166.1	154.6	
			(100	16	81	71	36 %)	(100	22.8	83.8	78.0 %)	

$\Delta Nt = 0.35\ (Nt_{i-1} - Nt_i) + 0.35\ (Nt_i - Nt_{i+1})$

i : Class of DBH

Nt:stand density of all kinds of tree, Vt:stand volume of all kinds of tree ΔNt : stand density of dominated tree, ΔVt :stand volume of dominated tree. Ntp : present stand density of ″ ″ , Vtp : present stand volume of ″ ″. Nm : stand density of Mukusi, Vm : stand density of Mukusi. Nmp : present stand density of Mukusi, Vmp : present stnd volume of Mukusi.

Table 23 (2) Yield Table II (Mukusi forest stand)

Standard structure of stand: Number of trees and volume classified by DBH

(2) Site Class II

DBH	H	v	Nt	ΔNt	Nm	Nmp	Vt	ΔVt	Vm	Vmp	(age)
cm	m	m³	n/ha	n/ha	n/ha	n/ha	m³/ha	m³/ha	m³/ha	m³/ha	y
6 ~ 10	5.8	0.012	108	--	50	9	1.27		0.60	0.11	19
~ 15	7.5	0.051	88	18	45	10	4.48	0.73	2.30	0.51	28
~ 20	9.0	0.127	58	15	32	10	7.41	1.51	4.06	1.27	38
~ 25	10.3	0.255	47	11.7	27	13	11.89	2.37	6.89	3.32	50
~ 30	11.5	0.429	36	8.5	22.4	13	15.47	2.91	9.61	5.58	62
~ 35	12.5	0.638	28	5.7	18.2	16	17.86	2.92	11.61	10.21	74
~ 40	13.3	0.870	21	4.3	13.3	17	18.44	3.02	11.57	14.79	86
~ 45	13.9	1.156	15	3.4	9.8	14	17.15	3.14	11.33	16.18	98
~ 50	14.4	1.415	10.8	2.5	7.0	7	15.69	2.94	9.91	9.91	110
~ 55	14.8	1.735	7.2	1.9	4.0	5	12.51	2.70	6.94	8.68	122
~ 60	15.1	2.003	4.6	1.3	2.5	3.2	9.13	2.20	5.01	6.41	134
~ 65	15.3	2.343	3.3	1.1	1.8	2.5	7.70	2.12	4.22	5.86	146
~ 70	15.5	2.856	2.5	1.3	1.3	1.7	7.26	2.98	3.71	4.86	158
			428	74.6	234.3	121.4	146.3	29.54	87.76	87.69	
			(100	17.4	54.7	28.4)	(100.0	20.2	60.0	59.9 %)	

$\Delta Nt_i = 0.35(Nt_{i-1} - Nt_i) + 03\ (Nt_i - Nt_{i+1})$

(2) Characteristics

In Yield Table II, the number of trees (Nt) of each diameter class deemed to be standard was estimated, and the volume of dominant trees and the volume of dominated trees of each diameter class were calculated. The number of trees becomes larger as the diameter decreases (this trend was confirmed in forest stands whose partial damage was slight), probably because the interior of the forests in this region is bright and the suppressed conditions for solar rays do not constitute an obstacle to the growth of the young trees. However, in many forest stands, young trees have not grown due to repeated forest fires (fires spread from prescribed burning) over the last 20~30 years and, therefore, it was found that the number of trees (Ntp) that belong to a diameter class of 30 cm or under is small. Especially, the number of such trees (Nmp) is probably small because of the low fire-resistant properties of Mukusi.

Normally, old and large-diameter trees are felled, with the hope that young trees will grow. However, even if the cutting and harvesting of large-diameter trees are conducted properly, a sustained yield cannot be expected in case there are no saplings or young trees that are essential for recovery.

Yield table II has been prepared so that forests having a similar stand composition will reappear when 20 years have passed following selective cutting and harvesting. This table is compiled to indicate the quantitative data on the assumption that the selective cutting is conducted with respect to all diameter classes i.e., total selective cutting.

3.1.4. Utilisation of yield table, problems and suggestions

As mentioned above, the Yield Table II was prepared to indicate the quantitative data on condition that total selective cutting is carried out in a forest of almost full density. However, in reality, setting aside the small logs to be used for fuel, the large diameter standing trees and the specific species which have commercial value as timber tend to be felled, which is a problem.

1) Felling of only large diameter trees and the allowable volume of harvesting

In reality, total selective cutting (thinning) of all diameter classes is not carried out and only large diameter trees are felled. The allowable harvest should be, to be exact, a volume equivalent to the number and volume of the secondary forest trees that belong to the target diameter class (DBH is 35~40 cm or over). However, as mentioned earlier, the density of the forest canopy will not be destroyed even if the stand density becomes slightly lower than the full density, so that the volume slightly larger than the volume including that of the dominated trees that belong to the diameter class smaller than the larger diameter class, i.e., the allowable volume only for the target diameter class, may be felled. For example, in case of Site I in the Yield Table II, the allowable number of trees and the volume per ha that may be felled during total selective cutting are 78 trees and 45 m^3 (23%), respectively. If the trees to be used for saw timbers whose diameter is 35 cm or over are to be felled, the number and the volume would be 18 trees and 29 m^3 (15%), respectively, according to the calculations made based on the table. However, even if the density of the major forest trees, whose diameter is 35 cm or over, becomes 35% (25 trees) less than the full density (74 trees), the closure of the forest canopy will not be destroyed and, therefore, the felling of about 7 more trees may be allowed. In other words, the harvest volume may be increased up to $\{29 \times (25/18) = 40\ m^3\}$. Based on these values, the number of trees and the volume of 18~25 trees and 29~40 m^3 may be harvested. Furthermore, it is anticipated that a some of the small diameter trees may be dead due to natural thinning and the number of such trees will be reduced.

2) Induction to the maximum forest stand volume

The forest stand composition described in Yield Table II is that of the forest whose approximate age is 100~110 years old. However, as can be seen from Yield Table I, the period when the forest stand shows maximum volume and the average diameter of the major forest trees shows the highest merchantable volume ratio (DBH is 40 cm or over) is when the forest age is younger than the above, i.e., 70~90 years old. In order to achieve a maximum harvest in terms of both quality and quantity, it is necessary to fell the old trees whose age is 100 years old or over, thereby rejuvenating the forest to some extent. From this viewpoint, too, a slightly increased felling of large diameter trees is permitted.

3) Harvesting of Mukusi wood

In the above, the study was made assuming that all the species are harvested and utilized. Discussed below is a case when only the useful species (for example, Mukusi) are harvested. The volume of Mukusi accounts for about 80% for Site I in the Yield Table II and around 50% for Site II in the total stand volume. Therefore, the allowable harvest of only Mukusi should be 80% and 50%, respectively, of the allowable volume for the entire forest trees. However, the average area occupancy of Mukusi in the region is 50%, according to the photographic interpretation. Therefore, generally speaking, the appropriate allowable stand harvest should be 50%.

If only Mukusi is harvested and other species are excluded from harvesting, the mother trees of other species will increase and their breeding potential will also increase. As a result, the volume of Mukusi in the stand decreases gradually, and eventually it will be difficult to secure a sustained yield as a mixed stand. The area occupancy of Mukusi at Site I in the standard composition was estimated to be 80%, and the fact that it was actually 50% may be attributable to imbalanced fellings in the past.

In order to secure a sustained yield in a Mukusi mixed stand, it is necessary to not only adjust the felling volume of the major forest trees, but to take afforestation measures such as rearing of Mukusi seedlings in an attempt to strengthen the breeding potential.

4) Harvesting in stands whose canopy is open due to forest fires

The yield table given above shows values that assumes the canopies are closed. In reality, however, many forests have only 30 to 60% (in some cases even lower) of the volume values shown in the table due to open canopies caused by forest fires or other abnormal conditions. For the damaged stands, it is necessary to refrain from the felling and to take measures to restore the standard stand composition. Even in these open forest stands, the forest trees compete with one other, when a certain level of closure is secured, and as a result, the dominated trees are produced, indicating that harvesting is possible in some cases.

In open forest stands, competition among forest trees is not keen, causing less natural withering. As a result, the growth of trees in open forest stands may be higher than in closed forest stands in some cases. If a yield is decided taking only the growth shown in Table 22 into consideration, a great contradiction will result.

Figure 29 shows the relation between the stand volume of an open forest and the stand volume of dominated forest trees that exist in the same forest. If the forest stand volume as a matrix is less than $75m^3$, weakening (losing in competition) does not occur. If the stand volume is larger than $75m^3$, approximately 35% of the stand volume in excess of $75m^3$ is known to become weak.

Thus, the volume of secondary forest trees (volume of dominated trees) in an open forest stand is:

$$\Delta V_{20}' = 0.35\,(V - 75) \quad \ldots\ldots\ldots\ldots \quad (3.1)$$

V : Stand volume (m^3/ha)

$\Delta V_{20}'$: Stand volume of secondary forest trees in the forest stand to which a 20-year selective cutting cycle is applied (m^3/ha)

If they are harvested every 20 years, the remaining major forest trees (DBH>25 cm) grow by 0.4~0.6 m^3 in 20 years, so that such harvesting should not impede the recovery of the forest stand as a whole. The allowable harvest can be obtained using the above formula (3.1). If the harvest volume is less than the value obtained from this calculation, not only will the sustained growth be maintained, but also transitions to forest stands that yield a higher volume can be expected.

5) Succeeding trees and prevention of forest fires

The forest stands with an insufficient number of succeeding trees will eventual disappear even if an adjustment is made with the dominant trees. Therefore, such adjustment is meaningless insofar as the sustained yield is concerned. The most significant reason for causing such a situation is the burning of forests. Unless burning is stopped, the problem with sustained yield will not be solved.

