Chapter 9

Reflections, conclusions and recommendations

The first four research objectives have been addressed in the preceding chapters. The current chapter addresses the last objective and reflects on the whole research.

This study is to help identifying the most important elements needed for the development of a tool to provide adequate technical and scientific support for decision-making in natural tropical forest management. These elements concern the data needs, the methods for analyzing the data, the equipment and the methodology for generating information about the consequences of alternative management options. In this chapter, key elements that decide on the quality of a system for supporting decision-making in tropical forest management are highlighted. A critical review of TROPFOMS is In addition made in order to identify its limitations.

9.1 The design of TROPFOMS and its mathematical programming approaches

9.1.1 Reflections on the design of TROPFOMS

The ambition of this research is to put together a methodological tool that can assist forest management decision-making within the complex ecological and socioeconomic environment in which tropical forests are managed. This tool has been designed using available scientific methods and techniques and information from many fields, and it is suggesting an approach to combine these elements and procedures to process the information in order to obtain the intended support. It uses quantitative information and provides quantitative guidance for forest management at the stand level.

The importance of the issues addressed by the output of TROPFOMS for forest management is self-evident. These issues relate to the key management parameters listed in section 2.3.3. However, there may be criticism about the level of analysis and the quantitative approach adopted.

In fact, many aspects of forest management are qualitative and this particularly applies to the case of tropical forests. For example, cultural values of forests and forest use by the local population are hard to quantify, and so are the political motivations of a government which designs forest policy. However, the attractiveness of a quantitative analysis is that it provides a common language for different stakeholders in forest management. Quantitative analytical methods also allow the analysts to be more neutral in their analyses. After all, the primary role of an analyst is to provide decision makers with a basis for their decisions, and it is the task of decision makers to combine quantitative and qualitative information while making decisions. Thus, the quantitative support provided by TROPFOMS can be combined with qualitative information to help in decision-making.

Similarly, concerning the level of analysis, stand level information does not constitute the only source of information needed for forest management at the Forest Management Unit (FMU) level. For example, more information on land utilization types, land suitability, land ownership and public forest policy is needed for land use planning and zoning at the forest level. However, stand level information should be incorporated in decision-making on a forest use at the FMU level. One of the interests of the design of TROPFOMS is that it puts together many aspects at the stand level. The intention of this research is not to assist in making the complete range of decisions required in tropical forest management, but to make a contribution to the information needed at stand level.

9.1.2 Reflections on the mathematical programming approaches of TROPFOMS

TROPFOMS includes Linear Programming (LP) as an optimization technique to obtain steady state stand characteristics. In addition, numerical simulations are used to make projections regarding the conversion period. LP is the most commonly used mathematical programming technique. It is an efficient and proven way to obtain optimal solutions for problems as defined in this study (Winston, 1987). The advantage of LP is that it can be used in a wide range of situations and its logic is simple to understand. However, the main problem of LP rests on meeting its underlying assumptions (See section 5.3).

In this case, the non-negativity assumption poses no problem. However, the linearity assumption makes it difficult to include the cutting cycle as a decision variable. To overcome such an obstacle, successive values of the cutting cycle were used in a step-wise simulation approach that can lead to a sub-optimal solution concerning the cutting cycle. However, the fact that the growth period (See section 4.4.1e) is five years long does not leave much choice, only cutting cycles that are multiples of five years could be examined meaningfully. Another point of concern is the available knowledge about the system to be modeled. The solutions provided by LP are as good as our knowledge of the system. Limitations in the knowledge of the system are further discussed in section 9.2. The information about the management environment certainly has shortcomings, but it was the best available. The positive side is that it makes clear what information is needed and determines which one is lacking (See section 9.2).

9.1.3 Conclusion on the reflections about the design and the mathematical programming approaches of TROPFOMS

The design of TROPFOMS uses information about the management environment expressed in quantitative terms and produces figures that can support forest management decision-making. The output of TROPFOMS has to be combined with other information at the forest level to provide a more complete basis for decision-making. The mathematical programming techniques used are well proven techniques, nevertheless, the usefulness of the outcomes depends on the input to the model.

