Chapter 5

Research methods

At the end of the preceding chapter, the basic information needed for the implementation of TROPFOMS was identified. This basic information has to include the growth matrix (called *G* in chapter 4) and the vector of tree prices (called *P* in chapter 4). Stand growth data and data from the market of timber products are used to estimate the matrix *G* and the vector *P* that both provide the coefficients for TROPFOMS. This chapter presents the methods used to estimate these coefficients. However, it also gives a brief overview of the forest inventory that later allows the description of the conversion period and includes a short characterization of the utilization of forest plant products by the local population. Finally, this chapter reviews the mathematical programming technique adopted in TROPFOMS.

5.1 Methods for the estimation of growth and yield parameters

The aim of the analysis is to estimate the transition probabilities and the ingrowth introduced in section 4.4.1a. However, tropical forests are very heterogeneous as described in chapter 2 (Section 2.2.2a) and it is difficult to develop a model concerning growth and yield on the basis of individual tree species. It appears necessary to aggregate first the individual tree species in groups, and to estimate later the transition probabilities on the basis of this grouping.

5.1.1 Species aggregation

Tropical forests are considered to be the most complex forest ecosystems on earth. Walter (1979) noted that: "When considering different ecological types, it should be emphasized that the greatest variety of plant forms is found in the tropical rain-forest". Describing the extent and variation of tropical forests, Palmer and Synnott (1992) noted that, in comparison with temperate forests, tropical forests often display complex structures, marked variations from one hectare to the next, relatively unpredictable growth rates and besides they are uneven-aged.

These attributes give tropical forests a special priority in all attempts to preserve biological diversity at the global level, but it also makes the development of management strategies for tropical forests difficult especially if sustainable timber production is one of the objectives. In fact, tropical forests are both ecologically rich (large number of species per unit area) and diverse. As a consequence, the number of individuals for any species is often small (National Research Council, 1982). This further complicates attempts to develop management methods and techniques, especially models such as growth models based on statistical analysis of sample data. Working with individual tree species becomes rather impractical not only because it will require too many coefficients and/or functions, but also because of the paucity of data for many species which may inhibit the development of reliable relationships (Vanclay, 1991b).

These facts have encouraged forest management specialists to group species based on more or less objective criteria. For example, Vanclay (1991b) working on data from tropical forests of North Queensland used a regression analysis to form 41 species groups out of the 237 tree species based on diameter increment. But he avoided "imposing any limit on the number of groups" which gives his work a high theoretical value. However, field implementation of these results remains difficult; 41 groups still being difficult to handle. In Cameroon, species are usually aggregated in three main groups, according to their current commercial status in the market (commercial, potentially commercial and non-commercial). Such a grouping certainly provides a practical tool when evaluating the current growing stock of forest resources, however it is almost useless when making growth and yield projections because species belonging to the same group do not necessarily have the same growth habits. Therefore, it would be desirable having only a few groups, in order to decrease the computation burden and to facilitate the handling of the growth and yield model, and to have an aggregation that is based on an objective criterion allowing growth and yield prediction as well as prediction of future stand structure and composition.

The purpose of this analysis is to contribute to the search of methods to form few groups from the multitude of species found in tropical forests on the basis of growth habits. It contributes to the achievement of research objective 1 (Section 3.2.2).

a) Principle of analysis.

Cluster analysis is a method for detecting natural groupings in data. The analysis was mainly concentrated on four variables: the average diameter increment (DI), the average dbh recorded at the beginning of the growth period (d_1), the commercial status (CS), and the minimum diameter for felling (DME).

Diameter increment was chosen because it has almost always been considered as one of the best variables when trying to model the growth of mixed tropical forest. For example, Alder (1983), in a review of growth and yield of mixed tropical forests noted that: "Mixed tropical forest growth information from permanent plots...has mostly been analyzed in terms of individual tree increment". He went on to identify diameter increment as "a basis for species grouping". In fact, Vanclay (1991b), in his important work on species grouping in tropical forests based his analysis mainly on diameter increment, but he preferred to use regression analysis rather than cluster analysis. Logically, if tree growth can be defined for forest management purposes as a change in a selected tree attribute over some specified time (Davis and Johnson, 1987), diameter increment - a change in tree diameter over a specified period of time - should necessarily be one of the best variables to portray tree growth.