However, supposing that forest fires can be completely prevented, and the regeneration of saplings and the regeneration of the forest by natural seeding or afforestation under the natural conditions are possible, then maximum felling that would not damage the forest composition might be allowed. In this case, a slightly larger estimate may be made for an allowable harvest volume in an open forest stand.

3.1.5 Resources management-from standpoint of existing resources

The growth process of forest stands was studied and a yield table was obtained in the preceding paragraph. This paragraph studies the allowable harvest volume of Mukusi resources and the forest stands to be felled.

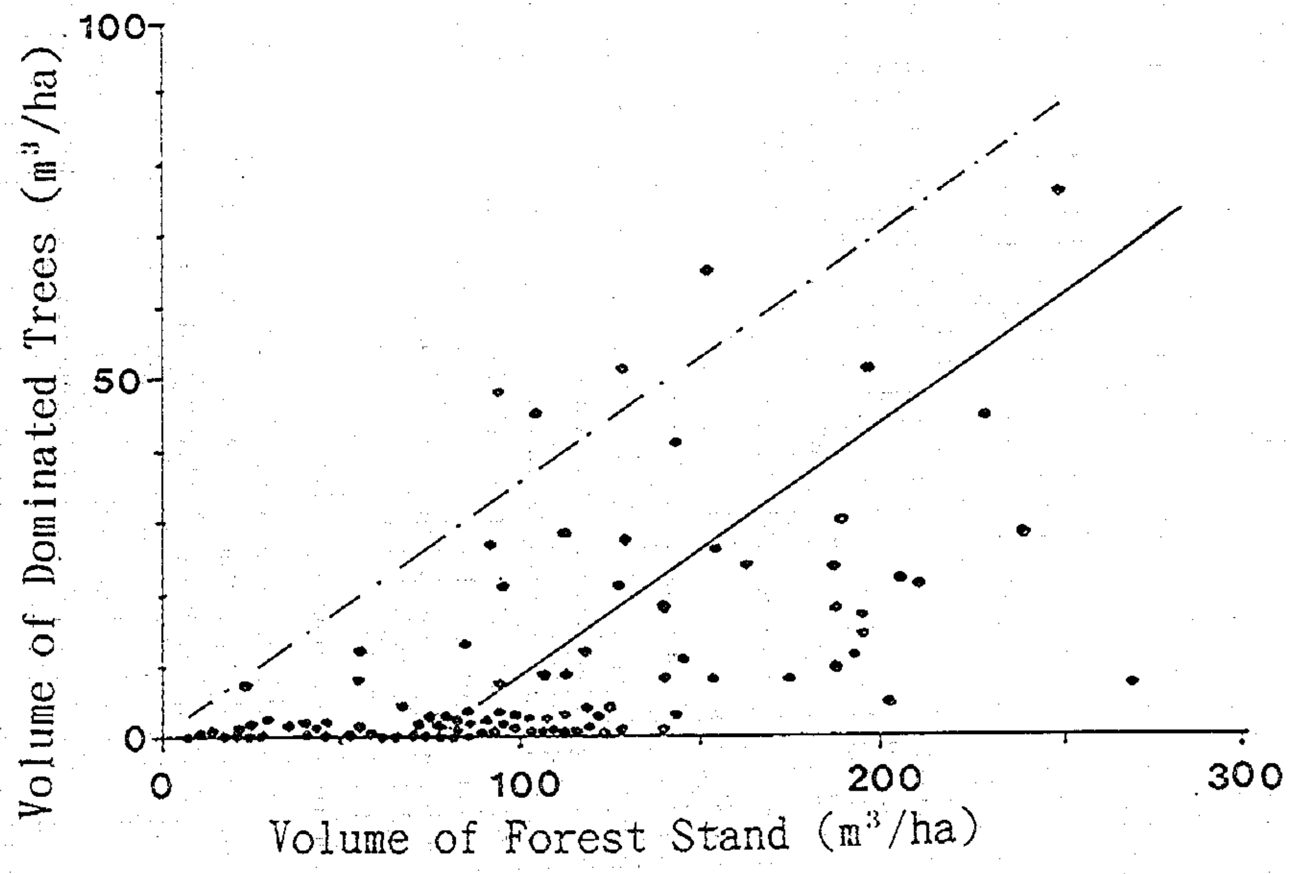


Figure 29

Quantitative relation between volume of dominated tree and volume of forest stand

(1) Study on the allowable harvest volume

The crown-volume conversion table formulated for calculation of the volume has been prepared, based on the crown closure compositions (D1-D3), crown diameter classes (C1-C3) and tree height decisions (H1 and H2).

Forest stands inside Forest Estates can be summarised in the following categories

Table 24 Stand volume according to forest type (in Forest Estates)

Crown diameter class \ Forest crown closure		D1 20%<Cc<45% Σm³ / Σha	D1 m³/ha	D2 45%<Cc<70% Σm³ / Σha	D2 m³/ha	D3 70%<Cc Σm³ / Σha	D3 m³/ha	Total Σm³ / Σha	Total m³/ha
Site I /C3	All tree	879,165	63	1,816,328	116	3,100,720	196	5,796,213	128
Cd>10m	Mukusi	370,258	27	986,319	63	1,673,958	106	3,030,535	67
	Area(ha)	13,955		15,658		15,820		45,433	
Site II /C3	All tree	69,216	42	42,735	77	29,920	136	141,871	59
Cd>10m	Mukusi	30,638	19	14,935	27	7,453	34	53,026	22
	Area(ha)	1,648		555		220		2,423	
Site II /C2	All tree	268,520	35	165,900	60	218,875	85	653,295	50
6<Cd<10m	Mukusi	71,026	9	35,964	13	37,387	15	144,377	11
	Area(ha)	7,672		2,765		2,575		13,012	
Site II /C1	All tree	29,053	17	21,398	26	21,245	34	71,696	22
Cd<6m	Mukusi	3,732	2	385	0	2,160	3	6,277	2
	Area(ha)	1,709		823		669		3,201	
	All tree	1,245,954	50	2,046,361	103	3,370,760	175	6,663,075	104
Total	Mukusi	475,654	19	1,037,603	52	1,720,958	89	3,234,215	50
	Area(ha)	24,984		19,801		19,284		64,069	

Large diameter trees (Site I C3, II C3) account for 70% or more of the area (47,856 ha). Forest stand D1C3 includes a fairly large number of stands which were cut over areas and were strongly affected by forest fires, remaining in a large fire hole in patch form.

The forest stand at Site I D2C3 has a volume of 90~146 m³/ha (116 m³/ha in average) and contains slightly open forest stands with a volume of 75 m³/ha or over.

The forest stand at Site II D2C3 has a volume of 60~110 m³/ha (77 m³/ha in average) and contains stands similar to those mentioned above.

Closed forest stands which can be cut are assumed to be the following:

Site I D3C3 (Site index I / Crown density: 70~100% / Crown diameter: 10 m or over)

Site II D3C3 (Site index II / Crown density: 70~100% / Crown diameter: 10 m or over)

Large diameter trees with crown closure

112 to 248 m³/ha
Area : 16,060 ha (25% of total forests)
Stand volume : 3,130,640 m³ (47% of total stand volume)
(Mukusi 1,681,411 m³)

Shown below are the results of calculations for possible annual volume of harvest using the harvesting method proposed in the preceding paragraph, including the forest stands of large diameter trees with a volume of 75m³/ha or over:

Site I D2C3 (Site index I / Crown density: 45~75% / Crown diameter: 10 m or over)

Table 25 A trial calculation for allowable annual cutting (Cutting cycle: 20 years)

Forest stand type		Area (ha)	Stand volume (m³/ha)	Stand volume (m³)	Cutting intensity	Allowable cutting (m³/year)
I / II D3C3	All Tree	16,040	196/ 136	3,130,640	20% to 25%	31,306 to 39,133
	Mukusi		106/ 34	1,681,411		16,814 to 21,018
I D2C3	All Tree	15,658	116	1,816,328	ΔV =0.35 (V-75)	11,235
					=0.35 (116-75)	
	Mukusi		63	986,319	=14.35	6,100
Total	All Tree	31,698				42,541 to 50,368
	Mukusi					22,914 to 27,118

If the forest stands whose average volume is 75 m³/ha or over are to be cut, the area will be 31,698 ha, which accounts for approximately 50% of the Mukusi forest area. It accounts for only 25% in the total Forest Estate.

The annual harvesting volume is estimated at about 43,000~50,000 m³ for all species and about 23,000~27,000 m³ for Mukusi. The forest stand at Site I D2C3 described above was calculated using the cutting ratio of the calculation, formula. If the cutting ratio of 20~25% is adopted, the possible harvesting volume would increase 50,000~60,000 m³ for all forest trees and 27,000~33,000 m³ for Mukusi, respectively.

(2) Study of forest stands to be harvested using mother tree preservation as a reference point

In selecting the cutting blocks, mainly the above-mentioned forest stands with high crown density (C3D3 of Site I and II) will be chosen. However, if only Mukusi is to be cut, it is necessary to take the mixing rate of Mukusi into consideration. Table 26 shows the totals for individual Mukusi composition rates which were taken from the Forest Inventory Book.

As shown in the table, a fairly large number of forest stands which have Mukusi mixing rates of 0% to 50% are included. Table 27 shows the total number of forests in each Forest Estate, selecting forest stands with a Mukusi mixing rate of at least 50% (assuming preservation of mother tree stands is possible).