To implement the methodology of TROPFOMS, good computing ability is needed, particularly a mathematical programming package such as AIMMS which was used in this study and a computer which has a sufficient capacity (24 to 32 megabytes (MB) of Random Access Memory (RAM)).

9.2 Reflection on the data needs and methods of analysis

The quality of the outcome of TROPFOMS depends much on the coefficients and parameters used. These coefficients and parameters concern characteristics of forest stands, market prices of timber products and the local use of forest products. The information that is necessary to implement and run TROPFOMS includes:

- A definition of species groups based on both the growth habits of different species and the market prices of timber products
- Transition probabilities which are estimated on the basis of diameter increments of trees of each species group. The diameter increments are obtained from periodic measurements of all trees in PSPs. In addition, an estimation of the ingrowth into the smallest diameter class is needed as well as an estimation of mortality.
- The stumpage prices expressed per tree for each species group and diameter class. The stumpage prices are derived on the basis of market prices of logs (or timber products), and information on logging waste and logging costs. All information on logging is expressed per species group and size class and preferably in relation to logging intensity.
- A discount rate.
- The maximum stocking achievable expressed as the maximum basal area per hectare that a stand can reach. This information may not be necessary if a significant relationship between stand growth and stand density can be established.
- Logging damage to the residual stand estimated as number of trees destroyed during logging operations for different species groups and diameter classes. The damage to the residual stand should be expressed in relation to logging intensity.
- The maximum proportion of the basal area which can be removed from a stand by logging and silviculture.
- The list and use of tree species by the local population with special emphasis on the ones which are also harvested by logging.
- The proportion of NTFP trees that management wishes to preserve.
- The minimum number of trees per species-size class that management wishes to preserve.

Among all this information, the definition of species groups, the transition probabilities and the stumpage prices are basic for any outcome. For that reason it appears to be important to pay special attention to them.

9.2.1 Methods of analysis and data needs for forest stands characterization

Species grouping. Natural tropical forest stands show a great deal of heterogeneity due to the high species diversity as well as their size diversity. This heterogeneity is an interesting feature for the multiplicity of uses that can be made of these forests, but it makes modeling difficult. It is generally agreed that species should be grouped according to some criteria and modeling and/or management would use species groups instead of individual tree species. Species grouping is done in almost every forest management organization throughout the tropical world. However, as inevitable as tree species grouping may be for forest management purposes, it appears worth noting that pooling tree species to groups, monitoring of species of special interest for conservation or other purposes is disadvantaged. Therefore, if there are tree species of special interest, forest management should record these during forest inventories and deal with their special issue when designing options.

Two approaches have in the past been used to aggregate tree species: an approach based on the commercial status of species, used mainly by forest management services and forest managers and a second approach based on diameter increment. Different techniques have been investigated by researchers (Meldthal *et al.,* 1985; Vanclay, 1991b; Atta-Boateng and Moser, 1998). The choice of using just one variable as the basis is inconvenient for projections needed in forest management planning. On one hand, the choice of using only the commercial status does not allow to make projections on future yields while on the other hand a grouping based on the diameter increment solely makes it difficult to make projections on values.

The approach used for grouping species within TROPFOMS bases species aggregation on both the commercial value and the diameter increment with a statistical method that is cluster analysis. This approach has interesting potentials provided that reliable data are available. However, a potential criticism against the species grouping made in this study is that the method assigned a commercial timber value to all species within a group, which may be different from market reality because all species are not currently commercialized at a regular basis, and thus the value projected may be inflated. But, it can also be argued that assigning commercial values to all species is positive because given the changes in the market, species not commercialized currently may have potentials to be better known in the future and commercialized more regularly. When industrial logging started in Cameroon earlier this century, the focus was only on Ebony (*Diospyros crassiflora*) and now more than 50 tree species are exported from the country.

Growth and yield module. The ability of making projections of future stand characteristics is essential in all approaches of forest management planning for timber production. In temperate forestry and especially for even-aged stands, models for predicting growth and yield exist already for a long time. However, uneven-aged stands are more complex and the modeling of their growth and yield has developed more slowly. Nevertheless, techniques now exist and recent developments have been substantial because of easy access to computers with a high level of performance. Among the methods used in growth and yield modeling of uneven-aged forests is the transition matrix method. Initially it has been criticized for the assumptions it includes, but it has gained more and more acceptance. The attractiveness of the transition matrix approach lies in its simplicity and it has been subject to many improvements, which, however, have decreased its simplicity as shown in chapter 2.

