IUFRO CONFERENCE ON GROWTH STUDIES IN MOIST TROPICAL FORESTS IN AFRICA

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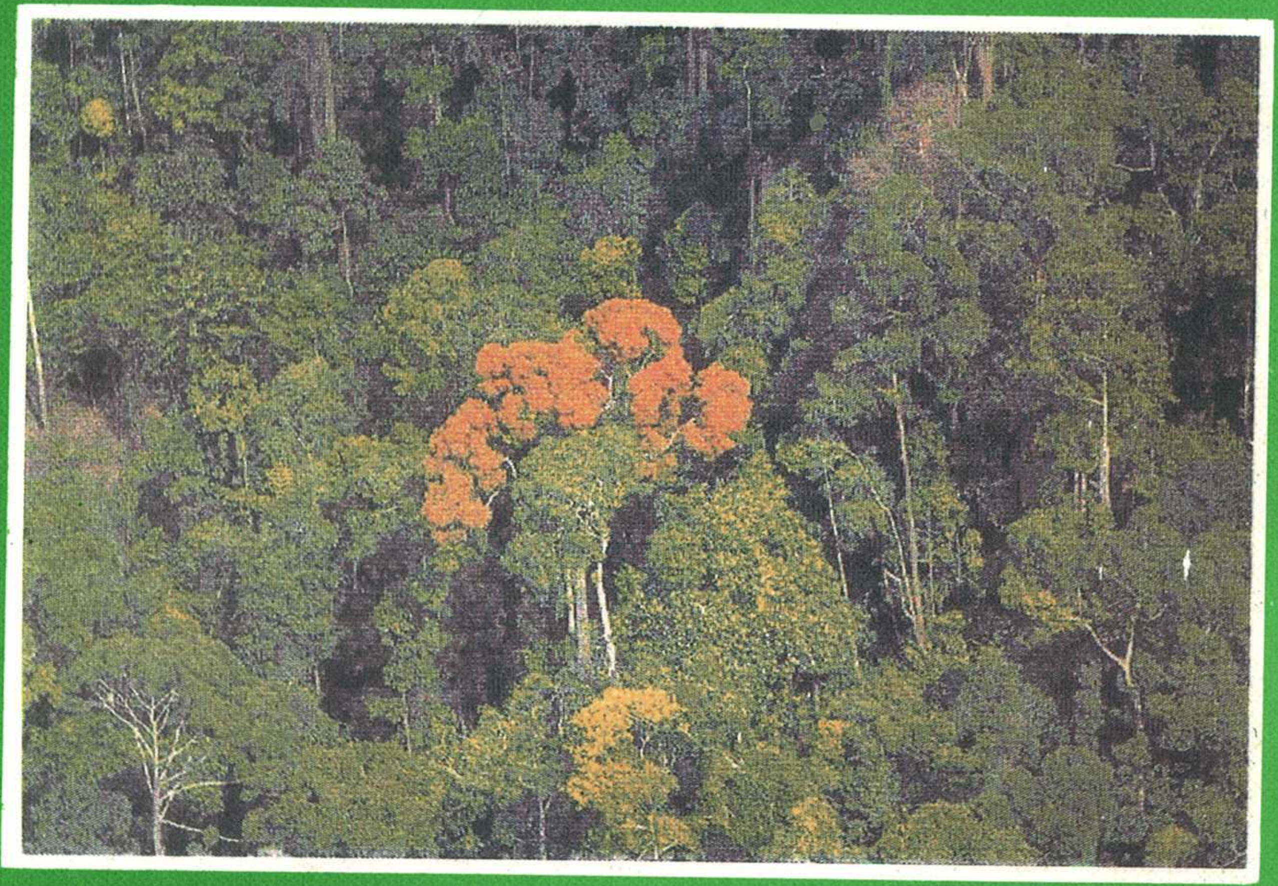

11-15 November, 1996, Kumasi, Ghana

PROCEEDINGS

IUFRO CONFERENCE ON GROWTH STUDIES IN TROPICAL MOIST FORESTS IN AFRICA

Held at Forestry Research Institute of Ghana, Kumasi
11-15 November 1996

Sponsored by ***IUFRO 1.07, 4.01, 4.02.03*** *and* ***SPDC***

Organised by
Forestry Research Institute of Ghana
in association with
CIFOR
CIRAD-Forêt
ODA (UK)
The Tropenbos Foundation

PROCEEDINGS

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Foreword

Many growth studies have been commenced in the tropical moist forests in Africa, but have lacked coordinated analysis and synthesis. A casual discussion of this obvious but serious short-coming led to the realisation of the need for a meeting of forest managers and researchers in Africa in the hope that the problem could be given some attention and cogent solutions found. With the support of IUFRO and SPDC a conference was consequently held in Kumasi, Ghana between 12 and 15 November 1996.

The Conference sought to bring together researchers involved in plot-based studies of forest growth and change, the principal objectives being to draw attention to existing permanent plots and other studies, and to promote more efficient use of these data. Another important objective was to foster more collaboration and cooperation between those working on such plot-based studies and related aspects.

The major issues covered by the conference, which focused on inventory methods, growth studies in tropical moist forests, and case studies in Miombo, secondary and plantation forests, were:

- extent and nature of data currently available;
- status of existing plots;
- priorities for re-measurement;
- analysis and implications of existing data;
- regional comparisons of growth change;
- assessment and monitoring of biomass and biodiversity;
- empirical studies on effects of fragmentation.

An account of the conference is provided in these proceedings. The proceedings follow largely the format of the Conference and is presented in two parts. Part I presents addresses in the opening and closing ceremonies while Part II covers speaker presentations in the technical sessions. The latter is presented as follows:

A. Inventory methods;
B. Growth studies in tropical moist forests; and
C. Case studies im Miombo, secondary and plantation forests.

Whereas every effort has been made to ensure clarity and readability in editing the proceedings it has not been possible to reproduce some maps and figures which, unfortunately, were not made available by the authors. In a few cases also some authors did not make available the full text of their presentations, for which reason only the abstracts are provided. Readers may therefore wish to contact the authors for fuller versions of their presentations.

The assistance, financial, material and otherwise, received from the following organizations and individuals towards the success of the Conference is gratefully acknowledged: - IUFRO, SPDC, CIFOR, CIRAD-Forêt, ODA (UK), The Tropenbos Foundation, Prof. Jerry Vanclay, Dr. Denis Alder and Dr. Marc Parren. The Conference Organising Committee also wishes to thank all conference participants for their valued contributions.

Dr. Albert Ofosu-Asiedu
Chair, Conference Organising Committee

Conference organisation

Conference chairpersons

- Dr. Vincent Beligne
- Dr. David Ladipo
- Mr. Chemist Gumbie
- Dr. R.G. Lowe
- Mr. J.G.K. Owusu
- Dr. Jean Joël Loumeto

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- IUFRO 1.07, 4.01, 4.02.03
- Centre for International Forestry Research (CIFOR), Indonesia
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Training Workshop Facilitators

The conference organisers thank the following participants who willingly acted as facilitators for the Growth modelling Training Workshop, which was organised for selected participants between 18 and 21 November to complement the conference: -

- Prof. Jerome K. Vanclay
- Dr. Denis Alder
- Dr. Chris G.K. Dake
- Dr. Douglas Sheil

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CORRIGENDUM

Footer should read:

IUFRO/CIFOR Conference on Growth Studies in Moist Tropical forest in Africa. Kumasi, Ghana. 11 – 15 November 1996

Summary of conference discussions

Summary of conference discussions

The conference involved the presentation and discussion of technical papers grouped under three broad headings, namely:

- Inventory methods;
- Growth studies in tropical moist forests; and
- Case studies in Miombo, secondary and plantation forests.

All delegates to the conference participated in the discussions and the general opinions expressed are summarised as follows under the respective themes:

Inventory methods

There was a consensus on the use of PSPs and forest inventories in general for both short and long term needs of forest management. For sustainable forest management it was noted that PSPs, among other things, should also provide information on biodiversity and multiple use values of the forest. There was a general indication that different methods have been used in PSPs for determining various parameters. Generally, there exists a large volume of data on specific aspects of the forests spanning short and long term periods, but these have not been analysed due mainly to the inapplicability of traditional methods of PSP data analysis. The main question put was: how can these data sets be analysed to provide very useful information for sustainable management?