The grand total will be:

Area : 10,223 ha (16% of all forests)

Stand volume : 1,999,988 m³ (30% of total stand volume; 196 m³/ha)
(1,438,364 m³ Mukusi)

According to a trial calculation similar to that presented in the preceding paragraph (using these forest stands), harvests of 20,000~25,000 m³/year for all species and 14,000~18,000 m³/year for Mukusi are possible. Since the estimated annual harvest volume in Forest Estates to be discussed in the following paragraph (3.2) is 13,000~14,000 m³, it seems possible to supply Mukusi wood mainly from these forest stands.

In selecting the forest stands to be cut, the Forest Inventory Book and the attached figures are to be utilised; it is desirable to cut the following forest stands.

a. Forest stands at Sites I and II D3C3 where the Mukusi is dominant (M3 and M4: 50% or over)

b. Forest stands around the above forest stands where the mixing ratio of Mukusi is below 50% (M1 and M2) and the forest stands at Sites I D2C3.

For the time being, the cutting of other types of forest stands should be postponed.

As discussed in the preceding paragraph 3.1.1, healthy succeeding trees are essential for the utilisation of the resources (cutting of Mukusi forests), keeping in mind the sustained yield. However, there are few healthy succeeding trees in the Mukusi forests in the region being studied and a sustained yield may not be secured. Based on a study using the aerial photographs, the growth of succeeding trees for Mukusi can be confirmed in the sapling forests, but it cannot be confirmed in closed forests. Selective cutting must be conducted and based on the survey results on the stand density, quality and the diameters of the forest trees, and the number of succeeding trees in order to secure the soundness of the forest stands and to increase productivity. In selecting the cutting blocks, it is necessary to convince the logging contractors to conduct the above-mentioned surveys under the control of the Forest Department before selecting trees to be cut. It is a matter of course that thorough care be exercised to prevent forest fires and that the forest management discussed later be implemented properly.

Table 26 Details of forest type D3C3

Forest name	Compart-ment number	Area (ha)	Forest condition						Volume		
			By aerial photographs								
			Mukusi mixing rate	Crown density class	Crown diameter class	Site index	Middle layer tree		Volume per ha	Total volume	Mukusi volume
		F	M_0-M_4	$D_1D_2D_3$	$C_1C_2C_3$	H_1H_2	S_1S_2		m³/ha	m³	m³
–	–	3,844	4	3	3	1	1/2		196	753,424	659,250
–	–	6,317	3	3	3	1	1/2		196	1,238,132	773,844
–	–	2,653	2	3	3	1	1/2		196	519,988	195,000
–	–	1,560	1	3	3	1	1/2		196	305,760	45,864
–	–	1,446	0	3	3	1	1/2		196	283,416	0
Sub total		15,820							196	3,100,720	1,673,958
Simungoma west	10	62	3	3	3	2	1		136	8,432	5,270
Zungubo	3	107	1	3	3	2	2		136	14,552	2,183
Sijulu	4	10	0	3	3	2	2		136	1,360	0
Lonze	48	41	0	3	3	2	2		136	5,576	0
Sub total		220								29,920	7,453
	Total	16,040								3,130,640	1,681,411

Table 27 Total of forest types M4D3C3 and M3D3C3

Forest name	Number of Compart -ments	Area (ha)	Forest condition							
			By aerial photographs					Volume		
			Mukusi mixing rate	Crown density class	Crown diameter class	Site index	Middle layer tree	Volume per ha	Total volume	Mukusi volume
		F	M_0~M_4	$D_1D_2D_3$	$C_1C_2C_3$	H_1H_2	S_1S_2	m³/ha	m³	m³
Kasiki	3	135	3/4	3	3	1	1	196	26,460	18,352
Malavwe	2	33	3	3	3	1	1	196	6,468	4,043
	8	1,980	3/4	3	3	1	1/2	196	388,080	285,183
Simungoma west	1	62	3	3	3	2	1	136	8,432	5,270
Simungoma east	10	2,364	3/4	3	3	1	1/2	196	463,344	401,411
Sikubingwa	3	303	3/4	3	3	1	1	196	59,388	50,005
Sisisi	6	537	3/4	3	3	1	1	196	105,252	81,365
Nanyota	1	86	3	3	3	1	2	196	16,856	10,535
Lumino	1	81	3	3	3	1	2	196	15,876	9,923
Kayumbwana	3	490	3	3	3	1	2	196	96,040	60,026
Sijulu	1	260	3	3	3	1	2	196	50,960	31,850
Kazu-Namena	2	430	3	3	3	1	1/2	196	84,280	52,676
Nanga	1	751	3	3	3	1	2	196	147,196	91,998
Lonze	9	1,276	3/4	3	3	1	1/2	196	250,096	159,937
Situmpa	13	1,435	3	3	3	1	1/2	196	281,260	175,790
Subtotal		10,223						196	1,999,988	1,438,364

3.1.6 Harvesting trees of other species

Although a full-scale plot survey was not conducted on trees of species other than Mukusi, a rough ocular estimation was conducted and the results are described below.

(1) Mukwa

Mukwa is a species that often grows in woodlands where Mukusi are mixed. There is a large demand for Mukwa to be used as board wood and plywood for furniture. It seems that the quantity of Mukwa and its distribution are not grasped precisely.

In forest stands where the mixing ratio of Mukwa is high, it has been estimated that Mukwa accounts for up to 35% of the quantity (of 440 trees per ha in a forest stand, 160 were Mukwa with a diameter of 6 cm or over) and up to 40% in terms of the volume (150 m³/ha, 65 m³). However, in reality, such high stand volume is rare, and there are many forests where the mixing ratio of Mukwa is negligible. Among the forest stands in regions that are subject to logging, there are many cases where the number of Mukwa, whose diameter is 25 cm or over, is as small as 4~5 and the volume 6 m³/ha. The average stand volume of Mukwa where it is mixed in woodlands only was estimated and based on a small number of plot surveys and observations. According to the estimation, there are at least 15 m³ of Mukwa per ha.

It seems that the land area suitable for Mukwa is broader than that for Mukusi and Mukwa is more widely distributed than Mukusi. However, since the number of Mukwa trees and the volume per ha are limited and the habitat has been reduced due to forest fires, the total volume of Mukwa in the southwest region seems to be significantly lower than that of Mukusi. Supposing that there are 20,000 ha of woodlands with Mukwa mixed in, the total volume should be at least 300,000 m³ and the average annual growth should be 3,700 m³, assuming that the average tree age is 80 years old. On the contrary, the present annual demand for Mukwa (in terms of the standing tree volume) is estimated to be 2,000 m³ and, therefore, it can be said that Mukwa trees are not being excessively cut at present. However, it is feared that if the production of boards, plywood, etc. increase in the future and the demand increases, the harvest volume will exceed the growth of Mukwa and, as a result, a sustained yield of Mukwa may not be secured.

The law specifies that Mukwa whose diameter at breast height exceeds 30 cm, may be harvested. According to the survey conducted at this time, it was made clear that the merchantable volume ratio of logs with respect to the standing tree volume is as high as 85% for those whose diameter at breast height is 35 cm or over. Therefore, it seems appropriate to raise the diameter class of the standing trees that can be cut from the present 30 cm to 35 cm. However, if only the diameter class that can be cut is reduced, the number of mother trees required for a sustained yield may not be reserved. It is, therefore, necessary to specify the number of mother trees to be reserved in order to secure a sustained yield of Mukwa stands.

Although the Mukwa seeds have a high driftability, at least 4~5 large diameter mother trees per ha are required for rearing the succeeding trees. Therefore, the harvesting of large trees whose diameter is 35 cm or over should be prohibited, even if the number of such trees per ha is 5 or under.

Moreover, in case more than 5 mother trees per ha remain after the harvest, the felling rate of the volume should be restricted to 25% or under. Mukwa grows faster than Mukusi and reaches a cutting age in 80 years, so that the cutting of 25% may be permitted under the 20-year selective cutting cycle.

(2) Mupane

The root system of Mupane is moisture-resistant and Mupane grows well in overhumid soil where stale water is retained during the rainy season (poor drainage). Other species cannot grow here because the roots rot in such soil, so in these places only Mupane tends to grow, forming pure forest stands.

Such overhumid areas can be found in the high flood plains along the main stream of the Zambezi River in the southwest region and in the delta plains formed in the downstream areas of the Machili River, Loazamba River, Loanja River, etc., the tributary rivers of the Zambezi River. The growth area amounts to only 30,000 ha in the district surveyed and is estimated to exceed 80,000 ha for the entire district.

Mupane trees grow in poor soil conditions and, therefore, never form a forest of closed canopy and, in all the cases, form a woodland. In a forest stand having a highly closed canopy, it was observed that about 100 trees per ha have grown to the height of 14 m and DBH 15 ~35 cm with the volume of 70 m^3/ha. However, in many cases, the forests have much more open canopies and the average volume (50,000 ha excluding the grassland) is about 20,000 m^3/ha and the total volume in 50,000 ha is estimated to mount to at least 1,000,000 m^3. In addition, the number of 15 cm, exceeds by far the number of trees whose diameter is 15 cm or over. Mupane is, therefore, a species that may be readily reproduced and is forming a suitable stand composition.

Mupane grows fast and, in about 25 years, grows to a forest tree whose DBH is 20 cm. Therefore, the total average annual growth in the district is estimated to be 1,000,000 m^3/25 = 40,000 m^3, which is equivalent to that of Mukusi

Mupane is widely used for roofing materials and fuel by local residents as well as for the construction of boats. Annual demand is extremely small when compared to its growth. If the harvest volume is less than the growth, Mupane can be reserved and will be a valuable woodland resource having a sufficient harvestable capacity. As a matter course, Mupane can also be used for other purposes, such as the production of charcoal, etc. In this case, selective cutting should be adopted in principle.