One of the most important difficulties encountered in using transition matrices relates to the lack of data for the estimation of transition probabilities. Working with data collected in temperate forests for decades, most authors, such as Michie and Buongiorno (1984), have preferred the use of simple proportions to estimate these probabilities. For the current research such data could not be obtained due to the lack of PSPs. In addition, simple proportions are not very suitable because some species groups may have no trees or only a few trees in some diameter classes, thus making proportions meaningless. It appears then desirable to develop some function that can use available data to estimate the probabilities needed. The logistic function was used for that purpose in this study and it has shown a quite interesting significance for some variables. But the analysis was not completely satisfactory due to the quality of data, which limited the sensibility of the model to stand conditions. Difficulties came particularly from the failure to obtain significant effects of the basal area on the ingrowth and the upgrowth probabilities. The basal area is considered an important variable and this research does not intend to contradict that, but the lack of significance encountered rather results from the quality of the available data. As mentioned in chapter 6, the range of variation was possibly too small to capture the importance of the basal area. Vanclay (1991b) alluded to such problems by regretting that: “Although experimental data are extensively used in developing plantation’s growth models, it is more common to develop growth models for mixed forests solely from passive monitoring data.” He later pointed out that there is a real danger that attempts to describe the behavior of the stand as a function of stand density may be confounded by other factors or fail. Another aspect of competition not incorporated in this study, as in most studies of growth and yield for tropical forests, is competition among different species groups. It is possible that different species groups compete with each other in special ways that need to be investigated.

Growth data. Modeling growth and yield requires a number of permanent sampling plots where all trees are measured periodically and records are kept, so that the evolution of individual trees may be traced over time. A major problem of this research was that there are no such plots in Cameroon. The data used were collected in another African tropical country (Liberia) and used in combination with information collected in Cameroon. This represents a serious limitation in the use of the model for practical applications, but hardly affects the theoretical analysis applied. It can be argued that, because the needed information on diameter increments is lacking in Cameroon, technical decisions are anyhow made at best on the basis of comparison with data from countries with similar forests. For example, Durrieu-de-Madron and Forni (1997) used a combination of data from Cameroon and the Central African Republic to propose a methodology for determining the cutting cycle for forests in East Cameroon. In the absence of information collected on the site, sound methodologies using imported data are still of interest.

The number of plots needed should be a function of the heterogeneity of the forest. In any case, it is advised to have more than 50 plots of one hectare per forest type (Synnott, 1979) measured periodically every two to five years. In the case of this study, the periodicity was right but only data from 20 plots where used and remeasured once with a five-year interval. The small number of plots and the fact that only two separate measures were taken made the data set skinny for some species groups and diameter classes, even after grouping.

9.2.2 Methods and data for the derivation of stumpage price

The residual approach which helped to derive the stumpage price for this research is a rather standard and widely used method for estimating such prices. The value of the raw material is obtained with this method after subtracting all availability costs from the sale price of related market products. The method is well accepted and does not present a source of problems in this study. However, a few problems may be mentioned in relation to the data. The application of the residual approach in this research can be criticized because the costs incorporated in the analysis include taxes that are paid to the government. The incorporation of taxes as costs means that the analysis is done from the standpoint of the forest manager and not the society as a whole. Such a criticism may appear pertinent, but the decisions supported by TROPFOMS usually confront the management at the concession level. Therefore, the primary users of the forests which are the local populations in and around the forest and the industrial logger are the first concerned. It should be noted that expenditures for the development of local infrastructure and fees due to local communities were not included. In Cameroon, it is required by law that an agreement be reached between the concessionaire and the local populations about the contribution of the logging company to the development of the local infrastructure within the first three years of concession holding. These three years are devoted to management planning. In addition, for sales of standing volumes, 1 000 FCFA/m^3 of timber harvested should be given directly to the local populations. Therefore, the analysis is not done only for the logging company but for both the local population and the logging company. In addition, logging taxes are low in Cameroon and are not expected to change a great deal of the solutions obtained.