The need to review the forest inventory design in the light of management information needs in the 21st century received attention. The importance of cost effective inventory design and procedures was also emphasised. Some of the issues raised were:

- What should be the cut-off point for stem dbh measurement in growth studies?
- How many trees are to be measured per plot?;
- What is the optimum number of sample plots per forest type?
- How are correct species identification and measurement ensured?

The conference agreed that the surest way to obtain maximum benefit from PSP and other forest inventory data is through proper data analysis and interpretation. The cardinal points identified as instrumental in achieving this are:

- Reconsideration of objectives of inventory design and analysis to find out if sufficient data have been collected to detect a trend.
- Checks for errors through data sorting, identifying biggest and smallest values and looking for sudden jumps in values.
- The use of graphs, especially in the preliminary data exploration phase of analysis is important, but simple graphical representations that contribute towards a fuller understanding of the data should be preferred.

- In examining commercial aspects such as timber volume, the extent of individual species' contribution and use of generalised/specific volume equations should be taken into account. Similarly, the definition of the volume being estimated or predicted needs to be given.
- For meaningful comparison of different data sets, variation of responses from replicates and treatment effects should be of interest as well as monitoring of responses over time as they relate to other changes in the forest.
- For multivariate analysis, a scatterplot matrix (cf. correlation matrix) helps to screen for possible confounding. For orthogonal data PCA will explain distribution of variance among variables.

Growth studies in tropical moist forests

Several growth studies and some attempts to improve upon growth and also develop models for growth prediction were discussed. Volume increment in the natural untreated tropical high forest was reported to be between 4.2 m^3/ha/yr in the drier forest to about 6.5 m^3/ha/yr in the wetter zones. Errors in estimating the increment were attributed to inconsistencies in stratifying samples and methods of diameter measurement of bigger trees. It was recommended that the possibility of using increment borers should be investigated.

Individual stem increment was reported to be greatest for stems between 30-50 cm dbh. However, value increment is highest above 50 cm. To cut down the cost of measurement it was recommended that increment studies for prediction of timber production should concentrate on stems above 50-cm dbh. The ability to predict growth and value of trees of various stem sizes would help to fix economic felling limits for species. This calls for more studies on the distribution of or contribution to total forest growth by various dbh classes.

The presence of lianas, which constitute a dominant feature of the tropical high forest, was noted as inhibitory to natural regeneration and tree development. Climber cutting was however recognised to enhance growth of younger trees and also reduce logging damage. The climber cutting operation if combined with timber/exploitation inventory could be more cost effective.

Tree crown dimensions were shown to have significant influence on stem sectional area growth. Models relating crown dimensions and sectional area increment indicated strong correlation. To improve upon such models and to have better understanding of tree crown behaviour, studies would need to be conducted at nurseries, plantations and in the natural forest.

Discussions on the presentations on stand models emphasised that a stand projection which is not corrected for stand-level increment and mortality tends to over-estimate achievable yields in natural forest. It was generally agreed that the application of any model would need specific local management regimes to achieve optimal results. There was a caution that since nature is very diverse, mathematical models may not be very efficient for forest monitoring and therefore field monitoring should be preferred. Mathematical models of the tropical high forest should serve mainly as indicators of possible directions to be pursued by forest managers. For instance, natural forest data on a single species cannot be transferred directly to plantation management but can indicate a trend to be expected in the plantation forests.

Case Studies in Miombo, secondary and plantation forests

The conversion of forest to cash food crop farms makes forest biodiversity monitoring by PSP in farming systems very uncertain. However, the situation could be improved if the local communities are involved in the inventory programme.

Indigenous knowledge on tree species preference for specific sites is necessary for tree growth studies on farmlands, at least for the selection of sites. The history and cultural practices of the farming system of any study area will also be necessary to understand the species dynamics after the farms have been abandoned.

For better understanding of the forest species dynamics or the patchy nature of a secondary forest, the nature of the soil and the past farming intensity needs to be known. About 33 species have been studied in PSPs in the Miombo woodlands of East and Southern Africa. Growth of these species was shown to be generally slow. Some of the fast growing species have a diameter increment ranging from 1.5 to 2.9 mm per year. The trees are estimated to reach mature sizes of 30-35 cm dbh in not less than 200 years. The discussion focused on the main problems in monitoring and assessing growth, paramount amongst which is the determination of suitable parameters that can best describe the growth dynamics of the Miombo woodlands. It is still not clear whether diameter, basal area or volume increment should be the variable to use. It was suggested that in order to exclude the negative contribution of bark shrinkage to stem increment measurement a considerable time lapse of 3 years measurement would be required.

Conclusion

The attendance and papers presented at the conference, and the level of participation in the discussions, indicated that many scientists in Africa are engaged in the area of forest growth and yield models through the use of PSPs. The extent of the discussions led to the conclusion that the benefits of PSP will be realised better if plot laying, data collection, data analysis and interpretation are done in the best professional way. It was therefore deemed necessary for scientists in the region to be in constant touch and to share ideas and experiences that will enhance professional expertise.

Part I: Opening and Closing Addresses

Part I: Opening and Closing Addresses

Welcome address

Dr. Christine Amoako-Nuama
(Hon. Minister of Environment, Science & Technology, Ghana)

Mr. Chairman, Honorable Colleague Ministers, distinguished guests, ladies and gentlemen, I am indeed grateful to the organisers for inviting me to this conference to welcome such a distinguished gathering of scholars, experts and policy makers on the problems related to forest resources, particularly in the tropical world. I am overwhelmed by the fact this is the second IUFRO meeting in this country, coming so shortly after the first one. Not quite a year ago a series of meetings were organised in this conference room by CIFOR and FORIG, at which an equally distinguished gathering of traditional rulers, policy makers, forest scientists and many important forest stakeholders from the West-African sub-region discussed issues relating to incentives for sustainable management of the forest resources of the sub-region. I remember throwing a challenge to that workshop to come up with some concrete guide-lines for managing our forest resources and thereby provide the momentum for achieving sustainable development with respect to our forest resources. I want to believe that it is in this direction, and as a follow-up to this challenge, that CIFOR and FORIG have once again brought together such an august group of scholars, scientists and experts in growth studies here today to exchange their experiences and opinions.

Mr. Chairman, FORIG is one of the constituent institutes of the CSIR under the Ministry of Environment, Science and Technology. Its involvement in planning and organising such meetings is therefore an indication of governments' commitment to ensuring that the forest resources of Ghana are properly managed.

The problem in most tropical countries is that of uncontrolled exploitation of forest resources. Indeed the dependence on timber as one of the major foreign exchange earners has increased in recent times. Coupled with this is the ever-increasing population which has resulted in the need for more agricultural land for feeding the people. Consequently forest depletion has been put into over-drive throughout the continent, at least where there is some forest cover.

It is in the light of these developments that issues relating to tropical forests are receiving more and more attention world-wide, not only in an attempt to arrest the problem of deforestation, but also to reverse its negative environmental consequences. Discussions on forest related problems are being held by most donor countries, international societies, international financial organisations, non-governmental agencies, as well as the local agencies responsible directly or indirectly for addressing forestry issues, as part of the UNCED initiative. This conference, I am sure, is part of such a process.

Mr. Chairman, distinguished guests, ladies and gentlemen, to date forest management practices and polices have been tailored to solve most of the forestry related problems, but the problems still appear to exist owing to lack of adequate information about the natural forest ecosystem. I am happy to note that this conference seeks to identify technical data currently available, as well as what is still needed, for providing governments and policy makers the requisite information, and therefore options, for addressing global forest issues. My challenge to you at this meeting is that your deliberations should focus on ways of evolving better methods for inventorying the forest, analysing the results and providing useful guidelines for policy-makers. The conference should also create a process that will provide us with the best tools with which to evaluate whatever set of guiding principles are inherent in our policies, and evolve methods which would be more appropriate for better management of the forest resources on the continent.