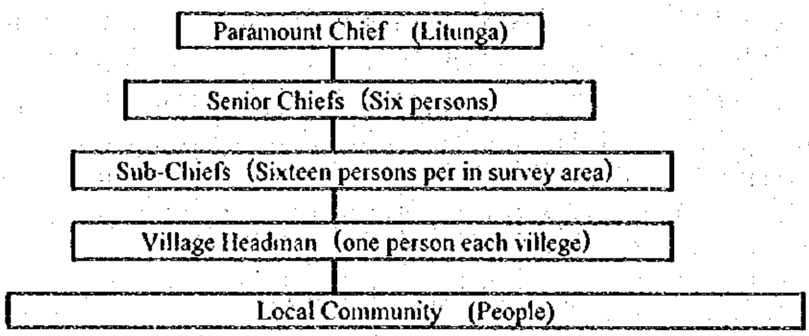
3.2. Socioeconomic Survey for Local Development

This section describes the characteristics of the chief system, land ownership system, forest protection system, which regulates the social economy in the areas of this study, and the property of farm households. Next, the results of a village survey and house-to-house peasant household survey are collected regarding the relation between the regional residents and the forest. Thirdly, the survey results on the actual situation and the future prospects of commercial utilization of Mukusi and Mukwa are described. Finally, a proposal is introduced on the present use of wood, its estimated influence on forest resources in the future, and socio-economic improvement in the regional community so as to make the best use of forests.

3.2.1. Socioeconomic characteristics of the study area

(1) Chief system

The chief system, which still remains in westem province of Zambia, is a traditional and customary class system of the Lozi tribe , which has continued since the days of the Lozi Kingdom. In effect, the Barotse Royal Establishment, as shown in Figure 30, has six senior chiefs, who are under a paramount chief (Litunga). The senior chiefs are stationed throughout westem province. Under them, sub-chiefs (16 in the study area) and village headmen (one per each village) are placed to form the hierarchy. Even today, the chief system is a valid system, providing a guideline for local community life.



Note: As stated by teak forest project manger

Figure 30 Hierarchy of chief system in Barotse Royal Establishment

The administrative system is made up of province, district and city. But an administration does not exist for the village, and the village headman, although holding the lowest position in the chief system, assumes a substantial part of the responsibility. In this way, western province has a dual constitution of power, so the provincial government cannot disregard the chief system. Particularly, at a village in the study area, the real state of affairs is that a village headman deals with various problems in consultation with the sub-chiefs.

In relations between the sub-chiefs and local residents, the residents revere and respect the sub-chiefs. On the other hand, the sub-chiefs are the people to talk to about daily events, as they have access to the local residents.

To the question "Did you give any gifts to the sub-chiefs?" the following replies were received:

- If the yield of maize or other crops is good, a part of the crops or some money (small amounts, such as K100 or K50 per household) may be presented to them by collecting crops or money from the local residents, provided some crops are sold.

- Four woven mattresses of grass grown in dambos were donated by a village.
- If the catch of river fish is good, some fish are dried and presented personally to the sub-chiefs.
- Rainfall during the rainy season was light this year, and the crop yield was poor. Nothing could be presented. If asked by the sub-chiefs to do shopping errands, or little tasks such as tending cattle, labor is provided to the chiefs.

To the question "Is there anything that cannot be done without a permit from a sub-chief?" the replies included the following:

- Expanding farm land.
- Moving one's home to another village.
- Building a new home.

The sub-chiefs are consulted through the village headman if problems that disrupt peace in a village happen (quarrels due alcoholic intake, farm land cheating, women problems, etc.).

In one village, males gather in the house of a sub-chief every Thursday and discuss affairs and problems in the village, such as farm land problems or construction of schools and hospitals. The sub-chief acts as an MC and counselor.

The local residents respect the sub-chiefs and associate with them every day as people who are close to them. However, the local residents revere the paramount chief, the senior chief, and the son of the paramount chief who lives in Muandi

The status and roles of the chief system are stipulated in the laws of Zambia as mentioned below.

Chiefs = The Chiefs Act, Chapter 479, The Laws of Zambia, describes the chief system. By this act, the status of the chiefs and the relationship between the state and chiefs is outlined. The composition and relevant parts of the act are as follows:

Composition:

1. Short Title
2. Interpretation
3. Recognition of Chiefs
4. Withdrawal and suspension of Recognition Accorded to Chiefs
5. Inquiries
6. Deputy Chief
7. Exclusion of Former Chief or Deputy Chief from a Specified Area
8. Payment of Subsidies to Chiefs and Deputy Chiefs
9. Kapasus
10. Functions of Chiefs and Deputy Chiefs
11. Preservation of Public Order
12. Offences and Penalties
13. Instituting of prosecutions
14. Payments Under the Act
15. Savings

Contents:

The Act as it relates to the status and roles of the chiefs and their relationship with the State is briefly mentioned below. The preamble includes the reasons for the enactment of the Act as follows: [This Act establishes recognition, status, function, and exclusion of the chiefs and deputy chiefs. Moreover, the status and function of the kapasu is also established, problems that are likely to occur, and succession.]

Recognition of Chiefs:

1) The President of Zambia approves the appointment and duties that relate to the following:

- Appointment of the Lozi Paramount Chief (Litunga) of western province and of other chiefs in the province
- Duties of the paramount chief, senior chief, chiefs and sub-chiefs

2) Duty officers are approved only in the following cases:

- If the President is convinced that persons can be recognized as duty officers under the African Customary Law.
- If approved by the traditional congress comprising members duly elected by the chiefs of western province, paramount chief of the Lozi and members of the ruling tribes of western province and the paramount chief of the Lozi.

Payment of subsidies:

The chiefs and deputy chiefs will be paid subsidies to carry out traditional functions required for their duties under the African Customary Law, which by special tradition, must be kept to maintain the status of their positions. The President of Zambia decides the amount of subsidies.

Functions of Chiefs and Deputy Chiefs:

The traditional duties under the African Customary Law shall be carried out as long as their implementation is not objected to by organizations, nor should this run counter to function, justice or morals.

The chiefs are required to take the means to maintain public order in the region and to lessen disorder without resorting to unreasonable means.

(2) Land tenure system

Since 1991, land in Zambia has legally belonged to the President of the Republic through the Land Acquisition Act, Land and Deeds Registry Act, and other acts. However, in reality, western province was proclaimed to be a special reservation area and the Barotse Royal Establishment of Lozi still prevails in western province.

Farm land, residential land and other land which local residents use every day is traditional land allocated for Land use by the chiefs. Basically, this land belongs to Litunga (paramount chief of the Lozi). The Litunga entrusts the director generals and induna of each district regarding Land use and heads (village headmen) of regions under districts to loan, distribute and perform acts related to land in dealing with peasants.

Such land can be divided roughly into (1) land which belongs to the ruling hierarchy and (2) land whose rights (farming rights) for production are bestowed to household masters.

"Rights for production" include the right to gather fruits and nuts from fruit trees, grazing rights on land and fishing rights in case the land is ponded. Other persons cannot infringe on these rights without good reason. Land management and usage rights are passed from parents to children.

Basically, "traditionally land" in forest land is construed in the same way as in farm land or other land. However, as reported in the Preliminary Study Report, Forest Estates which are separated from traditional utilisation land are contained in the study area. These Forest Estates seemed to have been decided by consultation between the Forest Department and chiefs. The local residents told us in the recent village survey: "We cannot enter the forests and what we can gather from them has been reduced." It appears that the local residents feel that "they have been forced to move out of the forests." Some measure to alleviate this friction will be needed.

(3) Forest protection system

According to the Barotse Royal Establishment of Lozi, which is a written law, all fruit-bearing trees are protected, and non of these trees can be cut or burned. Certain trees are protected under the Barotse Royal Establishment of Lozi. These tree species are listed below:

Fruit-Bearing Trees:

Muhuluhulu, Muwawa, Mumonsomonso, Muzinzila, Muhamani, Mujongolo, Mubula, Mungongo

Industry Wood:

Mwande, Mulombo, Muzauli and Mukusi

The following tree species are protected in western province under the Forest Act:

Mwande, Mulombo, Muzauli, Mukusi, and also other species which are traditionally protected.

Almost all forests published in the official gazettes of western province are designated by the Barotse Royal Establishment of the Lozi as forest reserves. Under the Barotse Royal Establishment of the Lozi, fruits, mushrooms, dry trees and honey can be gathered freely from these forests. Hunting is also allowed. However, at present, one needs a permit from the Forest Department to gather firewood in the forest reserves. Again in this case, there are conflicting aspects in accordance with the difference in the stand. Felling of trees in the forest reserves is allowed by neither the Barotse Royal Establishment of Lozi nor the Forest Act.

Charcoal-making is prohibited in western province in accordance with the Barotse Royal Establishment of the Lozi. The Forest Act allows only those who have obtained a license to produce, transport and sell charcoal within the licensed scope. For this reason, officially charcoal is not produced in western province at present. Firewood is used for cooking, heating and other purposes almost exclusively by local residents. Production of charcoal could not be confirmed during the field reconnaissance, village survey, and individual peasant household survey.

Thus, wood is protected against charcoal production.

(4) Farm household assets

Cattle are a valuable asset to the farmer. In western province, the possession of many cattle is recognized as a traditional symbol of wealth. For example, as a customary practice, a bridegroom is expected to give four head of cattle to the family of the bride (may change depending on his economic situation). This custom is still practiced, and in certain areas there remains a large number of people who think a great deal of this tradition.

The affluence of a family can be gauged by counting how many head of cattle the family has.

3.2.2. Village survey

Interviews were conducted in four villages to understand the relation between local residents and forests, wood utilisation and other items. The survey method and themes were as follows:

- The village headmen were interviewed about the general condition of the villages.
- We interviewed the villagers collectively about firewood-gathering.