In addition to diameter increment, which is a variable representing growth, it appeared important to have at least an additional variable which characterizes the initial stand at the beginning of the growth period. For this, the average DBH per species at the first round of measurement was chosen. Many authors such as Rollet (1974) and Jonkers (1987), have shown or used the relationship between average diameter of a species and the distribution of stems of the same species among size classes in the stand. The average diameter can thus be reasonably seen as a stand characteristic.

As for the DME, it is the minimum diameter allowed for logging according to current regulations. The DME varies by species. It was chosen because it gives an idea of the maximum size that a tree of a given species can reach. The DME illustrates the idea that a tree of a given species at maturity will be larger or smaller than a tree of another species also at maturity. For example: say there two trees one of species A and the other of species B. Suppose that a mature tree of species A can reach a maximum DBH of 150 cm on that site while a mature tree of species B can reach only 90 cm. If both trees have an equal actual DBH of 85cm, one would expect their growth rate to be different because the tree of species B is almost at the end of the growing phase of its life. Thus, the DME of species A will be larger than the one of species B and is different from the actual mean DBH. This illustrates the fact that trees of the same species on different sites with different mean DBH can grow at different rates (all other things being equal).

Each tree species *j* could thus form a single statistical case characterized by the average diameter of the species at the beginning of the growth period d_{1j}, the average diameter increment for that species DI_j, its commercial status CS_j and DME_j. These statistical cases which correspond to species are then aggregated.
These averages were simply computed as follows: let d_{1ij} be the value of the DBH measured for tree *i* of species *j* at the beginning of the growth period and d_{2ij} the DBH recorded at the end of the growth period for the same tree. DI_{ij} the diameter increment for tree *i* could be computed as:

$$DI_{ij} = d_{2ij} - d_{1ij} \tag{5.1}$$

d_{1j} and DI_j were found as:

$$d_{1j} = \frac{\sum d_{1ij}}{n_j} \tag{5.2}$$

$$DI_J = \frac{\sum DI_{ij}}{n_j} \tag{5.3}$$

Where n_j is the number of trees of species *j*.

The four values d_{1j}, DI_j, CS_j and DME_j are used as coordinates to locate each tree species on a four-dimensional plan. The principle of the clustering procedure consists of calculating the distance from the location of a randomly chosen species to the location of its nearest neighbor (Newnham, 1991; Kent and Coker, 1992). The measures of distance used in this study are the

Squared Euclidean distance and the Euclidean distance. The Squared Euclidean distance is the sum of the squared differences between the values of the clustering variables. If the starting species is *j* and its neighbor species *j+1*, $E_{j,j+1}$ the Euclidean distance between the two is:

$$E_{j,j+1} = \sqrt{(d_j - d_{j+1})^2 + (DI_j - DI_{j+1})^2 + (CS_j - CS_{j+1})^2 + (DME_j - DME_{j+1})^2} \quad (5.4)$$

$E_{j,j+1}$ can be squared to obtain the Squared Euclidean distance.

Similarly the distance from *j+1* to its nearest neighbor can be calculated. If the nearest neighbor of *j+1* is *j*, then a potential cluster has been formed. Otherwise, the aggregation continues by choosing another species that is not in the previous cluster and then trying to form a new cluster until all trees have been considered.

Some measure of the central location of each cluster can be calculated, and further, clusters themselves may be clustered. One of the commonly used central points in the cluster analysis is the center of gravity of the cluster also called the centroïd (Eriksson, 1993). Say a cluster has *m* species, each species *j* is located on the plan by its coordinates d_{1j} and DI_j, CS_j and DME_j the centroïd of the cluster noted *C* can also be characterized by coordinates d_{1c}, DI_c,

$$d_{1c} = \frac{1}{m}\Sigma d_{1j} \quad (5.5)$$

$$DI_c = \frac{1}{m}\Sigma DIj \quad (5.6)$$

CS_c and DME_c defined as:

$$CS_c = \frac{1}{m} \sum CS_j \quad (5.7)$$

$$DME_c = \frac{1}{m}\sum DME_j \quad (5.8)$$

The process yields a hierarchy of cluster solutions, ranging from one overall cluster to as many clusters as there are cases. A cluster at a higher level can contain several lower-level clusters, but within each level the clusters are disjoint. Depending on the objective of the analysis (for example a predetermined number of groups), an appropriate level is chosen as the final solution.