The sale prices chosen are the FOB prices for logs as these are the best documented prices in Cameroon. The difficulty related with the data on prices is that they do not show variations with the size of the log as some market realities suggest. Instead, only average prices were obtained. To overcome this difficulty, theoretical assumptions were made in section 7.2.1b. Nevertheless, there is a need for a stronger basis to portray the relationships between the log size and price.

The most important limitation comes from the logging costs. To improve the quality of the outcomes, it is desirable to have information about the variation of logging costs with the diameter of the trees being logged and with logging intensity. There are at least two reasons why the stumpage value per unit volume is expected to be a function of the diameter. One reason is that, logging waste per cubic meter harvested tends to be higher for trees of smaller diameters than for trees of large diameters. Therefore, the commercialization coefficient which was defined in chapter 4 as the ratio of the marketable volume to the volume of stumpage estimated on standing trees during forest inventory before logging, will decrease as the diameter increases (CTFT, 1972; Fourier-Djimbi and Fouquet, 1998). The other reason stems from the fact that logging costs are higher for trees of smaller diameter than for the ones of bigger diameter when expressed per unit volume. This is because there are some fixed costs per tree harvested. Thus small trees with less volume have higher fixed costs per unit volume. Some of such costs are the costs of the times spent by a skidder or a felling crew to walk from one tree after felling to the next. Unfortunately, the available data did not allow differentiating between logging costs of trees of various size classes and different logging intensities.

Another shortcoming from the data on logging costs results from the transitional phase in which the logging industry in Cameroon was when the data was collected. The tax system was not stable. For example, with the former regulations, there was a fixed annual per hectare tax for holding a logging concession granted for five years. This tax was not due for logging companies that were granted one year "ventes de coupe". The new regulations made provisions for the same type of taxes but new concessions were not yet issued and only "vente de coupe" were granted to loggers with less taxes. For that reason, the logging costs in this research may have been underestimated compared to the reality faced by the logger when holding concessions, which are now granted for 15 years.

9.2.3 Conclusion on the data needs and methods of analysis for forest stand characterization

The data used are the best currently available and the methods for their analysis seem scientifically satisfactory. However, significant improvements of TROPFOMS outputs can be obtained if the information included in the system is more specific to south Cameroon and more precise. Specifically, there is a need to have growth data from PSPs established in south Cameroon which include enough variation in basal area in order to improve the sensitivity of the system to stand stocking level. The outcomes can further be improved if the stumpage prices are determined more specifically not only by species group, but also by diameter class and in relation to logging intensity. Such a determination of stumpage price will require more information about the relationships between logging waste and tree size on one hand, and logging costs and tree size on the other hand.

9.3 Reflections on the outcomes of TROPFOMS

The system designed uses matrix algebra, linear programming and numerical simulations. The outcomes relate both to the stand characteristics at steady state and during the conversion period.

9.3.1 The outcomes related to the steady state

The outcomes in chapter 7 suggest a steady state with a cutting cycle of 30 years for the sustainable production of timber and a cut as high as 117 m^3/ha or 11.42 trees/ha which corresponds to a PAI (See section 4.2 for definition) of 3.9 m^3/ha/year. Part of the discussion about these figures was done in section 7.4.1. Such a harvest may seem too high when compared to the current levels in Cameroon where 0.5 to 1 tree/ha are harvested with 6 to 10 m^3/ha (Eba'a, 1998b; van der Hout and van Leersum, 1998). However, two points are worth keeping in mind in the examination of these numbers.

The first one is that the harvest now is very selective and concerns species of group 1 and 4 almost exclusively. Thus, if the market remains the same as now only about one to two trees/ha would be harvested at steady state with a volume of 15 to 25 m^3/ha. However, because of the time span involved, the market is unlikely to stay the same. In fact, when observing the changes that have occurred in the history of logging in Cameroon (Eba'a, 1998b) and other African countries, there is a tendency towards diversification of species harvested. That tendency can be expected to continue either because of the exhaustion of the most valuable species and/or better knowledge of other timber species resulting from ongoing efforts for their promotion. The outcomes of the model are maximums because all species are included in the estimation of timber cuts.