(1) Economic condition of surveyed villages

App. Table 20 summarises the surveyed villages.

1) Katongo village

Katongo village is located on the southwestern edge of the study area, along a national road 18 km east of Sesheke. Among the four villages surveyed, this village is located nearest to Sesheke.

The village headman did not know exactly how many people and how many households there were because there were relatively many people and households in the village.

There were 50 head of cattle in the village and the number of livestock raised was relatively small. The village was not engaging in burning and rotating cultivation.

The village was not able to yield maize and other agricultural products at all as they failed to grow due to a lack of rain during the rainy season. Some farm households could feed themselves. There were families which had meals only every other day due to a lack of food.

2) Namei village

As with Katongo village, Namei village is located on the southwestern edge of the study area. The village is located 30 km east of Sesheke and is next to Katongo village.

The population of the village is 169 and the number of households 50, so the village is a relatively small. In livestock ownership, there were as many as 750 poultry, but only 40 head of cattle. Both Namei and Katongo Villages are ruled by Sub-chief Katundu.

3) Kobia village

Kobia village is located in the center of the study area and is surrounded by dambos. It is located 5 km northeast of the Masese Forest Station.

Kobia village has a population of 1,450, with 300 households, making it a large village. There are up to 200 head of cattle in the village. Up until several years ago, some of the dambos in this village were submerged throughout the year, and the villagers fished from canoes. At present, there are no dambos that are submerged, except during the rainy season, and fishing is no longer possible. It was mentioned that the rainfall during the rainy season in the past two years was scant and that the yield of farm products was decreasing.

4) Mahare village

Mahare village is located on the northwestern edge of the study area. The village is sandwiched between two Forest Estates, Kanyanga Local Forest (No. 391) and Nanga Local Forest (No. 390), and like Namei village, is a small village with a population of 170 and 38 households. The village had 200 head of cattle, or more than five head per household.

A serious problem for the village is that the yield of maize and other farm products has decreased recently because farming has been performed on the same land for the past 20 years.

These four villages share the following points in common:

- Farmers engage in fixed cultivation only. Organised burning and shifting cultivation are not carried out.
- Charcoal is not produced, either for villager consumption or for sale. Only firewood is used as a fuel.
- Recently, the yield of farm products has decreased drastically due to a lack of rainfall during the rainy season. An absolute food shortage is being experienced.
- Adequate clothing is lacking. Many residents are in poor economic shape, hardly capable of feeding themselves.

(2) Firewood gathering

As mentioned above, charcoal is not produced and the gathering of firewood for household consumption is a very important task.

Table 28 shows the results of an interview regarding firewood gathering days, places and methods. We spoke with local residents who gathered for village surveys.

The following can be surmised based on the foregoing results:

- Firewood is gathered only in woodlands.
- Except for Namei village, firewood is gathered almost entirely by picking up dead wood. However, it is possible to pick up a dead tree that was cut beforehand.
- Firewood is gathered every other day in Katongo village, every day or every other day in Namei and Mahare villeges, and once every three days in Kobia village.

Table 28 Frequency of firewood collection

Village name	Population (person)	Collection day, Percentage			Place of collection	Collection method rate	
		Yesterday	Today	Tommrow		Pickup	Felling
KATONGO	51	21.6	1.9	43.1	WOODLAND	98.1	1.9
NAMEI	66	75.8	15.2	53	WOODLAND	41.9	58.1
KOBIA	89	30.3	0	0	WOODLAND	100	0
MAHARE	31	22.6	54.8	64.5	WOODLAND	100	0

Note: Population means total number of interviews.

Yesterday : percentage of persons who collected firewood yesterday.
Today : percentage of persons who went or will go to collect firewood today.
Tomorrow: percentage of persons who will go to collect firewood tomorrow.

3.2.3. Farm household survey

Five farm households from each of the four villages interviewed in the village survey were selected (total 20 households) and were interviewed based on a questionnaire to determine in detail the actual living condition of the local residents and agricultural production and the present status of wood utilisation.

(1) Characteristics of surveyed farm households

App. Table 21 summarizes the surveyed farm households.

1) **Households by age of household masters**

The age brackets of household masters were classified as follows and the number of households by age bracket is shown below:

- 60 years and older .... 7 households
- 40 to 60 years old .... 6 households
- Below 40 years old .... 7 households

2) **Number of children per household**

The number of children per household is five on average.

By sex, there are three boys and two girls.

3) **Farmland area**

The average farmland area per farm household is 2.4 ha.

Compared with the average farmland area per farm household in Zambia of 10 ha, this is extremely small. Only one farm household was cultivating an area larger than 10 ha. Four farm households were farming less than 1 ha of farmland. However, farmland areas and farm product yields are not proportional. For example, a 10 ha farm household did not have a maize yield, while a 1 ha farm household had a yield of more than one ton of maize.

4) **Number of livestock**

Regarding livestock, on average, a surveyed farm household kept 4.7 head of cattle, less than half the average of ten head for Zambia. It raised 0.7 goats. Goats were not raised except for four households. Many farm households raised hens and 5.8 poultry were kept on average.

Cattle ownership, which represents the size of wealth for the Lozi, is divided into the following steps, and the number of farm households owning applicable numbers of cattle is shown below:

- More than 5 head of cattle .... 8 households
- 1 to 5 head .... 7 households
- None .... 5 households

5) **Farm product yields**

Except for those farm households who seeded timely, yields of field crops are decreasing drastically in recent years due to a lack of rainfall during the rainy season. Yields are not sufficient for self-consumption and none of the farm households sold crops.

- Maize

  The average yield is 150 kg, so this value can be attributed to the very high yield household. The number of households by yield is shown below:

  91 kg or over .... 4 households
  90 kg (1 bag) .... 8 households
  Less than 90 kg .... 4 households
  No yield .... 4 households

• Millet

The number of households by yield is shown below:

25 kg .... 4 households
No yield .... 16 households

• Sorghum

The average yield per household is 33 kg. The number of households by yield is shown below:

90 kg (1 bag) .... 5 households
Less than 90 kg .... 7 households
No yield .... 8 households

• Others

Harvested vegetables for self-consumption include some beans, tomatoes, Chinese cabbages, rapes and okra.

6) Ownership of farm implements

Adequate farm implements are not owned in the survey area in western province, including Sesheke District.

The only farm implements owned by households are plows, hoes and axes. The number of implements owned is shown below:

• Plows

A steel farm implement pulled by an ox to plow the fields. An average farm household owned 0.9 plows, or less than one plow per farm household. The number of farm households by ownership class is shown below:

2 plows .... 2 households
1 plow .... 13 households
None .... 5 households

• Hoes

An average farm household owns 3.3 hoes, while all farm households owned more than two hoes. The number of farm households by ownership class is shown below:

5 hoes or more .... 3 households
3 to 5 hoes .... 9 households
2 hoes .... 8 households

• Axes

Axes are important implements with which to fell trees and to cut firewood. One farm household owns 2.7 axes on average. The number of farm households by ownership class is shown below:

5 axes or more .... 3 households
3 to 5 axes .... 4 households
2 axes or less .... 13 households

(2) Present status of wood utilisation

Wood is utilised by farm households for two important applications, as firewood and as building materials for residential houses.

1) Firewood species

Table 29 shows the number of farm households using firewood according to tree species.

Ten tree species were found to be used as firewood by the farm households. Among these ten species, species that were used by almost all farm households as firewood were Muhonono (*Terminalia sericea*) by 17 farm households, Mububu by eight farm households, Mukusi by seven farm households, and Mwangula by six farm households. Mukusi was used as firewood only by gathering cut, withered trees which were dry, rather than cutting and gathering standing trees.

Firewood used by villages:

- Katongo village : Mainly Mohonono
- Namei village : Mostly Muhonono and Muhoto
- Kobia village : Four species, Muhonono, Mububu, Mukusi and Mwangula were evenly used.
- Mahare village : Mukoka was used more than Muhonono.

Table 29 Species used for firewood

(household)

Village	Muhonono	Mububu	Mukusi	Mwangula	Muhoto	Mukoka	Musese	Mubako	Isunde	Mupanda
KATONGO	5	2	0	0	0	0	1	2	1	0
NAMEI	4	1	2	0	4	0	2	0	0	0
KOBIA	5	4	5	5	0	0	0	0	0	0
MAHARE	3	1	0	1	0	4	0	0	0	1
TOTAL	17	8	7	6	4	4	3	2	1	1

2) Firewood gathering frequency

Table 30 breaks down the frequency of firewood gathering by farm households.

Those farm households which gather firewood once every week total nine at most followed by six farm households which gather firewood everyday.

Firewood is gathered by the farm households in the villages as follows:

- Katongo village : None of the farm households gather it everyday. Firewood is gathered several times in week.
- Namei village : Some farm households gather it everyday, while other farm households gather it once per week.
- Kobia village : None of the farm households gathers wood everyday. Firewood is gathered once per week.
- Mahare village : Almost all farm households gather firewood everyday.

Table 30 Number of firewood collections in survey of peasants

(households, %)

Village	Number of times				No answer
	Everyday	Once a week	3,4 times/week	2 times/week	
KATOGO	0	2	1	1	1
NAMEI	2	3	0	0	0
KOBIA	0	4	0	1	0
MAHARE	4	0	0	1	0
TOTAL	6	9	1	3	1
%	30.0	45.0	5.0	15.0	5.0

3) Building materials

Table 31 presents the number of farm households that use wood as building materials.

Only a few farm households use wood as building materials. However, three tree species are used for these purposes, and are included among those species that are used for firewood, too. Wood for building purposes is gathered by cutting standing trees in good shape, instead of picking wood up in woodlands. This is different from firewood gathering.