I am confident that this conference and the subsequent workshop, which is designed to provide participants an insight into current growth modeling techniques, will make a significant progress towards the exchange of views and experiences among participants; and will generate important ideas and recommendations towards the development of improved forest management techniques. My Ministry will follow keenly the developments from this meeting.

Mr. Chairman, I now have the singular pleasure and honour to welcome all participants to this conference and workshop. For those of you visiting Ghana for the first time I hope the organizers will make it possible for you to enjoy the beautiful scenery of Kumasi and the country-side. I wish you every success in your deliberations, and a happy stay in Kumasi. Thank you.

Keynote Speech

Dr. Kwabena Adjei
(Hon. Minister for Lands and Forestry, Ghana)

Mr. Chairman, colleague ministers of state, distinguished guests, foreign participants, ladies and gentlemen, I am grateful to the organisers of this august Conference and Workshop for calling upon me to give the keynote address.

The economy of Ghana and for that matter the whole of the West African sub-region is heavily dependent on the agricultural, including forestry, sector of the economy. For example, at present, timber is the fourth largest foreign exchange earner and accounts for about 6% of total Gross Domestic Product (GDP) of Ghana. The forestry sector also contributes indirectly to the economy by supporting the livelihoods of a large proportion of rural communities in the country and provides over 70% of the total energy requirements of the country.

Due to the importance of forest resources to national and local communities and the potential for the resources to be over-exploited, there is therefore the need for Governments to put in place policies leading to Sustainable Forest Management (SFM). The implementation of sustainable forest management by all countries, especially those in the tropics was one of the major issues that dominated the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil in June 1993. The "Rio Conference" concluded that Sustainable Forest Management can only be achieved through the formulation of effective and efficient strategies that ensure conservation and sustainable use of forest resources.

Even before the onset of the "Rio Conference" the Government of Ghana through the Ministry of Lands and Forestry supported by the Overseas Development Administration (ODA), U.K., launched a series of programmes, for example forest inventory and botanical survey projects, aimed at ensuring sustainable forest management by the year 2000 in line with the International Tropical Timber Organisation's (ITTO) Target 2000.

Two major forest inventories have been undertaken since the 1970's. The first was carried out in the late 1970's, covering only part of the forest zone and supported by the FAO. The second, the Forest Inventory Management Project (FIMP), which was supported by the Overseas Development Administration (ODA), U.K., was more extensive and covered both reserved and unreserved forests. The FIMP was aimed at providing baseline information on national growing stock estimates on which policies and plans leading to sustainable forest management could be formulated. The first phase of the FIMP, which lasted from 1985 to 1989, cost about £1.2 million while, the second phase which lasted between 1989-1995 and managed through the Forest Resource Management Project (FRMP) was estimated to cost £3.7 million. Apart from the above inventories, a tree botanical survey of all forest reserves in the forest zone has been undertaken.

Based on the results of the botanical survey and the national forest inventory the Ministry of Lands and Forestry has approved a protection strategy which has placed 22% of the reserved forest under permanent protection. The strategy also indicates that 32% of the reserved area will be rehabilitated with only 46% being put to productive use. My Ministry has also taken further steps based on the results of the inventory project to reduce the annual allowable cut (AAC), which was previously set at 1.2 million m^3, to 1.0 million m^3 in 1995.

Apart from the above mentioned programmes the Ministry of Lands and Forestry has also placed a ban on round log exports and also tightened felling controls over the off-reserves. Additionally, the Ministry has put in place programmes aimed at downsizing the timber industry and minimising logging and mill residue to ensure that the forest resource base does not dwindle. All these measures taken by the Ministry can be effective only if the dynamics of the forest is taken into account. This implies that data such as those collected through the national inventories should be properly analysed and meaningful deductions made from them to form the basis for management decision-making.

Mr. Chairman, ladies and gentlemen, it is indeed true that many growth studies have been carried out in the tropical moist forests of Africa, but the fact that they lack coordinated analysis and synthesis can not be over-emphasised. It is therefore gratifying to note that this conference seeks to bring together researchers involved with plot-based studies of forest growth and change. Among other things this conference aims at drawing attention to existing permanent plots and other studies aimed at promoting a more efficient use of available data, and to foster more collaboration and cooperation between those working on these and related aspects.

Mr. Chairman, I am happy to note that researchers who are members of the International Union of Forestry Research Organizations (IUFRO) have been brought together under the auspices of the Government of Ghana and IUFRO to try and discuss major issues such as:

- extent and nature of data currently available;
- status of existing plots;
- priorities for remeasurement;
- analysis and implications of existing data;
- regional comparisons of growth and change;
- assessment and monitoring of biomass and biodiversity;
- emprical studies on effects of fragmentation.

I wish you success in your deliberations over the next few days. I now have the pleasure in declaring the IUFRO/CIFOR conference and workshop on Growth Studies in Moist Tropical Forests of Africa duly open.

Closing Address

Mr. E.C. Saka
Secretary, Council for Scientific & Industrial Research, Ghana

Mr. Chairman, distinguished participants, ladies and gentlemen, it is already ten days now but it seems like only a few days ago since you gathered here at the opening ceremony, looking forward to availing yourselves of all that the IUFRO Conference and Training Workshop on Growth Studies in Tropical Moist Forests of Africa held for you. Ten busy days have passed and I am sure that your expectations have been fulfilled.

On behalf of the Director-General of the Council for Scientific and Industrial Research I wish to congratulate the organizers on their successful running of the Conference and Workshop. There are probably some who may have had misgivings about holding these meetings in Ghana. But it is now apparent that they need not have worried.

I am sure you will all agree with me that the planning, preparations and actual running of the Conference, the field trips and the Workshop have been virtually perfect. I have it on good authority that the quality of the scientific session was very high and that FORIG intends to have the papers published in the Ghana Journal of Forestry. The one thing which the organizers may not have been able to offer satisfactorily is TIME. Notwithstanding what you have learnt about the various techniques of modeling and predicting change in the natural forest I am doubtful if any of you would be able to help solve that problem by inventing a method for creating it! Mr. Chairman, I wish to assure the organizers, both here in Ghana and overseas, that they can take justifiable pride and satisfaction in having done an excellent job.

In his welcome address the Minister for Environment, Science and Technology threw a challenge to the meeting to evolve better methods of inventorying the forest, analyzing the results and providing useful guidelines for policy-makers. I am confident that you have lived up to this challenge and that what has been learnt here will go a long way to help us manage the forest resources of Africa more efficiently. The workshop must have generated lively discussions and exchange of experiences amongst you. This interaction is a priceless process, and I would wish that this group would develop a kind of network to foster a stronger link between you forest practitioners on the continent well into the future. This will not only ensure a constant exchange of ideas, but will also engender a collective approach to solving forestry problems in Africa. I am hopeful that the organizers will give serious thought to forming this network.

Mr. Chairman, distinguished ladies and gentlemen, in the knowledge that this IUFRO Conference and Training Workshop has been a great success it is now my pleasant duty to bring it to a close. I thank you all for coming here, for your participation and scientific contributions to both the Conference and Workshop, and for visiting our country. To those who are travelling back to their respective stations I wish you a safe and pleasant journey, and may God bless you all. Thank you.

Part II: Technical Sessions

A. Inventory Methods

Part II. Technical Sessions

A. Inventory Methods

***Session I**: Chair: Dr. Vincent Beligne*

Inventory for management planning: Experience in Ghana

J.L.G. Wong
Information Systems Specialist
Ghana Forest Sector Development Project

Abstract

Since its inception the Forestry Department has undertaken static inventories of the forest reserves and most recently of the off-reserve lands within the high forest zone and commercial NTFPs. The paper briefly describes the purpose, design and achievements of each of these. These data have been used to explore a wide range of forest management issues. Strategic questions that have been addressed are the determination of the AAC, the derivation of yield quotas and the categorisation of species according to the degree of over-exploitation. Management planning has benefited as the data has been used as a guide to the identification of protection areas and as background information for the preparation of harvesting schedules. The data has also been used to prepare regeneration profiles for nearly all the larger tree species and thereby provide a significant contribution to our understanding of forest ecology. Attention is drawn to the wealth of information contained in static inventory records and the considerable scope for further analyses is highlighted.