The second point is that these values represent the expected harvest at steady state and not what can be obtained now from the current forest. To obtain such a forest structure many cutting cycles of conversion should first be completed.

Concerning the length of the cutting cycle, it falls within the range of values already suggested for the management of tropical forests. Nevertheless, it should be noted that the inclusion of ingrowth estimations and transition probabilities that are more sensitive to basal area may reduce this cutting cycle to a lower value. This is because there will be a tendency that the growth rate declines with the length of the cutting cycle. This makes it less beneficial to maintain the growing stock with a discount rate that will stay constant while the stand growth declines.

The suggested cutting cycle of 30 years or shorter goes in an opposite direction of the recent suggestions of cutting cycles for management of tropical forests in south Cameroon and elsewhere in Africa. Most of the existing estimations are based on professional judgment, but more and more estimations are based on scientific or technical arguments. Durrieu de Madron and Forni (1997) suggested a cutting cycle of 30 years for primary forests in east Cameroon and a longer harvesting periodicity for secondary forests. In the management plan of the Lokoundje Nyong permanent forest in south Cameroon, the cutting cycle has estimated to be 40 years (Poulin-Theriault Inc., 1998). In Ghana, the cutting cycle has shifted recently from 25 years to 40 years (Nolan and Garthey, 1992). In all these and in many other cases the basic reasoning is to estimate the time period that is necessary for the current forest to recover after logging. In other words, say a forest stand now has V m^3/ha of growing stock and a harvesting occurs that takes away h m^3/ha and leaves V_o m^3/ha. The question tackled in these cases is then: how many years of growth does it require to the reserve growing stock V_o to be increased by h and become equal to V again? Such an approach assumes that the stocking of the forest at the beginning is the best capable of meeting management objectives. Thus, knowledge of the current structure of the forest and the growth rhythm of different species groups that constitute the stand is enough to simulate the time needed to make up for the harvest damage and reach the initial stocking. Durrieu de Madron and Forni (1997) give a good illustration of such a line of thinking as they proposed the use of the *"pourcentage de réconstitution"* (percentage of reconstitution) to estimate timber harvesting periodicity (or cutting cycle). Their definition of the percentage of reconstitution is given by equation 9.1 as follows.

$$\% \mathrm{Re} = 100\frac{[N_0(1-\Delta)](1-\alpha)^T}{N_P} \qquad (9.1)$$

Where:

%Re = percentage of reconstitution of the number of stems that were above the DME at year 0,

N_o = number of trees in the three or four diameter classes immediately below the DME,

Δ = rate of logging damage,

α = mortality rate,

T = time needed for a tree in a given diameter class to grow up to the next diameter class

N_P = number of mature (DBH $\geq$ DME) trees in the stand at year 0.

To calculate *Re* with this formula, only inventory data and growth characteristics are needed. For different values of multiples of *T*, it is possible to find out the time that is necessary to have *Re*=100, which means the stand will have recovered from timber exploitation entirely. However, based on a subjective professional judgment one can also desire to reconstitute a proportion of the harvest different from the initial one.

The basic concern of the above mentioned approach is to determine the cutting cycle and the harvesting rules in relation to some level of wood production. In fact, if data allow it would be better to determine the number of years after logging for which the highest PAI is obtained.

In contrast to the preceding line of thought, the reasoning in this research does not suppose that the structure of the initial forest is the one to maintain, but it looks for the stand structure that is best capable of meeting forest management objectives at any given cutting cycle. The production of timber in a sustainable way per se is not seen as an objective here, but income generation through sustainable timber production, nature conservation and improved living conditions for the local populations through production of NTFP are the actual objectives. Therefore, in addition to growth and inventory data, other aspects such as the characteristics of the timber product market or the plant species utilized by the local population are incorporated. This can result in a tendency to reduce the cutting cycle also because the opportunity costs of both land and capital are taken into account.