Table 31 Species used for building materials

(household)

Village	Muhonono	Mukusi	Mwangula
KATONGO	1		
NAMEI			
KOBIA			
MAHARE	1	1	1
TOTAL	2	1	1

(3) Fruit gathering and fruit-tree cultivating

Wild fruits are gathered from forests and woodlands in different seasons, supplying vitamins and minerals that are essential to the diet of the local residents. Some residents cultivate fruit trees around their homes and in the field to stabilize gathering. The actual state of fruit gathering and cultivation was determined during an interview survey.

1) Gathering of wild fruits

Table 32 shows the number of farm households by type of wild fruits gathered, summarising the interview at four villages. Eleven kinds of fruit are gathered. Of them, muchinga (popular name: basard dwababerry) was most popular and was gathered by 18 farm households, followed by muzinzila (bird plum) by eleven farm households, mufurefure (bitter grape) by eight farm households and mubilo (wild medlar) by six farm households.

A breakdown of wildfruits gathered by the farm households in the four villages is as follows:

- Katongo village: Eight kinds of fruits. Muchinga was gathered by all of the farm households.
- Namei village : Nine kinds of fruits. More farm households gathered muzinzila and mufurefure than muchinga.
- Kobia village : Two kinds of fruits were gathered. All of the farm households gathered muchinga.
- Mahare village : Muchinga was the only fruit which was gathered.

Table 32

Number of households which collected wild fruits from forests and woodlands

(households)

Village name	Muchinga	Muzinzila	Mufurefure	Mubilo	Munionsomonso	Mubula
KATONGO	5	4	4	4	2	1
NAMEI	3	4	4	2	1	1
KOBIA	5	3	0	0	0	0
MAHARE	5	0	0	0	0	0
TOTAL	18	11	8	6	3	2

(households)

Village name	Mungongo	Mubuyu	Mukonongwa	Mutente	Mulutulua
KATONGO	0	1	1	0	0
NAMEI	2	0	0	1	1
KOBIA	0	0	0	0	0
MAHARE	0	0	0	0	0
TOTAL	2	1	1	1	1

2) Planting fruit trees

Table 33 shows the proportion of farm households with experience in planting fruit trees and tree species.

"Have planting experience" accounted for 70%, far exceeding the 30% with "No planting experience." Two out of three farm households have had experience in planting fruit trees.

Six kinds of fruit trees are planted, including mango and muzinzila. Some peasants have had experience in planting cassava, sugar cane and other plants besides fruit trees.

Fruit trees which were planted by farm households are broken down by village as follows:

- Katongo village : Some peasants planted guyaba and papaya.
- Namei village : Fruit trees can be divided roughly into muzinzila and mungongo.
- Kobia village : A relatively large variety of fruit trees are planted in this village. It is characteristic of this village is that three farmers were planting lemons.
- Mahare village : A relatively large number of peasants have no experience in planting fruit trees.

The planting of fruit trees is done by cutting branches and inserting them in the ground, except for the seeding of mango by some peasants. Only few fruit trees bear fruit, and some trees die due to low temperatures at night or a lack of water, or the roots are gathered for food. Most of the fruit trees wither within years after planting or within one year at the earliest. Among these fruit trees, some of the Muzinzila grow into large trees and bear a large amount of fruit in March of every year. The growth of fruit trees is greatly influenced by the weather of that year. But the important thing is to plant in land favored with water, and not to neglect culture management, such as supplying water in the dry season or taking countermeasures against the cold. As a concrete countermeasure against cold in the dry season, even covering a sapling with an empty can be quite effective. Another important purpose to plant fruit trees is to acquire shade in the garden, in addition to harvesting fruits. Only by staying in the shade is it possible to spend the day comfortably.

Table 33 Number of households which tried to plant fruit trees

(households)

Village name	Planted	Plant species							Not planted
		Mango	Muzinzila	Guyava	Lemon	Papaya	Mungongo	Others	
KATONGO	4			1		1		2	1
MAMEI	4		2				2	1	1
KOBIA	4	2	2	1	3	1		4	1
MAHARE	2	2		1				2	3
TOTAL	14	4	4	3	3	2	2	9	6
%	70	28.6	28.6	21.4	21.4	14.3	14.3	64.3	30

Note: When seeds and blanch are used to plant fruit trees.

3.2.4. Commercial use of Mukusi and Mukwa

(1) Present use of sawmills

Three sawmills are located in the study area, namely, the Sesheke and Mulobezi Sawmills of Zambezi Sawmills, Ltd. and the Mukusi sawmill of ITT Supersonic, Ltd. As is generally observed in sawmills of developing countries, these sawmills follow an integrated approach to production from standing tree felling to lumber production. The two companies have acquired logging concessions in National Forest to March of 1995 and in Zungubo to July of 1995. Zambezi Sawmill, Ltd. has a logging concession in the Mazaba woodland, and ITT Supersonic in the Ngambwa woodland. Among these three sawmills, the Mukusi sawmill is expanding the production of Mukwa while reducing the production of Mukusi. The Mulobazi sawmill has halted its operation at present.

1) Mukusi wood

Production Trend:

Tables 34 and 35 show the production of Mukusi at Zambezi Sawmills Ltd. and ITT Supersonic Ltd. since 1992.

Even though production at Zambezi Sawmills is decreasing, the company cuts more than 6,000 standing trees in a year and produces approximately 2,500 m^3 of lumber from approximately 6,000 m^3 of logs. This production quantity includes some Mukwa, but the majority of production is in Mukusi. Production at ITT Supersonic is very small compared with that of Zambezi Sawmills and was below 100 m^3 in 1995. This was caused by a change in the production policy of ITT Supersonic, when it shifted from Mukusi to Mukwa.

Specifically, the Mukusi sawmill has stopped its operation at present and is replacing the sawmill machines. It is installing a slicer and is expected to start producing Mukwa board lumber and Mukusi veneer for panels.

As described earlier, Mukusi is produced almost entirely by Zambezi Sawmills, Ltd.

Table 34 Production of Mukusi in Zambezi Sawmills

Year	Number of felled trees	Input volume (m^3)	Output volume (m^3)	Production rate (%)
1992	7,567	N.A	2,925	N.A
1993	7,125	N.A	2,510	N.A
1994	6,458	5,812	2,325	40
1995	8,500	7,500	3,000	40

Note: 1995 numbers are target numbers.

Table 35 Production of Mukusi in ITT Supersonic Ltd. (Mukusi sawmill)

Year	Production volume
1992	250 m^3
1993	350 m^3
1994	210 m^3
1995	80 m^3

Standing Trees for felling:

Mukusi trees that are at least 30 cm in diameter at breast height can be felled. The same applies to the Mukwa.

Size of Dissected Bole:

When producing sleepers, three logs are yielded on average from one standing tree with a 1.2 m log size. When producing industry wood, such as boards and squares, logs are yielded to 3 m.

Log Utilization Rate:

At 40%, the yield rate for sawn wood at Zambezi Sawmills is low. Some of the remaining 60% is used for making deck brush handles and other uses. However, almost all of them is used as firewood.

The yield rate at ITT Supersonic is 50% for sleepers, and 75% for boards. This is relatively high. At present, the log yield rate is 40 to 50% for sleeper production and 75% for board production.

Uses of sawn lumber:

At Zambezi Sawmills, Ltd., 42% of its total production is for sleepers, which is the main production item. ITT Supersonic produces a diverse variety of products, such as sleepers, flooring materials and veneer for panels.

Sales channels for sawn lumber:

Zambezi Sawmills plans to export 30% of its total production. ITT Supersonic exports 50% of its sawn lumber (10% Mukusi) and sells the remaining 50% on the domestic market. However, Mukusi exports are decreasing year by year.

2) **Mukwa wood**

The demand for Mukwa wood is increasing as furniture wood. Nearly 90% of ITT Supersonic's production is in Mukwa wood. Mukwa wood accounts for 40% of its exports. Compared with Mukusi, Mukwa is light and its texture is soft so that it can be processed easily. Mukwa grows fast and is abundant in resources. Mukwa is fast attracting attention as an industrial wood.

However, the stand volume, composition in forests and woodlands and other parameters of Mukwa are not determined yet. At present, the cutting of standing Mukwa trees in woodlands is permitted if the diameter at breast height is at least 30 cm. In many respects, the sustainability of Mukwa is yet to be clarified and a future study will be required.

3) **Employment opportunities**

Zambezi Sawmills, Ltd. employs a total of 250 personnel. Of this number, 186 employees are engaged in felling and sawing. At ITT Supersonic, 60 of its 180 employees (total) are sawmill workers.

These two companies employ 430 employees, of which 246 work in tree felling and sawmill operation. This number represents 2% of the total number of households in a Sesheke District of 12,206, so the employment opportunities are still low at present.

4) **Lumber demand and resources**

The demand for lumber in Zambia is stagnating because the market is small and the purchasing power is still low. Railways in Zambia could be extended to increase the demand for sleepers, and the living standard in urban areas could be enhanced to increase the demand for residential flooring materials, thereby increasing timber consumption and expanding the lumber market. At present, the possibilities are remote. For this reason, the prospect for expanded production of the sawmills and expanded sales is not good.

On the other hand, this study has indicated that the Mukusi resources are smaller than thought to be. Also, the quantitative demand for resources has been understood to be low.

Under these circumstances, the sawmills seem to fully understand that Mukusi resources are decreasing. However, measures to counter this situation, such as importing logs from other countries and afforestation, are not being seriously considered for the reasons mentioned above.

ITT Supersonic is shifting its emphasis to production veneer from Mukusi logs for processing into panel plywood. This trend is attracting much attention from the standpoint of a more efficient processing of lumber and effective utilization of resources.