The question is posed of how often static inventories should be repeated and what might be required to ensure that periodic large scale inventories can be used to gain an understanding of the longer term and broader changes in the condition of the forest.

Introduction

Managing the tropical high forest is a daunting task given the complexity of the ecosystem and the paucity of knowledge about how it responds to disturbance. However, it is not possible to place an embargo on exploitation of the forest until foresters have a complete understanding of the system. Foresters are therefore forced into a position in which they must use whatever information is at hand to make decisions concerning the intensity, timing, sizes and species that can pragmatically be removed without compromising other forest values. Rigorous inventory as a prelude to reasoned management planning has always been a strong feature of Ghanaian forestry and has been intimately linked with the development of management prescriptions. Both static inventory and PSP monitoring for growth and yield have been undertaken for many years though the adoption of the 'leading desirable' concept in the 1950's for PSPs resulted in an extreme bias in the historical growth data. This paper examines the Ghanaian experience with inventory and management from the beginning of the Forestry Department to the present day. The emphasis is on the design and use of static inventory data while the development of the PSP programme is dealt with in a later paper.

Forest management and inventory 1909 to 1985

The selection and reservation of a permanent forest estate in Ghana began in 1909 with the formation of the Forestry Department. The procedures for reservation were elaborate and involved lengthy consultations with landowners and rights holders as the intention was for reservation to be voluntary and management undertaken by the traditional owners on the advice of the Forestry Department. The reservation procedures provided for the preparation of an interim management plan once the reserve had been settled. The objectives of reservation were in nearly all cases environmental with the emphasis on watershed protection and climate amelioration and the early plans generally dealt with reserve protection (mostly boundary issues). It was the intention that the non-reserved areas would be cleared of trees to become agricultural land and it was appreciated that this would necessarily mean that the reserves would at some time in the future be required to provide a sustained yield of timber from the 'Selection Working Circles'.

In the late 1920's the rather low emphasis given to inventory of the reserves was gradually replaced by a more formal requirement for a 1% inventory of all reserves. The 1% inventory was laid out as a systematic transects 20 m wide at 2 km intervals perpendicular to any hills and rivers. In the strips all trees greater than 30 cm d were enumerated but only the 'valuable' trees were tallied into the plot and reserve summaries. Maps indicating rivers, vegetation changes etc. the were also created for the reserve from the demarcation field books. Specimens were taken of all un-named trees and added to the Kumasi herbarium. By the time this inventory was abandoned in the 1950's a total of 1.22 million hectares had been enumerated.

By the 1950's a programme of management plan preparation was begun with more emphasis being given to timber exploitation under a polycyclic selection felling system. A strong feature of the 1950's management plans was the careful calculation of yield using a formula devised by Kinloch and Jack which was then checked against a simple stand table projection for reserve level inventory data (Jack 1960). The growth estimates came from measurements of early growth plots and grouped species according to their 'times of passage' across a 20 cm diameter class. It was considered that the 1% inventory data was not precise enough for the calculation of yields and a new higher intensity inventory was developed (Jack 1958) and adopted in 1954. The new inventory was a nominal 5% inventory though in practice the sampling intensity was varied according to the size of the reserve. The basic sampling design was stratified random with the strata defined as 1 square mile (1,609 m x 1,609 m) blocks within which 2 parallel random plots were enumerated. The strips were 40 m wide x 1 609 m = 6.5 ha in size. Within the plots all trees greater than 10 cm d were enumerated. Analyses of the plot data showed that the 5% sampling intensity gave satisfactory precision for reserves between 39 and 181 km^2 in size. Smaller reserves had a higher intensity inventory or, more likely were amalgamated with other reserves to form management plan areas (e.g. the six 'Ben' reserves were all dealt with in the Ben Group Management Plan). Reserves larger than 181 km^2 could have the sampling intensity reduced as it was found that the desired sampling precision could be obtained with enumeration of 20 blocks (40 plots). By the time the inventory petered out due to a lack of resources in the 1970's a total of around 1.1 million hectares of forest had been enumerated.

Unfortunately the data, analyses and reports of these inventories are not readily available except as reserve or block summaries appended to the management plans and a few papers. Although the data from these inventories does not seem to have been used strategically the 5% inventory set the yields from the reserves for the 20 year duration of the 1950's management plans which records indicate were followed fairly rigorously. During this period it is also clear that the data were in constant use to answer questions about the commercial stocking of particular reserves and also as a research tool (Silviculturist's archive, Kumasi).

In the 1970's as the 20 year management plans lapsed the Forestry Department adopted a 'Salvage felling cycle' in which all 'over-mature' trees i.e. greater than the felling limit were to be removed without reference to the harvesting schedule or yield control. The collapse of the economy in the late 1970's ensured that this did not lead to the demise of the forest but also meant that by 1980 when the fifteen year period was over it was not possible to re-introduce yield control as was intended. In

1981-2 the FAO sponsored an inventory of a few reserves in the south as part of a feasibility analysis for establishment of a pulp mill (Alder 1982) and it was hoped that this would provide the impetus and skills to undertake a national inventory (François 1989). The FAO inventory was a stratified systematic design with a 40 x 250 m, 1 ha plot on which all species were enumerated.

High forest zone static inventories undertaken from 1985 to 1996

In 1985 the Planning Branch of the Forestry Department supported by the ODA has undertaken three large-scale tree inventories, a regional botanical survey and several regeneration studies. The objectives of each of these was the provision of information to guide the re-introduction of sustainable management at various scales. A brief description of the design and objectives of each is presented followed by a discussion of how the data has been used to inform a variety of management decisions from strategic to species levels.

Temporary Sample Plot Inventory - TSP (1985-92)

The primary stated objective of the Temporary Sample Plot (TSP) inventory at its commencement was the provision of a national growing stock estimates for strategic planning (François 1989) though this later evolved along with the whole project into the provision of reserve-level data for incorporation into management plans. The target set for the inventory was a 20% sampling error at a 95% probability level. The design was adapted from the FAO inventory and was a systematic sample of 20 m x 500 m 1 ha plots laid out at the intersections of a 2 km square grid. All trees greater than 5 cm d were named and enumerated with trees less than 30 cm recorded from nested sub-plots. The first stage of the inventory (1985-88) covered 500,000 ha of reserved forest and the results were presented in 1989 (Wong 1989). The inventory then continued for a further 3 years and was completed in 1992 by which time 2,907 plots had been enumerated over 1,162,800 ha of forest in 128 reserves. Figure 1 illustrates the extent of the TSP inventory.

The inventory was perhaps a bit of an over-kill in terms of achievement of its original objectives as the sampling errors for national data are less than 3%. However, this has meant that national scale analyses of the data are very robust. However, the low sampling intensity and therefore high errors at the reserve level have meant that the later objective of providing local level information for incorporation into the management plans has not really been achieved although the data is proving extremely useful at this level.

NTFP inventory (1989-93)

In 1990 a market based study of the use of non-timber forest products (NTFPs) commenced, this prompted a lot of discussion within Planning Branch of how NTFPs could be included in inventory. However, since no additional resources were made available it was decided to graft NTFP enumeration onto the on-going TSP and PSP programmes. The objective for the NTFP enumeration was to collect data that could be used to inform strategic planning and to provide information on the status of certain species which were of particular concern because of anecdotal evidence of resource depletion. In all 54 reserves were sampled for NTFPs.