The aggregation of species was done using the Hierarchical Cluster Analysis procedure of SPSS (SPSS Inc, 1993). The centroïd clustering method was used based on Euclidean distances. The variables chosen were different in magnitude and ranges, for example DME varies from 50 to 100 while the diameter increment varies mostly between zero and five. For that reason, all variables were standardized within the range of 0 to 1. A single solution of four clusters was retained.

b) The data set

The data analyzed here were collected in Liberia, West Africa. Starting from 1978, several pilot projects were installed in the country with the cooperation of German institutions, the general objective being to determine the silvicultural potentials of logged-over forests (Parren and de Graaf, 1995). Within the framework of these projects, about 39 one-hectare Permanent Sample Plots (PSPs) were established in four stations: Cavalla (12 plots), Grebo (20 plots), Gola (three plots) and Kpelle (four plots) with different specific research objectives. In Grebo, the objective was to monitor the development of the stand after logging without any treatment. At the three other stations, studies aimed at testing the effects of different silvicultural treatments after logging.

Within each PSP, trees with a diameter at breast height (DBH) larger or equal to 10 cm were numbered and their species determined. For each numbered tree, measurements were taken including: dbh, total height, bole height, crown diameter and exposure to light. Each tree was also located on the map using rectangular coordinates. A total of more than 15,000 trees of 245 species were thus monitored.

Because of variations among silvicultural treatments that were tried from one station to the other, and due to the inconsistency in re-measurement dates, only the 20 plots of Grebo were used. The plots of Grebo represent a data set of 7664 re-measured trees. The analysis focused mainly on species met in both Cameroon and Liberia. Annex 1 gives a list of the tree species concerned with their scientific and pilot names. All together, these plots provided a data set of 3735 trees of 46 species re-measured five years apart (growth period). Annex 1 gives a summary of the data set used for species aggregation.

It should be noted that it would have been better to avoid using data from Liberia out of their physical context and use data collected in South Cameroon instead. Unfortunately, as it is the case in most tropical countries, a network of PSPs that could provide such data was not yet established in Cameroon when this study was conducted. At least five years are needed to obtain data on which such an analysis can be conducted. Thus, we used data from a different tropical country of Africa to estimate the growth rates. However, even though the bio-physical conditions are not exactly the same, there is a great similarly in species composition between the forests in both countries.

5.1.2 Estimation of growth and yield

a) Principle of analysis

The methods utilized here contribute to the achievement of research objective 1. As already described in chapter 3 (Section 3.2.4: theoretical approaches in TROPFOMS), the matrix approach was chosen to model growth and yield. The methods here are designed to estimate coefficients of the growth matrix meaning the ingrowth into the smallest diameter class per species group and the transition probabilities (a_{ij} and b_{ij}).

Ingrowth equation is estimated by ordinary least square regression as a function of both the basal area of the stand and the number of trees per species group in the stand. The basal area of the whole stand expresses the competition which occurs in the stand. As one can imagine, a tree of a given size and a given species competes not only with trees of the same species, but also with trees of other species. If the equation for ingrowth can be written as:

$$I_{jt} = \beta_o + \beta_1 B_t + \beta_2 N_{jt} + \beta_3 N \quad (5.9)$$

Where: I_{jt} = the ingrowth

B_t = the basal area at the beginning of the growth period

N_{jt} = the number of trees of species group j in the stand

N = the total number of trees in the plot and

β_0, β_1, β_2 and β_3 are regression coefficients

β_1 is expected to be negative, meaning that for a constant number of trees, ingrowth will be smaller in stands where trees are larger since in such stands the canopy of the larger trees tends to suppress the growth of smaller ones. On the other hand, β_2 is expected to be positive because at a constant basal area, stands with more trees per unit area are younger and the ingrowth should be more active (Buongiorno and Gilless, 1987). In mixed stands, a larger number of stems for a given species group should also mean more chance for seed production and better regeneration.