Another important point that may affect the outcomes for the steady state is the maximum basal area set at 40 m^2/ha. The constraint was included to limit the growth since the expected relationship between stand growth and stand density was not established with the available data. The value of 40 m^2/ha may appear too high, which means the resulting cutting cycles are probably longer. However, the observations of Bibani (1996) on the TCP research site show that, although the average stand has a basal area of about 34 m^2/ha, the actual basal area of individual plots varied from 30 to 40 m^2/ha. Therefore, since the interest was to set a maximum and not an average, it appeared reasonable to chose 40 m^2/ha. Nevertheless, it would be better to avoid setting such a maximum if better information on the relationship between stand density and stand growth exists.

9.3.2 Outcomes related to the conversion period

The outcomes for the conversion period have been obtained in the case of a strict application of the cutting rules for the target steady state in chapter 7. The basic actions to be conducted during the conversion period consist of removing trees not only by timber harvesting and related damage, but also by silvicultural operations to orient the forest towards the desired structure. This resulted in removing 50% of the basal area at the beginning of the conversion period. It is believed that such a strict application may be the fastest approach to move towards the steady state. However, such an approach may be questionable on ecological and social considerations especially because of the high level of removal.

In fact, because the conversion period did not undergo an optimization sequence but was rather simulated, some room is left for the manager to use professional judgment and adopt an intensity of actions to orient the stand towards the steady state. For example the manager may avoid removing trees of species groups 1 and 4 at the beginning and focus more on removing trees of the less valuable species. This may allow trees of the most valuable groups to be removed in later cycles when they will have reached commercial sizes. This may extent the conversion period but may prove more interesting on financial grounds.

In any case, it should be reminded that the steady state will probably never be achieved because of the time span involved. For a period as long as 120 years, it is almost certain that management objectives will change during that long period. Then the estimated steady state will no longer be suited to best meet the revised objectives. Similarly, the technological environment will progress and new techniques and parameters specifications will lead to new solutions. Nevertheless, the interest of these solutions is that they help orient the course of action today with the long-term future horizon in mind, and today's concern about the future is one central element of the notion of sustainability.

9.3.3 Conclusions on the outcomes

The numerical outcomes of this research presented many interesting points as mentioned in previous sections. These outcomes are obtained not in the interest of maximizing wood production, but with the idea of achieving better satisfaction of management objectives beyond wood production. Therefore, it is important to include in the analysis more information than only stand characteristics.

However, when examining these outcomes one should have in mind that: "the purpose of mathematical programming is insight, not numbers" (Dykstra, 1984). An important suggestion that can be retained from these outcomes is that it is possible to find a more valuable stand structure that can generate higher income levels through logging in the future, in coexistence with other objectives. Compared with the current logging intensity, it is possible to achieve a higher timber harvest in south Cameroon in the future and maintain it. However, silvicultural operations seem necessary in order to modify the structure of forest stands.

Cutting cycles of 30 years or a bit lower are viable options and possibly the most attractive for production forests where sustainable production of timber is foreseen. At each cutting cycle, it is better to harvest trees that have reached the maximum size. The conversion period should take a long time (more than 100 years), but while undergoing conversion, positive financial returns can be attained from forest management.

This study confirms the conclusions of van Dijk (in press) that generation of income through timber production and other forest productions for the benefit of the local populations do not have a high level of incompatibility. On one hand, a complete ban of timber harvesting of the critical tree species that are of interest for both the logging company and the local populations results in a decrease of less than 7% of the STV. On the other hand, it is expected that cutting trees of NTFP species which have 100 cm of diameter or more as suggested by the outcomes here, will not have an important impact on the supply of forest products to the local populations. This is because these trees with a DBH of 100 cm or more will have been producing products of interest to the local populations for some decades. Cutting these trees may help regeneration of NTFP species, and trees smaller than the ones eligible for harvesting are able to supply the local populations with needed forest products. However, management should check the current inventory of these trees and take special measures if there are irregularities in regeneration. One of the observations made by van Dijk and Wiersum (1999) is that "the most limiting factor to further development of NTFP extraction from the natural forest is the relative low density of NTFP species rather than damage caused by commercial logging", which goes in the same direction as the conclusion of this study.
Similarly, a strong incompatibility between timber production and species-size diversity has not been established with TROPFOMS. The outcomes of all runs of TROPFOMS under different assumptions suggest that all the species groups will be rather substantially represented in the steady state stand. In addition, it is possible to have at least one tree per size class and per species group within 50 hectares at steady state without important sacrifice in financial returns. The possibility of having a representation of all species-size classes within smaller areas seems to be more limited by the growth characteristics of different groups than by timber harvesting.