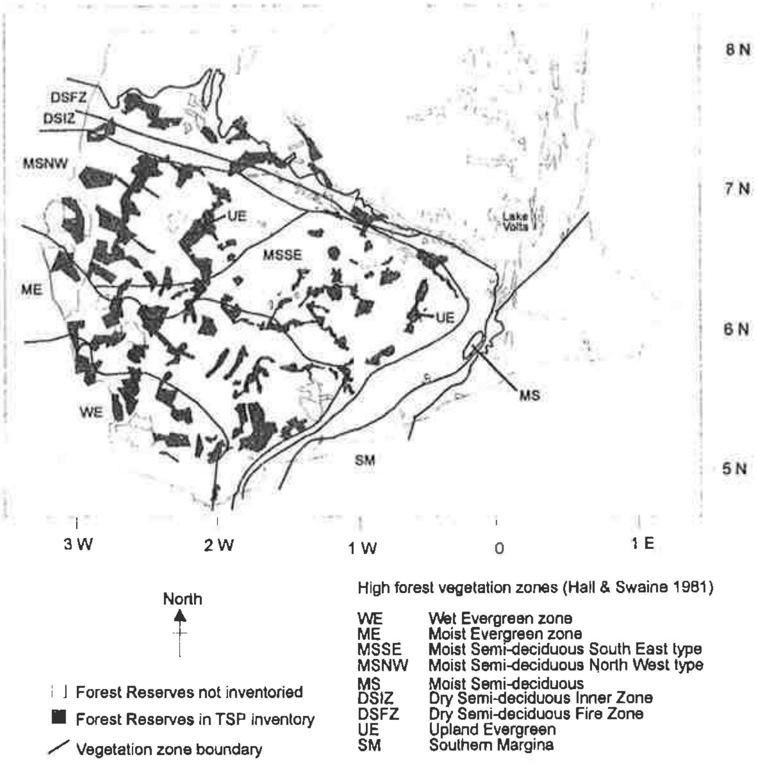

Figure 1 Forest reserves in southern Ghana sampled during the TSP inventory 1985-92

Data were collected for selected plants (local names were used so these may not be synomonous with species) from three groups of NTFPs. The plants selected were those which are most heavily commercially exploited. Data was collected for 5 species of cane, 23 climbers and 11 herbaceous plants. For the canes, the numbers of immature (green), mature (brown) and cut (harvested) stems and clumps (plants) was enumerated. The cane data can therefore be used to give an impression of the level of abundance, replacement and exploitation across the vegetation zones and within reserves. The numbers of plants of climbers and herbs were simply tallied for each plot and so can only give an impression of abundance at the time of enumeration.

Unfortunately the TSP inventory had visited most of the large reserves before 1990 so the NTFP data are not representative of the whole forest. However, the NTFP data can be used to investigate patterns between forest types (wet, moist and dry) and within reserves to give a general picture of resource distribution and abundance. Analyses undertaken so far clearly demonstrate the concentration of NTFPs in the moist and wet forest types and the high degree of variability within reserves.

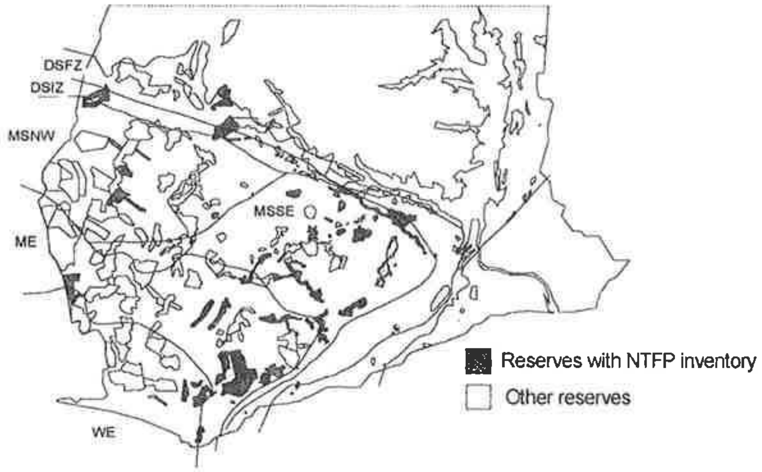

Figure 2 Forest reserves in southern Ghana in which NTFPs were enumerated

Off-reserve inventory (1994-96)

In 1993 the Ministry of Lands and Forestry transferred responsibility for the regulation of harvesting of off-reserve trees from the Lands Commission to the Forestry Department. The Planning Branch was therefore charged with the responsibility of devising new procedures to control the rate of cutting of the remnant off-reserve trees. (The off-reserve land has almost wholly been converted to farmlands and the trees being logged are mostly relicts from the forest or have grown up in fallows.) Since the FD had previously no direct involvement with off-reserve timber no large scale inventory of the resource had been undertaken. Accordingly the Ministry requested that an inventory be done with the purpose of determining the stocking of economic trees in the non-reserved lands to establish an off-reserve AAC. Since there were very few resources available and time was limited it was decided to make this a very low intensity rapid reconnaissance inventory.

The inventory was stratified random using a 2 ha 10 x 2,000 m plot divided into 20 sub-plots. The Hall & Swaine (1981) vegetation zones were used as the strata with a target of 50 plots to be located in each strata. The number of plots per strata and the achievable sampling error was optimised using the results of a pilot study. This yielded a very efficient design which achieved a SE% of 11% for the Scarlet star trees across 5 million hectares of farmlands with an inventory of 189 plots that took a year to execute.

Sustainable management of the high forest

There are many uses of inventory data, the timber man may wish to know the quantities and location of a particular species, the ecologist may want to examine the distribution of species, the zoologist the density of animal food trees and the forester? The forester is charged with the responsibility of 'managing' the forest but what does this entail and what information is required? The first objective of the Forest and Wildlife Policy of Ghana is to 'Manage and enhance Ghana's permanent estate of forest and wildlife resources for preservation of vital soil and water resources, conservation of biological diversity and the environment and sustainable production of domestic and commercial produce'. The puzzle placed before foresters is to prepare management prescriptions that are based on concrete information about the forest that are ecologically based, can be justified and achieve many, often conflicting, objectives. Management systems are more often evolved that designed and prescriptions are honed as new information becomes available and strategies developed to meet the exigencies of the present as revealed by the exposition of inventory data. Figure 3 illustrates the linkages between the various components of the present incarnation of the Ghanaian management system. Judicious analysis and interpretation of inventory as well as other sources of data has a role to play at all levels and forms the essential feedback loop that turns rules into a management system.

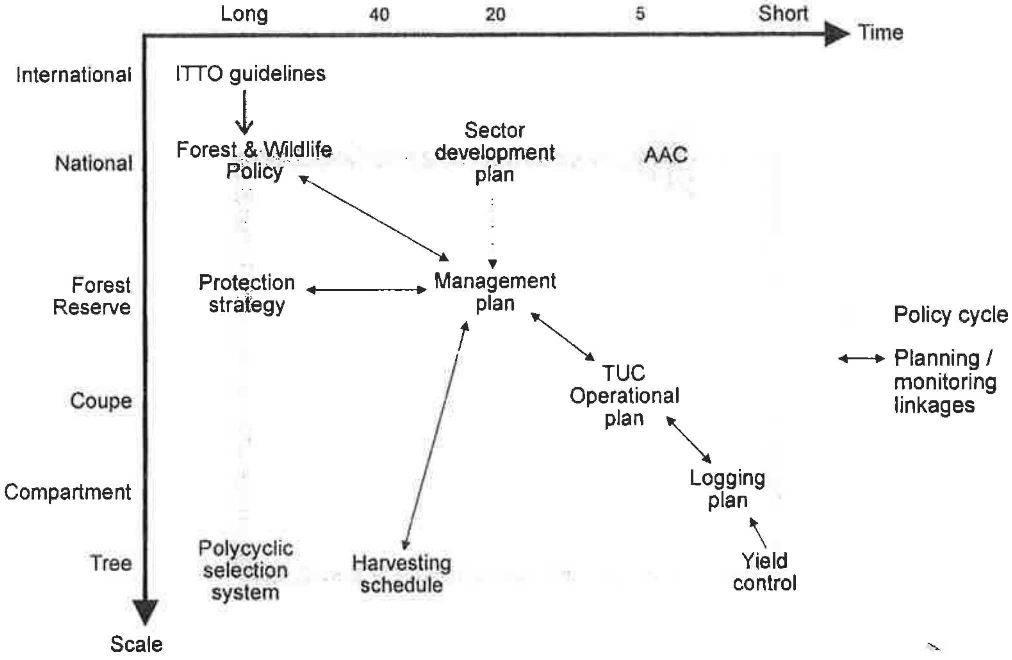

Figure 3 Schematic diagram of planning and management of on-reserve timber resources

Figure 3 clearly shows the range of scales both spatial and temporal over which data is required. Short term data is provided by temporary or static inventories, at the national, forest and coupe scales by the TSP data and at the compartment level by the 100% pre-harvesting stock surveys. Long term data is provided for by the PSP programme at either the forest or national scale depending on the design adopted and also by successive static inventories. This latter point is often overlooked and the question is posed of how data from successive, often very different inventories covering the same area can be used to explore the longer term and larger scale changes in the forest. If this is possible are there any ways in which successive inventories should relate to each other to facilitate these types of analyses? This is a pertinent question as management plans are prepared on a 20 year cycle and if an inventory is to be conducted at the same intervals then the next national inventory should commence in 2005.