The probabilities a_{ij} - the probability for a tree of species group *j* and diameter *i* to stay alive and in the same diameter class after one growth period - and b_{ij} - the probability for a tree of species group *j* and diameter *i* to move to the next diameter class after one growth period - were estimated using logistic regression. The general form of the logistic equation used was:

$$\Pr(e) = \frac{1}{1 + \exp X} \quad (5.10)$$

where: *Pr(e)* = probability of the event *e*. The event in this case is changing a diameter class for a given tree during one growth period, in the reverse event the tree is staying in the same diameter class during one growth period.

X = a function of the diameter class in which the tree was registered at the beginning of the growth period, the basal area of the stand and the number of trees per ha.

Mortality was taken into account in the process using estimates from prior observations.

The smallest diameter class of interest was 20 cm to 30 cm. The diameter classes were defined as shown in table 5.1.

Table 5.1: Definition of diameter classes

Diameter class	Values (cm)
1	[10,20[
2	[20,30[
3	[30,40[
4	[40,50[
5	[50,60[
6	[60,70[
7	[70,80[
8	[80,90[
9	[90,100[
10	≥100

b) The data set

The data set described in section 5.1.1 was used to estimate the transition probabilities. It allowed for each individual tree to know whether it stayed in the same diameter class or grew up or died.

5.2 Stumpage derivation

a) Principle of analysis

Stumpage price derivation was designed to contribute to research objective 1. The purpose of the analysis is to estimate the value of a standing tree of a given species and of a given diameter class based on market prices of timber products. The general principle for the derivation of the stumpage price is that stumpage price at a specific location will equal the log price at the mill minus the cost of availability (Gregory, 1972). The approach adopted is the so-called residual approach for which the starting point for determining stumpage price is the selling price of the product or products that are to be produced from the raw material. By subtracting all costs from the product's sale price one derives a residual value. As industrial logging is especially oriented towards the export market in Cameroon, the Free On Board (FOB) price for logs was used in place of the price at the mill.

The first step of the derivation of the stumpage price was the estimation of FOB prices for logs of each species group. This was done by gathering information from timber exporting companies, the forestry administration and the Société Générale de Surveillance (SGS). The price to be assigned to the unit volume of a log belonging to a given species group was estimated by averaging available FOB prices of all species in the group.

Next the cost of availability is estimated. The costs of availability include different taxes, transport costs (from the forest landing to the seaport log yard), all logging costs and all overhead costs. These costs are expressed per unit volume of log (CFA Franc (FCFA)/ m^3 of log)[3].

Then the value of a unit volume of stumpage can be estimated. It can be anticipated that a cubic meter of marketable logs represents more than one cubic meter of stumpage because of logging waste. The stumpage value is derived as:

$$P_j = cc_j(FOB_j - AC_j) \qquad (5.11)$$

Where: P_j = value for a cubic meter of stumpage of species group *j*
cc_j = commercialization coefficient for species group *j*
FOB_j = FOB price for a cubic meter of log of species *j* and
AC_j = cost of availability for species group *j*

The commercialization coefficient *cc* is the ratio of the volume of marketable logs over the volume of stumpage as estimated before logging and during the forest inventory; *cc* can be expressed as:

$$cc = \frac{V_L}{V_S} \qquad (5.12)$$

where: V_L = log volume and
V_S = stumpage volume

The commercialization coefficient *cc* should be less than 1. The *cc* is developed by measuring standing trees to estimate their stumpage volume (V_S) using mainly the DBH and bole volume equations. DBH is measured directly in the field and the stumpage volume is found using pre-developed equations of which the implicit formula is:

$$V_S = f(DBH) \qquad (5.13)$$

The trees are subsequently felled, limbed and then skidded to the forest landing. Once at the forest landing, the trees are bucked which reduces them into marketable logs. Logs are then measured to obtain the v_L (the volume of individual logs obtained from bucking a given tree). The v_L for individual logs was estimated by subdividing the log into 2 m bolts[4] and