Under these circumstances, the impact of these two sawmills on the reduction of resources seems to be small, judging from the current demand level. In the present situation, expansion of demand and commercial development are necessary, but valuable resources must be preserved. In the future, it is necessary to view the use of timber from a long-term point of view. If this can be achieved, the forests will serve as a defence against desertification.

(2) **Pitsawing**

Pitsawing of Mukwa is "small-scale classical sawmilling." A felled Mukwa log is put on a crosspiece, which is put in an excavated pit in the ground. A saw is moved vertically inside the pit and above the log to saw lumber. Excavation of holes is hard labour, so logs are put on a scaffold for sawing.

A permit is required from the Forest Department before pitsawyers can fell trees. At present, the concession period is 3 years.

Normally, pitsawing organisations are formed by masters, who have obtained a logging concession and who employ several groups of pitsawyers. Two or three pitsawyers belong to one group, and they lodge at pitsawing sites in order to cut fell and saw. Pitsawing is extremely hard work, as two men manually saw planks directly from logs using a 2 m saw. Because pitsawing is manual, more than 30 minutes is required to vertically saw a log, so productivity is low.

In view of the labour requirements, wages are based on output, while the masters pay for saws and meals at sites. Sawmill workers are, therefore, males in their high teens to 30 years of age.

Although 7 permits were issued in the past, 5 have been revoked, leaving only two pitsawing licences in Seshcke District of western province. The pitsawing concession areas are the Mazaba and Lutaba Woodlands, the latter of which was studied.

1) Pitsawyers in Lutaba woodland

Lutabe woodland is located north of Masese, and the Simatela forest. Table 36 outlines pitsawing in the Lutaba woodland.. At this site, 40 to 60 employees in 20 teams are employed and a 300 ha area of Mukwa is sawed over a period of seven months. Approximately three sizes of planks are sawed.

The annual sawmilling production (that is, sales quantity) can be estimated to be 63 m^3, based on typical board sizes. One pitsawing concession is producing less than 100 m^3 of sawed lumber. Because the number of licence is small, the technical level is low and the felling quantity is small, the impact of pitsawing on resources is considered to be very small at present.

Table 36 Outline of pitsawing in Lutaba woodland

Licensee	Sibeso village. 33 years old male.
Groups of Pitsawyers	20
Number of Pitsawyers	40～60
Species	Mukwa
Licence area	Over 300 ha
Job period	May to November (7 months)
Lumber	Planks
Standard (m)	0.03×0.2×3.0
Sales number (month・planks)	500
Sales number (year・planks)	3,500
Estimated production volume (year・m^3)	63

Note: Estimated production volume = volume of one plank x sales number (year・planks)

Only the lowest blocks of standing Mukwa trees are cut into logs, while the upper parts of trees are left in forests. Only one log is cut from one tree. Mukwa itself is crooked and has many branches so the standing-tree utilisation rate is lowered accordingly.

Sawed lumber is sold to wholesalers in Livingstone. In 1994, the transportation cost to these wholesalers is K150,000 one way, carrying 200 planks on a truck. The sawed lumber is priced low at present. One typical plank of 3 cm x 20 cm x 3 m is priced at K1,000, or K200,000 for 200 boards. The difference between the transportation cost and sawed lumber price is only K50,000. After paying wages to workers, the sawmilling operation is completely in the red. Sawed lumber was hardly sold during May to July and the demand is stagnant. However, this was before the introduction of the tree-felling fees system. Thus, pitsawing operators are also suffering from the weak domestic demand for lumber, as are sawmills.

(3) Casual licences

Casual licences are granted to area residents who make their living by carving handicrafts. Under these licences, which are valid for 14 years, standing trees necessary for handicraft work can be felled.

(4) Felling fees

Table 37 shows the tree felling fees per tree by tree species.

Mukusi and Mukwa, the principal tree species in the study area, require a felling fees of K10,000. Before 1994, a set quantity was imposed on the annual number of trees that could be felled. But beginning in 1995, the system was changed to a payment system, allowing tree felling for those who have a license and who pay a fee. It is not clear at present whether or not this change will increase the harvest volume. The target of Zambezi Sawmills, Inc. for felling Mukusi standing trees in 1995 is 8,500 trees. By simple calculation, Zambezi Sawmills must pay K8.5 million as logging fees. This amount converts into US$12,000. It is believed that the fees are too high for small-scale pitsawing operators to pay.

3.2.5. Present status and future of wood use

(1) Estimated amount of firewood consumed daily by local residents

Several farm households were interviewed in the individual farm household survey to inquire about the configuration (length and diameter) of the firewood gathered, the quantity gathered per gathering trip and the frequency of firewood gathering. Firewood is purchased by a private house (an FD employee) near the consultants's living quarters in Sesheke was measured. Using this basic data, the firewood consumption in Sesheke District was roughly estimated. Table38 summarises the basic data, calculating method and estimated consumption.

The annual firewood consumption in urban parts of Sesheke District (assuming firewood is purchased) was estimated to be 9,750 m³ and that of villages (assuming firewood is supplied by themselves) was estimated to be 25,735 m³. It was estimated that Sesheke District would consume 34,485 m³ of firewood per year.

On the other hand, the possible yield of all species (annual allowable felling volume) in traditional land was estimated from the entire stand volume other than Forest Estates (Table 20) to be 900 m³/year. Since this volume exceeds the consumed amount, cutting is not being carried out to excess. But in traditional land, it is questionable whether there are sufficient small trees to fill the requirements for firewood.

(2) Use of building materials by local residents

Due to a lack of basic data, it was difficult to determine the volume of building materials used by local residents. The quantity is estimated to be small, compared with the consumption of firewood.

Table 37 Fees for forest produce (per tree)

Species	Fees per tree (K)
Afelia quanzensis (Mupapa)	6,000
Albizia species (Musase)	5,000
Baikiaea plurijuga (Mukusi)	10,000
Entandrophragma species (Mupemena)	8,000
Erythrophleum Africanum (Mubako)	5,800
Faurea Saligna (Mushokoso)	8,800
Guibourtia coleasperma (Muzauli)	6,000
Khaya nyasica (Mululu)	6,000
Mitragyna stipulosa (Mupa)	6,000
Pericopsis angolensis (Mubanga)	8,000
Pterocarpus angolensis (Mukwa)	10,000
Daniellia alsteeniana (Mukulabushiku)	8,000
Other species	4,000

Note : Species in parenthese are Lozi names.
$1 approx. equals K700

Material : Government of Zambia Statutory Instrument No. 133 of 1994.
The Forest Act, The Forest Licence (Amendment) Regulation, 1994.

Table 38 Estimated volume of firewood production

Precondition for calculation	Urban	Rural
Households	1,648	10,558
Rate of population (m)	13.5	86.5
Purchase per one month (m3)	0.493	-
Firewood measure (L:m • D:m)	-	1.5 • 0.1
Number of single collection	-	12.5
Number of collection per year	-	52
Number of purchases per year	12	-
Consumed volume household per year	5.92	2.44
Total volume consumed per year (m^3)	9,750	25,735

Note: Households of urban and rural calculated by rate of population.
Total consumed volume (urban)
= Households x purchases per month x number of purchases per year
Total consumed volume (rural)
= Households x volume of single collection x number of collections per year

(3) Impact on commercial volume and on forest resourses

1) Mukusi

As mentioned in the paragragh for commercial utilisation, two companies are felling Mukusi and using it commercially, Zambezi Sawmills, Ltd. and ITT Supersonic Ltd. On a sawmill log arrival basis, in 1994, Zambezi Sawmills Ltd. felled 5,813 m^3 and ITT Supersonic Ltd. 525 m^3, respectively, totaling 6,337 m^3. Thus the standing tree volume was about 13,000 m^3, with an assumed yield rate of 50%.

Quoting the Teak Forest Project of the Forest Department, the preliminary report mentioned that the production of sawmill logs totaled 10,762 m^3.

On the basis of this data, over the past ten years, the annual felling volume was 14,000 m^3 of standing trees, when estimating the felling volume of Mukusi in the Forest Estates. To sum up this data, the annual felling volume of Mukusi is estimated to be in the range of 13,000 m^3 to 14,000 m^3 of standing trees at present.

At such a felling volume, the two sawmills company are not expected to deplete the resources if the present demand level is maintained.

2) Mukwa

Two sawmills, Zambezi Sawmills, Ltd. and ITT Supersonic Ltd., fell and commercially utilise Mukwa, along with two pitsawyers. Consumption by sawmills is not clear. However, consumption by the Zambezi Sawmills is small, while that by ITT Supersonic is rather large.

As mentioned in the paragraph for commercial utilisation, a pitsawyer in Lutaba woodland is estimated to produce 63 m^3 of sawed lumber per year. Assuming that the other pitsawyer produces a similar quantity, the annual pitsawing production in the study area can be estimated to be approximately 130 m^3. Assuming that the standing tree yield rate is 30%, the annual standing-tree harvest volume can be estimated to be 430 m^3.

If the harvest volume is less than 500 m^3, the impact of pitsawing on future resources will be considered to be negligible assuming felling is not concentrated in one area.

3.2.6. Recommendations for forest use and enhancement of regional social economy

(1) Wood use by local residents

As indicated above, local residents can obtain enough firewood by gathering it from woodlands, even if the gathering of forest products and entry into Forest Estates are prohibited. However, with regard to small diameter trees, it is doubtful that there is a sufficient supply of firewood. Accordingly, Forest Estates attach great importance to the succession of small diameter trees. Although they want to prevent the cutting of trees for use by local residents, it is possible for local residents to use leftover logs and wood that was discarded after logging. In this case, it is necessary to come up with a rule to the effect that only such wood would be used for firewood.