9.4 Final conclusions

The overall objective of this research was the development of a system which can support decision-making for the management of natural tropical forests. This overall objective was subdivided into five specific objectives as presented in section 3.2.2. The main points which can be retained in accordance with the specific objectives and related research questions are:

a) A methodological tool was developed and given the acronym TROPFOMS. It provides quantitative information at stand level to support decision-making for tropical forest management. The information obtained from TROPFOMS concerns the optimum cutting cycle and stand structure both for the steady state and the conversion period. To provide support for forest management the system combines information from forest stands, timber products markets, use of the forest by the local population and ecological limitations of the forests. In addition, characteristics of the logging techniques used and the statement of management objectives are needed.
b) The system developed is based on tree species groups. The basic coefficients included in the system relate to the growth characteristics of forest stands and market prices of timber products. The growth characteristics are incorporated in the form of transition probabilities, which permits to make growth and yield projections. The timber market information is included as stumpage prices and it permits to estimate the timber values of forest stands at different points in time. Tree species were grouped by cluster analysis based on both diameter increment and FOB prices of logs. Transitions probabilities were estimated by logistic regression analysis while stumpage prices are derived by residual approach.
c) The optimal cutting cycle obtained for sustainable timber production was estimated to be 30 years. The steady state harvest for species that are currently commercialized was estimated at 13.41 m^3/ha but can raise as high as 117 m^3/ha if all the species are harvested. The harvesting rule only allows cutting of trees of 100 cm of diameter or more. The structure of the stand before harvest is constituted by all species groups with a negative exponential distribution of trees among diameter classes. Such a distribution is characteristic for uneven-aged forest stands.
d) The average forest stand at the TCP research site shows important differences with the desired steady state structure. The total number of trees per hectare is currently higher. However, for the most commercialized species group, this number is smaller. It would require about 120 years to convert the current forest stand at the TCP research site to the desired steady state structure, but during the conversion timber harvest with positive financial returns is possible.
e) The objective of income generation can be achieved simultaneously with the use of the forest by the local population without important consequences to income due to this use. Similarly, it is possible to have at least one tree of every species group in every diameter class within an area of 50 ha without important reduction of financial returns from logging.

9.5 Recommendations

9.5.1 Recommendations for policy and management

- ***Increase of minimum diameters for felling (DMEs)***. One of the most important measures taken to promote sustainable management in Cameroon is the utilization of DME. From this study, it can be concluded that the use of DMEs is a legitimate tool for the sustainable management of tropical forests. The optimization has also proposed a harvesting policy for the commercial species, which consists of harvesting trees from a certain diameter class onwards. However, the difference is that all the harvest here occurs only at the highest diameter class, which disagrees with the current setting of DMEs (See section 6.1.1). The suggestion is that current DMEs are low, it is both economically and ecologically sound to raise the DME towards the maximum size of trees of each group. Raising the DMEs for all species to be around 100 cm (about the maximum size for every species group) will lead to a decrease of the harvest at the beginning of the conversion period with the current characteristics of timber products markets, but will increase the value of forest stands in the long run.