[3] 1 Euro=656 FCFA
[4] A bolt here means a subdivision of a bole measuring 2 meters of length (See also Fonweban, 1997)

measuring sectional diameters with a caliper. The volumes of bolts were next calculated using Smalian's formula as:

$$v_B = \pi(dh^2 + ds^2)L/8 \tag{5.14}$$

v_B = volume of a bolt in m^3
dh = diameter at the large end of the log
ds = diameter at the small end of the log and
L = length of the bolt (2 m)

Bolt volumes are later summed to give the volume of the log v_L. The method has been considered by many forest inventory specialists as one of the least biased, the most accurate and the most precise (Cailliez, 1980; Pardé and Bouchon, 1988; Fonweban, 1997). The volumes of all individual logs bucked from the same tree are further summed to obtain the log volume of the corresponding tree V_L.

Finally, calculations can be made to estimate the value of a tree of a given species *j* belonging to a given diameter class *i*. Let p_{ij} be that value, it can be estimated as:

$$p_{ij} = P_j * v_{ij} \tag{5.15}$$

where: v_{ij} = volume of a tree of diameter class *i* and of species group *j*.

Bole volume equations are developed for the estimation of volumes of standing trees (v_{ij}). They predict stumpage volume based on one, two or more dependent variables (one, two or more entries). Usually single entry equations use the DBH as dependent variable while double entries equations use both the DBH and the bole length. In standard forest management, single entry equations with the DBH are preferred because the diameter is the easiest variable that can be recorded at low costs. This type of equation was chosen for the development of bole volume equations used for the development of TROPFOMS.

The development of single entry equations required the DBH of a number of trees measured in the field and the corresponding volume estimated as accurately as possible. Two techniques were used to estimate these variables, one with standing trees the other with felled trees.

On standing trees, the DBH was taken with a diameter tape, then the bole was optically sectioned in four bolts using the mirror relascope. The diameters at the small and large ends of each of the bolts was also estimated optically as well as the lengths of the bolt in order to use the Smalian's formula (described above).

Of felled trees, the DBH was taken before felling. After felling, the same technique was used to estimate the volume of individual logs above to obtain the volume of the tree. It should be noted that, in both cases, only the trunk was measured (up to the first big branch). A problem then appeared to know whether or not the data collected on standing trees could be mixed with data collected on felled trees. In other words, are the volumes estimated with one technique different from the volumes estimated with the other? A test of hypotheses was conducted (Paired t-test) with a number of trees on which the measurement was made with the two techniques. Each of these trees was measured optically and a second round of measurement was made after felling so that one could have for each tree: the DBH, the volume estimated with the mirror relascope and the volume estimated by direct measurements after felling. For each tree in the sample v_R the volume estimated with the relascope was recorded as well as v_f the volume estimated after felling (Mfou'ou, 1996). The difference DIFF = v_s - v_R was also calculated. The hypotheses tested were:

H_0: $\overline{DIFF} = 0$, the mean difference is not significantly different from 0
H_1: $\overline{DIFF} \neq 0$, the mean difference is significantly different from 0

Based on previous experiences found in the literature (Medeng, 1988; Nkie 1994, Mfou'ou, 1996) three different types of regression equations were tested for each species group. These are:

$$V = b_0 + b_1(DBH) \text{ (Linear)} \quad (5.16)$$
$$V = b_0 + b_1 \ln(DBH) \text{ (Logarithmic)} \quad (5.17)$$
$$V = b_0 + b_1(DBH) + b_2(DBH)^2 \text{ (Quadratic)} \quad (5.18)$$
$$V = b_0(DBH)^{b_1} \text{ (Power)} \quad (5.19)$$

Where: V= average tree volume for a given diameter
b_o = a constant
b_n = regression coefficient
DBH = tree diameter at breast height
ln = the natural log base

One of these types was selected, based on the coefficient of determination and the standard error.