Informing management decisions

Inventory data is only worth collecting if it is used to discover more about the forest and informs management decisions. Case studies of some of the ways in which the recent Ghanaian data has been used at various levels are presented.

Policy and strategic issues

Perhaps the most striking impact that the inventories have had to date is at the policy level particularly on the perception of the forests and on timber sector policy and strategies. By mid-1994 sufficient analysis of the TSP inventory data had been done to reveal that 24% of the permanent forest estate was degraded to the extent that there were practically no trees left (< 5 m^2 ha-1) and 7.5% had stocking that was so poor that they could not be considered for timber production in the current felling cycle. Although it was intuitively known that the forests were degraded it was something of a shock to know just how close Ghana is to running out of trees. The importance of securing a large scale investment to re-habilitate the degraded forests has since become a much higher priority and even the industry has become more interested in planting. Besides pointing out the condition of the forests the same analysis of the inventory was able to re-calculate the AAC (Planning Branch 1995).

The annual allowable cut (AAC) is simply the amount of timber that can be cut from an area in a year and at the national level is used as a 'target' for the logging industry. As such it is hotly contested and requires substantial justification as it determines the available level of raw materials for an industry that contributes 6-7% of GDP. There is no fixed methodology for determining an AAC and in this case was calculated by applying the current management prescriptions (40 year felling cycle, girth limits and yield control) on a plot-by-plot basis to the TSP inventory data within the 760,000 ha of timber production forest (see Figure 4). The calculated cut was then summed to give estimates of the AAC at vegetation zone, regional and national levels (Planning Branch 1995, Planning Branch 1996). The results of this analysis set the sustainable AAC from the permanent production forest at 500,000 m^3 per year. To this figure was added a guesstimate of 500,000 m^3 per year being available from the off-reserve lands by the Forestry Commission (1995) giving a total AAC of 1,000,000 m^3 per year. Given that the timber industry is estimated to have an installed capacity of 2,000,000 m^3 per year the strategic implications of the AAC are profound and were expounded in a hard-hitting analysis of the implications of a restricted timber supply to the industry (Forestry Commission, UK 1995).

In the past few months the data from the off-reserve inventory has been used to re-examine the off-reserve AAC. There are even fewer precedents for calculating an AAC from farmlands - it is after all the farmer and not the forester who does the 'allowing' and very often the 'cutting'. However, the need to provide guidance on the amounts of timber that might come from the farmlands meant that an attempt had to be made. The principle applied was of trying to estimate how long the existing resource might sustain a pre-determined AAC. This was done relatively simply by dividing the total stocking by an AAC. After making allowances for the heavy level of damage, dead and rotten trees (40% of all off-reserve trees) it was estimated that a cut of 500,000 m^3 per year could be sustained for around 80 years without replacement. Although this might seem like a very long time given it will take 40-60 years for exploitable sized trees of prime species to grow and since strategies and incentives to promote such planting are not yet in place it would not be wise to advocate a higher rate of cutting. Furthermore, no allowance was made for the high errors on the inventory nor, more importantly, for the contribution to the total stocking of sacred groves and other forest remnants which should be protected (at the bequest of the owners).

The NTFP inventory has not as yet been fully analysed but some work has been done on the canes in response to an initiative from the Export Promotion Council that was considering the promotion of cane exports. The inventory data revealed that canes are not very plentiful and that there was probably barely sufficient to meet the expanding domestic market and that planting would be required to provide a surplus for export. In other words the same story as the timber.

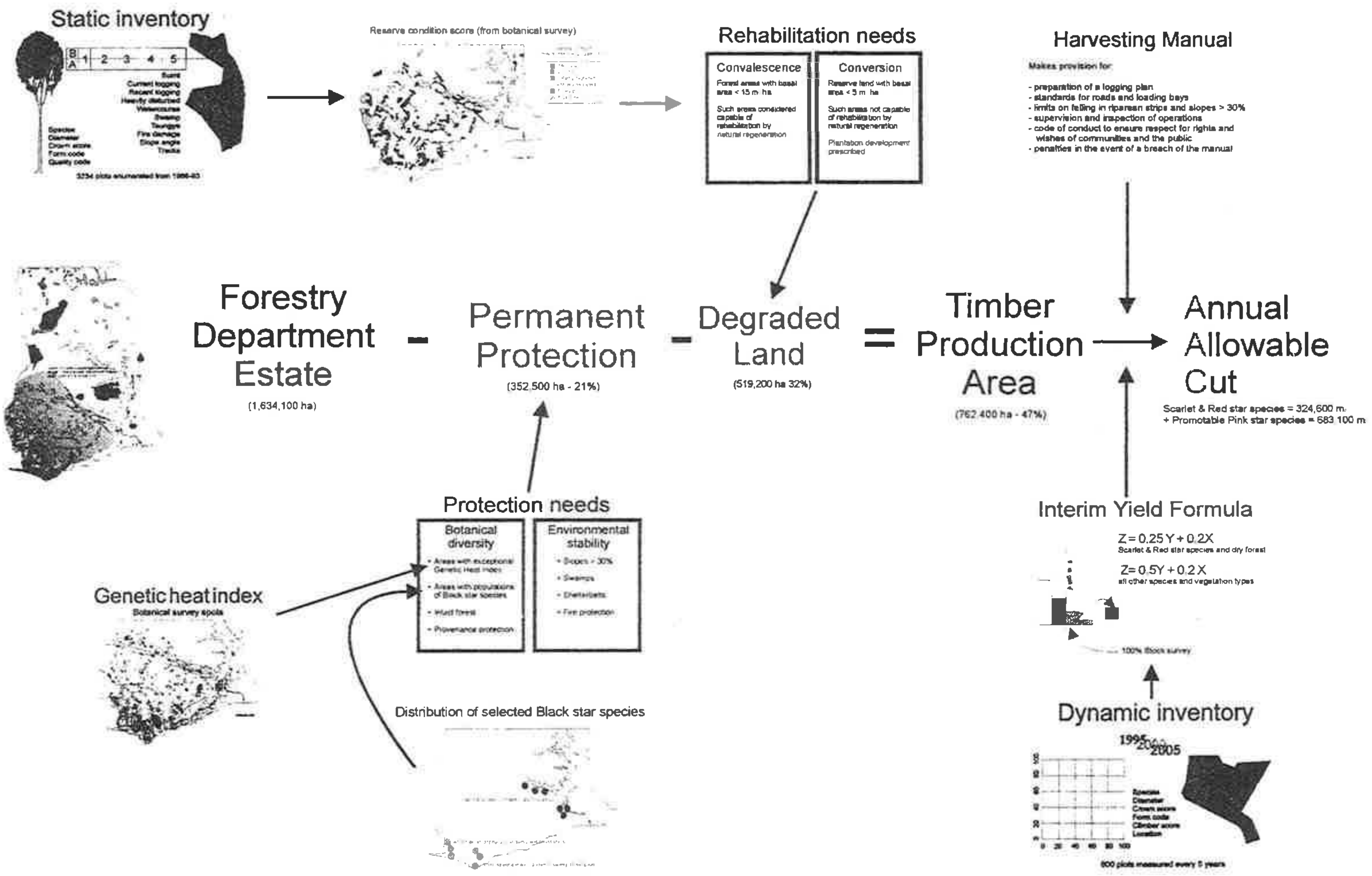

Figure 4: Derivation of the AAC from Forest Reserves in Ghana

Classification of species according to degree of exploitation

Hawthorne (1993a) proposed a star system for classifying plants according to their rarity expressed as a genetic diversity value and also on the degree of exploitation. The reddish star species are those that are exploited with Scarlet star species being over-exploited, Red stars being exploited roughly in balance with supply and Pink stars being effectively under-exploited. The species level AAC has been calculated and used as an index of sustainable production against which exploitation levels as recorded by the Forest Products Inspection Bureau (FPIB) are compared. This has enabled the reddish star rating to be applied objectively and in a manner that allows year by year tracking of exploitation trends (Planning Branch 1994). Scarlet star species have been defined as those were the five year running mean cut is more than 200% of the sustainable cut, Red star species are roughly sustainability exploited i.e. with a cut of between 50 and 200 % of the AAC. Pink star species are those were less than 50% of the AAC is removed. Pink star species have been further broken down into those that can be promoted on the grounds of abundant or possessing ecological characteristics that make them thrive in logged forests (i.e. pioneers). These classifications are being used to control the exploitation of the Scarlet star species through yield reductions for these species (Forestry Department 1995) and, if proposals are accepted, a royalty weighting. Although this is only a small start it does at least begin the process of developing species-specific management.