- ***Silvicultural operations***. Another important point to be considered by the management is the necessity of opening up the forest stand by removing trees to allow more growth. If trees of species groups 2 and 3 are not demanded in the market, it is recommended to remove trees of these groups to make room for more growth of higher valued species. Removing trees of these groups is not necessarily done by logging operations. Silvicultural techniques may be used with less damage than logging.
- ***Periodicity of timber harvesting***. The cutting cycle to be adopted should be around 30 years in production forests. However, slightly lower values may be acceptable because it is anticipated that if the model becomes sensitive to stand density, it will recommend a reduction of the cutting cycle (See also section 9.3.1). In general, the outcomes suggest having more frequent harvests than 40 years or more, but smaller harvests because the DME will be increased.
- ***Computations equipment and trained personnel***. The research as a whole has highlighted the complexity of the computations to be performed for adequate technical support to forest management decision-making. It is therefore important for the management to acquire the necessary logistic equipment for the needed computations. In general, a computer with adequate capacity (about 24 to 32 MB RAM) is sufficient. In addition, trained manpower capable of using the software adequately as well as planning and implementing silvicultural prescriptions should be present. It is presently not in the habits of logging companies to have such personnel among their staff.
- ***Information base and archives***. The quality of the information on which the analysis made with TROPFOMS is based, is of primary importance. Therefore, management should carefully archive all information related to all management activities to improve the quality of future analyses. All information about the quality and the quantities of forest products harvested as well as various costs and benefits should be well gathered and stored.
- ***Permanent Sample plots.*** In order to improve forest management gradually, a good monitoring system of the forest is needed. It is necessary that for each forest type, a number of PSPs be maintained.

9.5.2 Recommendations for further research

In order to improve the outcomes of TROPFOMS and implement them more confidently, more research is needed in relation to the following items:

- ***Silviculture***. The importance of removing trees in order to achieve the expected harvest at steady state has been shown in chapter 7. Similarly, in chapter 8 the steady state is approached by tree removal during the conversion period. Not all trees removed are harvested for timber production because of market characteristics. Therefore silvicultural operations are necessary. In order to obtain the desired results, more knowledge is needed to assess the impact of silvicultural treatments on stand dynamics in general and on tree growth in particular. In addition, the costs of treatments should be studied in comparison with the gains in growth.
- ***Growth and yield***. The information on stand growth and yield is a key factor on which all outcomes depend. One weakness of this research is that it relies on growth information gathered outside Cameroon (See section 9.2.1). Therefore it is of primary importance that a network of PSPs be established and monitored properly in south Cameroon. Such a network should consist of at least 50 plots of one hectare per forest type, and all trees should be monitored irrespective of their current commercial status. These PSPs should provide a framework within which the effects of changes in stand density on growth and ingrowth will be investigated.
- ***Maturity of tree species***. One constraint incorporated in the analysis was to restrict harvesting to mature trees that have been in a reproductive stage for a number of years. This was necessary because the system relies on natural regeneration. It makes sense to leave to a tree an opportunity to reproduce before it can be harvested. Therefore, a more accurate knowledge of the relationship between tree size and reproductive maturity is needed. A study should be conducted to determine at which sizes different species groups start to produce enough viable seeds.
- ***Ecological information.*** A few ecological constraints were introduced, such as the restriction on the proportion of basal area permitted to be removed. The values used came from common practice described in the literature. There is a need to improve the understanding of the sensitivity of ecological variables to logging.
- ***Logging efficiency, costs and damage***. In addition to growth and yield, the stumpage price is one of the main factors that determine the steady state as well as the conversion period. Therefore there is a need to obtain an accurate estimation of stumpage price. However, the stumpage price is affected by logging efficiency and costs. In this research a need has come up to characterize the relationship between the total volume harvested, the size of the trees and the logging costs expressed in FCFA/m^3. Similarly, it is important to know how logging waste varies with the size of the trees and how logging damage is distributed between different size classes. All these themes need to be studied to improve the needed insight obtained while modeling forest management with the methodological tool presented here.
- ***The utilization of forest by the local population***. The research presented here has used information about the utilization of forest by the local population. The information about forest use by the local population should be better developed to include not only NTFP

trees and other plants, but also non-plant products. In addition, it appears that not all the existing NTFP trees effectively supply the local populations with the needed products. The understanding of the way the local population chooses NTFP supplier trees should be developed in order to better conceive the type of restrictions to be imposed on timber harvesting to guarantee proper supply of the local populations with desired products. Similarly, it is important to improve the understanding of the effects of logging and silvicultural treatments on NTFP supplier trees.

- ***Royalties.*** Sensitivity of forest management to royalties should be investigated. Such an investigation will allow to obtain more insight into the way tropical forest management can better contribute to generating government revenues, and the way a forest revenue system can contribute to sustainable forest management.