b) Data set

Four types of data were needed for the analysis: prices and costs, data for the estimation of the commercialization coefficients, data to test for differences between volume estimation techniques and data for the development of bole volume equations:

- Prices and costs. The FOB prices collected for 30 species from *Société Générale de Surveillance* (SGS) are presented in table 5.2. SGS is a multinational inspection company which monitors international timber trade in Cameroon. These are average prices from Cameroon seaports and for all destinations. As for the costs, they were provided by the records of the industrial logging company operating on the TCP research site. The records allowed to have the total volume of logs produced per year, the yearly overhead costs including equipment, traveling, maintenance, insurance, personnel and taxes. Detailed costs per cubic meter were available for inventory, felling, skidding, road construction, felling taxes, concession fees, equipment, insurance and miscellaneous.

Table 5.2: FOB prices (per m^3) for log exports from Cameroon in 1997 (1FF = 100 FCFA)

Species	Price (FF)	Species	Price (FF)
Assamela	262.3	Padouk	130.6
Bubinga	232.3	Teak	130.0
Doussie	280.0	Aiele	108.2
Sapelli	193.3	Amouk	95.6
Sipo	193.6	Andoung	73.1
Acajou	145.7	Azobϑ	104.9
Pachyloba	175.0	Bilinga	97.8
Ayous	120.8	Fromager	76.1
Bibolo	115.0	Ekop	98.9
Bosse	133.0	Eyong	88.9
Framire	103.3	Faro	74.4
Iroko	158.7	Frakϑ	106.6
Bete	153.3	Koto	99.1
Moabi	151.5	Niove	76.1
Movingui	129.0	Tali	91.9

Source: SGS Forestry (1997)

- Data for the test of the difference between volume estimation techniques. A total of 27 trees were measured both standing (with the mirror relascope) and after felling following the selection of the logging company. Table 5.3 gives more details on the trees measured.

- Data for development of bole volume equations. These data were collected at the TCP research site. In total, 500 trees of 32 species were measured, of which 103 were felled and 397 were standing. Annex 4 summarizes the data set.

- Data for the development of commercialization coefficients. Data were collected in and around the Tropenbos Cameroon research site. The collection was done in collaboration with the field crews of GWZ, the industrial logging company that was operating at the site. The logging company selected the trees based on their market demand and current regulations, they also used their logging equipment and technique on the trees on which measures were taken. All groups of species were not equally represented in the data set, because of the selection by the logging company and because the plot could not normally have the desired species. In total 360 trees were monitored.

Table 5.3: Data used for the test of difference for volume estimation techniques

Tree	V^1_s	V^2f	DIFF[3]	Tree	V_s	V_f	DIFF
1	14.532	14.580	-0.048	15	7.933	8.090	-0.157
2	10.270	10.010	0.260	16	12.809	13.325	-0.516
3	12.940	12.600	0.340	17	8.574	8.928	-0.354
4	11.840	12.040	-0.200	18	11.443	13.325	-1.882
5	33.130	33.440	-0.310	19	9.390	8.497	0.893
6	14.076	13.490	0.586	20	14.030	13.545	0.485
7	17.636	17.500	0.136	21	14.095	14.640	-0.545
8	9.956	10.007	-0.051	22	14.657	13.960	0.697
9	8.858	9.196	-0.338	23	13.708	14.240	-0.532
10	15.550	14.642	0.908	24	8.134	5.046	1.088
11	16.070	15.280	0.790	25	18.490	18.274	0.216
12	8.610	8.620	-0.010	26	20.990	19.765	1.225
13	36.100	37.174	-1.074	27	14.630	14.250	0.380
14	11.443	11.238	0.392				

[1] Volume (m^3) of the tree measured while still standing (with the relascope)
[2] Volume (m^3) measured after felling (with tape and caliper)
[3] Difference between the two volumes

5.3 Analysis of inventory results

a) Principle of analysis201

The analysis of inventory results was made to achieve research objective 2. The purpose was to have a quantitative assessment of forest stands in the TCP research site and to summarize the current stocking so that it can be utilized to feed TROPFOMS. The inventory results should be presented in terms of number of trees per species group and per diameter class for every forest type within the production forest of the TCP research site.

b) The data set

Due to financial limitations an inventory of the whole production forest at a rate of about 1 % as wished was not made. However, the inventory made for the establishment of PSPs in the site could provide enough information to feed the model. The inventory concerned a forest area of about 165 ha divided into 18 plots of nine to ten ha each (Bibani, 1996). In each plot, all trees of 10 centimeters on DBH or more were identified in botanical terms and their DBH recorded.