Gathering of firewood and other wood from the woodlands should be restricted to dead wood, rather than felling trees. A mechanism for afforestation should be considered for tree felling.

As a means of enhancing the efficient use of wood as a source of heat and as a way to improve the area economy, the production of charcoal can be considered in developing countries. However, in this study area, resident demand for fuel has been met by the use of firewood, and since the demand for firewood does not exceed the allowable felling volume, the chief prohibits the production of charcoal.

So charcoal cannot be produced at the present time. In case there should be a plan to produce charcoal, discussions should be held between the chief, the Forest Department and local residents so that a consensus can be reached. In this case, the following matters should be discussed, so that any problems can be overcome.

- The danger of forest fires grows as the use of fire needed for charcoal-making increases.
- As the consumption of wood increases, the likelihood of reckless cutting also increases.
- If production is allowed, there is a question as to whether the areas for making charcoal can be limited to the areas agreed upon.
- The production of charcoal could expand into unsuitable areas in remote forest areas.
- Who will supply technical guidance for the production of charcoal?
- Who will sell the produced charcoal? Since the purchasing power of the local area is low and demand is not great, charcoal will have to be sold outside the area. There is a question as to whether such a market can be obtained.
- Will the local residents realize any cash income?
- Will the chief, the Forest Department and residents all abide by the agreement?

(2) Use of commercial wood

Sawmills have difficulty in drawing a clear vision of their future timber industry because of a decrease in forest resources and a decrease in the demand for timber. However, since there is a growing worldwide movement to restore tropical forests for the protection of the global environment, it is believed that the desire to restore destroyed forests will prevail in southwestern Zambia. Compared to the other regions in Zambia, a forest restoration movement should be particularly strong in the southwest owing to a greater need for the prevention of desert-spread.

In response to this social demand, sawmill operators should look toward the fostering of teak forest resources, so that efforts to increase the demand for teak timber would follow an increase in forest resources. The tree felling fees charged by the authorities ought be used in planting teak seedlings. Moreover, in the future, the Forest Department, sawmills and local residents need to discuss the possible introduction of the "principle of the cutter's pay obligation," whereby the one who cuts trees must also plant trees.

With regard to pitsawing if logs other than the best are left, the current usage note should be 30%. The remaining Mukwa is processed into laminated lumber, chipboards, or use d as firewood. A system to raise the level of wood use is needed. At the present volume of felling, it is possible to increase the number of licences.

(3) Enhanced agricultural production

In order to enhance the livelihood of local residents, the most important thing is to plan for the realisation of agricultural production.

1) Farm implements

A system to provide at least one plow for each farm household is necessary. Axes whose blades are not sharpened are used by applying more force. Grindstones to sharpen axe blades and other means should be used more widely.

2) Cultivation of crops, sweet potatoes and other agricultural products using dambos

Recently, yields of agricultural products have been decreasing even though the amount of rainfall has decreased during the rainy season in the study area. Due to this abnormal weather, some dambos, which are flooded with rainwater during the rainy season, do not have ponding water. Depending on the moisture condition of the dambo, the cultivation of crops, such as maize and millet, and sweet potatoes is recommended to enhance the people's diet.

In fact, paddy rice is being cultivated during the rainy season through the cooperation of the Netherland NGO aid group SNV, in dambos near Samasmo village north of Masese, as the Masese Agriculture Project. Paddy rice has been cultivated since 1982. In Samasmo village, two farmers are cultivating long-grained rice species and are selling harvested rice in addition to consuming some rice by themselves.

Recently, however, these farmers are changing from paddy rice to sorghum due to a shortage of rain during the rainy season as mentioned above.

Thus, agricultural production using dambos is possible in the study area.

3) Planting of fruit trees and grazing of cattle in farm land slashes (Agro-silvo-pastoral system)

One can see from the aerial photos that farm land is spreading along rivers. In addition to this farm land, land which is believed to be farm land slashes can be found in many places. The moisture condition for these farm land slashes is believed to be good. However, land may have already become infertile due to farming for a long period of time. Fruit trees, which do not require much fertilizer, can be planted in this land. What is important when planting fruit trees is to check the moisture conditions. For example, one index is whether or not leaves of deciduous trees remain green during the dry season. Cattle can graze on land when fruit trees grow to a certain height and soil fertility is recovered. If grass grows to some extent in farm land slashes, cattle may be set free for several years and fruit trees and agricultural products can then be cultivated.

This system should preferably be limited to flood plains and low terraces. The reduction of herbs in medium and high terraces by cattle grazing accelerate desertification. For this reason, the agro-silvo-pastoral system should be avoided

Nursery stocks of fruit trees such as lemon, mango and papaya might be produced in forest nurseries for this purpose. A mechanism is devised to have local residents plant these nursery stocks. Fruits on trees should be allowed to be harvested freely by local residents.

Agroforestry such as citemene, which requires burning, should be avoided in the study area from the standpoint of forest protection.

(4) Management of burning by local residents

The burning of forest land and grassland by local residents could be seen during aerial observation and from moving vehicles. Burning scorches the surface of standing trees and sometimes causes forest fires when the flames are fanned by winds. In eleven years, from 1981 to 1991, forest fires damaged a total of 15,792 ha of forests. However, historically burning has been practiced in western province repetitively by tradition and it cannot be prohibited unilaterally. However, according to the area Forest

Department, the frequency of forest fires since 1975 has increased so that socio-economic factors might be playing a part in the number of fires. Burning has been practiced traditionally for several purposes. According to information that we obtained through interviews, burning is carried out for a number of reasons. These can be summarised as follows:

1) Acceleration of growth of new pasture grass

Burning is performed in June and July during the dry season to burn dead and hard grass, which cattle dislike, and to accelerate the growth of new, soft grass. This is the first answer which always comes from local residents and officials of the Forest Department as to why burning is performed. Generally this is the reason given as to why burning in wide areas is permitted. It is true that burning is allowed almost unconditionally if this reason is given.

2) For cultivation of agricultural products

Agricultural products are cultivated during the rainy season (December to April). For this reason, agricultural products are harvested in April and May, and livestock such as cattle are set free for grazing. In October and November, agricultural products are cultivated. For this time cycle, burning is performed.

3) Prevention of insects

A variety of insects live in the bushes. Some of these insects are harmful to human beings and livestock, such as the Tsetse fly. Bushes are burned to prevent damage caused by these insects.

4) Removal of bushes for fruit gathering

Wild fruit trees grow in forests, such as Muchinga, Muzinzila, etc. Bushes are burned in order to gather these fruits.

5) Honey gathering

Honey is gathered by villagers of other villages, rather than by local residents. Bushes and forests are burned to find beehives more easily and to make bees lapse into a coma from the smoke. Careless use of fire sometimes causes forest fires.

6) Hunting of wildlife

When hunting wildlife, burning is performed to scare animals into the open. Hunting by burning is done more by villagers of other villages than local residents. Careless handling of burning also causes forest fires.

7) Burning without specific purpose as an established practice

Burning of this type is most troublesome, but it has become indispensable and is a daily custom for local residents. Local residents, especially, take it for granted to burn withered grass if there is withered grass, even if there is no specific purpose to it. They do not have guilty consciences in this regard.

The Forest Department is experimenting with burning in natural Mukusi forest experiment plots and other places. This is a test to check the regenerating condition of young growth by burning each year. There are pros and cons within the Forest Department regarding the impact of these burning experiments on the regeneration of your growth. According to a caretaker of an experimental plot, the grazing of cattle is not permitted in Forest Estates, but burning can be performed if a permit is obtained.

Thus veiwed, the Forest Department seems to regard burning itself affirmatively even if burning is prohibited.

A mechanism for burning, whose actual condition is described above, by autonomous local residents is needed. This is because even though burning is prohibited in the study area after August, burning is performed and fires break out after August as before. Measures are needed to provide some incentive or motivation, such as drilling a well for local residents, if even one forest fire does not break out in one year by making them responsible for management of a burning area for each village, instead of merely prohibiting burning.

(5) Understanding and cooperation of senior chief

It is very important for the smooth implementation of the management plan to have a full understanding of the said plan by the sub-chiefs and by senior chiefs, whose ranks are higher, and to obtain their views and consent on the management plan when executing the forest management plan, including these utilisation systems. Fortunately, the senior chief of Muwandi is interested in the resources condition of the forests and is expected to express his understanding on the results of the study and management plan. It may be advisable to have the cooperation of the senior chiefs on forest-protection educational activities to protect forests against their extinction by burning and other acts.

(6) Agroforestry that can be accomplished

Agroforestry that requires periodical branch cutting and burning as in Citemene should be avoided in the study area at this time, when forests are burned by burning and forest resources are decreasing. Agroforestry that can be accomplished in view of the socio-economic conditions of the study area falls into two categories:

1) Fruit tree planting and cattle grazing in farm land slashes and woodlands (Silvo-pastoral system)

What is to be accomplished and how it is to be accomplished are described in paragraph (3), Enhancement of farming. Woodland on low terraces should also be included in it. However , implementation of this system on woodland in medium and high terraces is not desirable from the standpoint of preventing desertification.

This system offers the following advantages:

- Many local residents have experience in planting fruit trees and are interested in fruit tree cultivation.
- Effective use of abandonment lands.
- Assist villagers in their diets
- Expansion of farm land can be prevented.

2) Apiculture in woodlands

According to men of learning, apiculture is found in tropical African and tropical Latin American countries. One often sees beehives clinging to trees so as to rear bees. Apiculture managed by villages would be possible in woodlands where many acacia trees grow.

Agroforestry offers the following advantages:

- With regard to the collection of natural honey, since management diffusion is under the control of the Forest Department, apiculture can be carried out practically and empirically.