Management planning

Management plans are the foundation from which effective action springs. In Ghana the Planning Branch takes responsibility for overseeing the preparation of management plans and supports and monitors both the planning process and implementation. The need to have reliable information to guide the forestry elements of the plans was the rationale behind the extension of the inventory after 1988 when it had fulfilled its original objective. Unfortunately little progress has been made on the incorporation of the inventory results into the management plan prescriptions to date mostly because of a pre-occupation with the policy and strategic levels. However, the data has not been completely overlooked and has contributed to the development of the harvesting schedules both by allowing initial screening for areas that might require protection and also as an indicator of better stocked areas which should come forward in the harvesting schedules. The TSP data is in fact not well suited to this task as there is only a single 1 ha plot to extrapolate over an area of 400 ha while the compartments which are the smallest functional unit in the reserves are generally 110 ha in size. Nevertheless the data has been pressed into service as it can at least indicate how to prioritise field investigations. A better alternative may be the development of a rapid means of collecting the detailed compartment level information required to properly inform management decisions. This may take the form of simple basal area and condition scoring (see Forestry Department 1995) cruises of the forest perhaps with some indicators of forest health, NTFP potential and history especially of fire and other forms of degradation.

Improving ecological understanding

Not all management decisions depend on site specific or stocking type data as many of the principles and rules are dependant on an understanding of the ecology of the species. Careful and innovative analyses of the TSP data alongside regeneration surveys have been undertaken by Hawthorne (1993b, 1994, 1995, 1996) and have been instrumental in refining knowledge of forest ecology and sustainable use. In particular the guild classification of nearly all species and the description of their regeneration profiles (Hawthorne 1995) could form the foundation of detailed species level management prescriptions.

Discussion and conclusions

There is a lot of experience in Ghana of inventory and of forest management stretching back to the turn of the century and the Planning Branch is presently in the throes of reviewing and up-dating its management systems based on the results of the latest round of inventory. Based on this experience a few observations are offered on the inventory process.

Perhaps the most important point is that inventory and careful analysis of the data are essential for the development of rational management systems. This may seem obvious but too often inventories are designed, executed and then remain as dry reports with the data only ever expressed as summary stand tables. With the advent of computers and the accessibility of databases more emphasis should be given to the handling and use of data by more than just inventory statisticians. Inventory databases must be a working tool of the forest manager which combined with maps and field experience allows him or her come to be better understanding of the forest and thereby more appropriate management decisions.

In Ghana there have been many different inventory designs used each tailored for a particular objective. The first 1% inventory was intended to provide strategic management information in the form of maps, species lists and stand tables. This has a lot in common with the TSP inventory which was also systematic and has been used to map, or at least make area estimates. The 5% inventory was designed to provide reliable figures on which to base yield regulation this was to be achieved by laying out a minimum of 40 plots in each management unit within which small reserves were amalgamated for management purposes. This also has its parallels with both the creation of Forest Management Units (FMUs) to achieve a required sampling error from the TSP data, and also in the off-reserve inventory which was to exploit stratified random sampling to optimise the number of plots required to achieve a target sampling error. Interestingly in each case the optimal number of plots was very similar (about 40) although the plots themselves were of very different sizes and the sampling fractions were different by orders of magnitude. This highlights the textbook assertion that it is the number of sample plots that is important in determining precision not the plot size or the sampling fraction. It is clear that both styles of inventory have their advantages and disadvantages, mapping and area estimates for systematic designs and optimisation of resources spent to achieve the required precision for stratified random designs. On balance both are probably required though it would seem that randomised designs which can be undertaken rapidly are perhaps best suited to policy and strategic level questions while systematic sampling at an appropriate scale might be best for detailed management planning at the reserve level espcially when pre-stratification is not feasible.

The real test of whether an inventory has been effective is not the efficiency of the design or the its precision but rather the management decisions it is able to influence and the use to which it is put. Since this is the case it is as well to be clear about the objectives of an inventory and have a carefully designed programme of analysis prepared beforehand so the presentation of the results address the relavant questions in a timely manner. After the initial questions have been answered the datasets should be treated to as innovative and wide-ranging use as possible.

It is clear that much detailed and varied information can be obtained from static inventories and this has been the focus of this paper. However, there are several vital pieces of the management puzzle that can only be obtained from PSP analysis. What these pieces are depend on the type of management being pursued, in this case a low intervention polycyclic system. The TSS experiments although silviculturally successful have been judged cost-ineffective (Alder 1993), this coupled with the increasing marketability and high prices for 'lesser known species' and the Herculean task of understanding the ecology of the tropical forest has meant that management is increasingly based on a precautionary principle. The premise adopted is that we cannot hope to manipulate the forest so we would rather know how the forest responds to damage at the stand level and let the timbermen find uses for the species nature gives them - at least from natural forest being managed for multiple benefits such as NTFPs and biodiversity. In fact monitoring of the response of non-timber values to logging is an increasingly important concern and the role that PSPs can play in providing a monitoring framework for non-tree resources is one that needs careful examination.

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Questions and opportunities in long-term growth studies: Sixty years in Bundogo forest, Uganda

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Abstract

This paper considers data from five long-term permanent sample plots (PSPs) established in a semi-deciduous rain forest, in Uganda, during the 1930s and 1940s and last remeasured in 1992 and 1993. Examining the original objectives of these plots and the extent to which they were achieved highlights a range of issues that relate to PSP methods and data interpretation. While some of these problems are troubling, progress remains possible and worthwhile. Many uncertainties in predicting long-term changes in tropical rainforest seem resolvable only if more long-term data sets were available.

Stem-growth data from the five long-term plots is critically examined. Initial overviews reveal the general data properties; i.e. growth by plot, by species, by stem-size, and over time. The variation between periods is considerable, particularly if viewed in terms of basal area. The impact of arboricide treatment performed on four of the five plots is briefly considered. The various factors that influence the distribution of growth data derived from PSP measurements are examined. Observation period and seasonal effects are found to be important. The Budongo data can illuminate these issues and raise significant concerns. The challenge is to distinguish artefacts from real growth patterns. While difficult, this task is possible though quantification and dis-entanglement of the various determining relationships.

While methodological issues cannot be ignored, long-term data sets generally have considerable value. It is suggested that many long-term plots still exist. Such data sources will ultimately shine a dim but useful light on the murky nature of tropical tree growth.

Introduction

During the early part of this century ecologists focused attention on vegetation processes and dynamics (Cowles 1901, Clements 1916, Gleason 1917, Tansley 1917). During the 1920s and 1930s the British Ecological Society emphasised the need for quantitative evaluations in tropical vegetation, an initiative that was closely linked to developments in tropical forestry (in the Commonwealth, see Tansley & Chipp 1926, Burt Davy 1938, Richards et al. 1939, [note there were some parallel initiatives in Francophone countries, e.g. Louppe et al. 1995]). Plots established in this era are the basis of many classic studies and those maintained as permanent sample plots (PSPs) have become the main source of long-term data (see sources in Richards 1952, Mathauda 1955, Mervart 1972, Rai 1983, Swaine et al. 1987a, Okali & Ola-Adams 1987, Manokaran & Kochummen 1987, Whitmore 1989). Such data sources are invaluable given the practical problems in addressing questions in long-term forest dynamics. Africa-wide it is certain that many old and derelict plots could be relocated, the potential loss of such data would be a great tragedy.