5.4 Analysis of forestry sector organization and regulations

a) Principle of analysis

The analysis contributes to the achievement of research objective 3. The purpose was to briefly describe the organization of the Cameroon forestry sector and highlight the existing regulations that are designed to ensure the sustainable management of forest resources. This should allow the evaluation of these strategies in the light of the results of the application of TROPFOMS methodology on the production forest of the TCP research area.

b) Information source

The main sources of information consisted of official documents of the forestry administration of Cameroon. These included the Forestry Law (Government of Cameroon, 1994), The decree of application of the Forestry Law (Government of Cameroon, 1995), The forest policy statement (Government of Cameroon, 1993) and the Zoning Plan (C⊥tϑ, 1993). Additional information was obtained through personal communications with different people interested in the management of Cameroon forests.

5.5 Forest utilization by local populations

a) Principle of analysis

The analysis contributes to the research objective 4. It aims at determining critical tree species that are covered by industrial logging as well as the local populations. This will allow later developing and examining scenarios and options on the utilization of those resources.

b) Data source

A detailed inventory of names and functions of non-timber forest product species was conducted in and around the TCP research site (van Dijk, in press). The inventory results give a comprehensive list of plant species that are utilized by the local population and their respective relative importance.

5.6 Mathematical programming methods

The main need for a mathematical programming method in TROPFOMS is for optimization. The optimization method adopted is linear programming.

Linear programming appears to be one of the most widely used mathematical programming method, and it has been the most broadly applied of all management sciences techniques in natural resource management and related disciplines. Dykstra (1984) gives an account of published applications of linear programming relating to natural resources until the beginning of the 1980s. Since then many more applications of these techniques have been made, boosted by new developments in computer science.

Linear programming seems to have been developed by an American mathematician called Dantzig (Winston, 1987; Dykstra, 1984). A typical linear programming problem can be summarized by the following three characteristics (Winston, 1987):

1. An attempt to maximize (or minimize) a linear function of the decision variables. The function that is to be maximized or minimized is called the objective function.
2. The values of the decision variables must satisfy a set of constraints. Each constraint should be a linear equation or a linear inequality.
3. A sign restriction is associated with each variable

These characteristics of linear programming match in general with a part of the problem to be solved with TROPFOMS as described in sections 4.4.2 and 4.4.3. The decision variables here are the elements of the vectors Y_j and H_j which define the composition and structure of the forest stand and the harvest strategy respectively at steady state. The linear function to be maximized is the objective function introduced in section 4.4.2 while the constraints are presented in section 4.4.3.

Linear programming problems have many solutions which satisfy the equations, but only one solution is optimal and provides the best satisfaction of the objective function. The simplex algorithm that is described in all references on linear programming is an efficient way to select the optimal solution among a host of solutions to a linear programming problem. However, the use of linear programming implies that certain underlying assumptions are satisfied. These assumptions are: linearity in objective function and constraints (included in characteristics 1 and 2 above); divisibility that implies that each decision variable can assume any real value including both integers and fractions; non negativity of decision variables (characteristic 3 above) and; deterministic or certainty assumption that means that all coefficients and parameters are known with certainty. Of all these assumptions, the certainty assumption is the most difficult to satisfy in natural resources management. However, to some extent uncertainties and randomness can be dealt with by means of sensitivity analysis.

In addition to linear programming, TROPFOMS uses simulation. Simulation here consists of describing the real system (forest stand) in a simplified and abstract way by equations that represent the behavior of the real system simulated. Simulation helps in making projections and depicts long-term effects of a course of action. In TROPFOMS simulation is used for checking alternative cutting cycles and in the description of the conversion period.