Emphasis on the problems of artefacts and misinterpretations (see Sheil 1995a,b, 1996b, in press a, Sheil & May 1996, Sheil et al. 1995, and this paper) while also claiming the high value of PSPs may seem contradictory. A few words of explanation are appropriate. Clearly the wider recognition of potential pitfalls is ultimately constructive. The better models and theories will best survive evaluation, while superior models and theories gradually develop, - such is the flux of the scientific method. Better PSP data and a less hindered view of tropical forest dynamics are possible. Long-term data provide unrivaled opportunities for progress.

Budongo Forest

Budongo is well documented (e.g. Eggeling 1947a, Synnott 1985). The combined Budongo Forest reserves, located at 1°37'-2°03'N and 31°22'-46'E, cover approximately 790 km^2 which includes 430 km^2 of closed forest. Most of the forest is on level ground lying between 1000 and 1100 m a.s.l. Soils are predominantly deep ancient latosols. The bimodal annual rainfall is usually between 1,200 and 1,800 mm. The canopy is generally high and emergent stems occasionally reach to over 60m. Most canopy species are deciduous, though the widespread shade-tolerant Cynometra alexandri, is a notable exception.

The Budongo Plots: history and objectives and use

W.J. Eggeling established permanent sample plots in Budongo Forest during the 1930s and 1940s. Some of these plots have been re-measured intermittently since then, and five of these 'research plots'('RPs' 2,5,6,7,&15) were evaluated recently (1992-3). Data from these plots now span six decades.

The Uganda Forest Department (U.F.D.) originally justified the plots through two general research questions (U.F.D., various sources unpublished) these were the need to understand:

1) forest productivity
2) how composition develops

The second question was assumed answered by the time Eggeling published his paper describing the plots as a successional series (Eggeling 1947a). Subsequent U.F.D. research objectives exclusively emphasised timber production and its manipulation through silvicultural treatments (Uganda Forest Department, U.F.D., various unpublished records). I will focus here upon aspects of the data that was collected.

From the earliest days management emphasised the sustainable productivity of the Ugandan forest estate. While there was some interest in non-timber products such as 'wild rubber' (from Funtumia elastica (Preuss) Stapf. and the lianas Landolphia and Clitandra), coffee (Coffea) and rattan (Calamus), timber was the overriding focus of management. At Budongo working plans were written for each ten year period from 1935 until 1965-74 (Harris 1934, Eggeling 1947b, Treneman et al. 1956, Philip 1965). The objective of all plans was to maximise sustainable timber yield and economic revenue, and this required an early commitment to control, monitoring and the experimental evaluation of options. While data from the PSPs were used in management planning this ultimately lacked sophistication and only crude generalisations are apparent, i.e. quoting mean girth or dbh increments for a species in very rough terms and not its variation or dependence on size. There are four reasons for this caution: 1) the variation observed within the small samples, 2) the considerable and inconsistent nature of period to period variations, 3) lack of clear analytical frameworks, 4) lack of easy large-scale computation methods (e.g. computers).

The Uganda Forest Department has maintained and archived detailed notes and reports on the plots - information that I have been able to examine and summarise. Descriptions and evaluations of the plot methods and background information are available elsewhere (Eggeling 1947a, Sheil 1995a, 1996a, in press b). Eggeling's plot siting and orientation were chosen subjectively. Each plot covers about 2 ha. [Note the plot summaries provided in Eggeling (1947a) are reduced to 400 by 400 feet to allow comparison with studies elsewhere.]. The set of species to be measured and the minimum stem sizes have varied, but a fixed list of 'timber' species has been recorded on each occasion (Appendix 1). Various conventions for dealing with buttressed stems have been used which complicates evaluations (see Sheil 1995a).

Information about the five plots examined for this paper is given in Tables 1-3. Plot 7 may be one of the oldest maintained tropical forest PSPs in primary forest anywhere in the world (1939-1993), it lies in a 'nature reserve' an area which has been spared silvicultural interventions. The oldest plot, plot 6, was established and first measured in 1933. Plots 6, 2, 5, and 15 have each been subjected to silvicultural interventions through arboricide treatment, i.e. between the late 1950s and early 1960s 'weed species' over specified minimum sizes were poisoned in these plots (also called 'non-desirables', 'non-economic' and 'non-timber' species; these had little or no commercial value). Refining operations varied in implementation from site to site (for details of methods see Dawkins 1954, 1955, 1958, and Philip 1964). Measures over these periods are restricted to only the 'timber' species. Limitations to interpretation arise as almost no record of what was poisoned or of its basal area survives.

Data

The pre-1992 data comes from files kept at the Forest Department HQ in Kampala. These files represent a compilation of surviving records. Notes for each PSP were historically kept in triplicate, but even so much information is now lost. The minimum common denominator that allows all measurement periods to be evaluated is to take these listed timber species (Appendix 1) with a dbh ≥ 25 cm and for that reason this defines the overview population referred to in later examples. In 1992 twenty percent of each plot was measured a second time to provide data on accuracy, this information and some of the implications are discussed in Sheil (1995a).

All girth changes used in this paper are calculated as change in drh ('diameter at reference height', 'diameter' actually being convex girth expressed as diameter of circle with equal circumference) for each pair of consecutive measurement dates for each qualifying stem in each plot: i.e. $Dd = drh_{t=n+1} - drh_{t=n}$, where drh_t is the measure at time t, and r, the reference height, is constant between successive measures.

Stem changes and woody growth - an approach

Short-term studies provide data on differences between successive stem measurements. The question that forest planners may ask in order to make use of this information looks deceptively simple:

> What is the relationship between short-term PSP Dd values and long-term timber yields?

This general goal can be divided into two broad questions.

- What is the relationship between short-term and longer term Dd values?
- How do the Dd values relate to real timber growth?

The unknowns that need to be defined in these questions are numerous - I will focus upon the first. Species, stem size and spatial relations are well established determinants. While these already give rise to considerable analytical complexity, additional factors also have significance. Dd has been discussed in Sheil (1995a) and I draw on that summary. There are three components of measured Dd (i.e. Dd_{meas}) that can usefully be recognised, each is complex in itself with different determinants and patterns of variation:

a) woody growth (Dd_{growth})

b) stem flex/swell (reversible changes) (Dd_{flex})

c) measurement error (Dd_{error})

When looking at stand yield, population-level processes must be added, i.e. recruitment and mortality (e.g. Vanclay 1994, Alder 1995). The Budongo study has already highlighted some issues in the estimation of such quantities (Sheil 1995a,b, Sheil & May 1996). These factors are not easily quantified without bias but may have considerable significance. For example if slow growing stems are more likely to die (c.f. Swaine et al. 1987a,b) then this, coupled with long-term growth auto-corrolations (Sheil 1995a), implies that short-term-mean growth is on average less than long-term-mean values. However this effect is not seen in the Budongo data, possibly because it is obscured by other influences. Here I focus on the stem level data and the influences that act upon them.

The analytical problems begin when we consider how influences interact to provide the measured stem changes - and what this in turn reveals about woody growth. A fully quantified model is clearly desirable, and detection though useful is only a first step. A stem measurement model would combine the previously mentioned elements:

$$Dd_{meas} = Dd_{growth} + Dd_{flex} + Dd_{error}$$

where the components of the measured diameter change are each multivariate functions with their own form and (largely independent) behaviour:

a) $Dd_{growth} = f_{growth}(t_1, t_2,$ species, size, site, rain, exposure, method ...), i.e. woody growth

b) $Dd_{flex} = f_{flex}(t_1, t_2,$ species, size, site, rain, exposure, method ...), i.e. reversible changes

c) $Dd_{error} = f_{error}($recorder, equipment, species-form, d, method ...), i.e. measurement errors

where f_x (a,b,g,e,...) are multivariate functions of a,b,g,e,... where a,b,g,e, ... may themselves have deeper multivariate structure. In such circumstances where each component function is itself highly multivariate, with unknown relationships, compound interaction terms and complex error structures, it can be seen that any characterization will not be trivial even ignoring population level processes.

Some results and comments

A data overview: time, plots, size and species

Data derived from the Budongo plots study have been used to examine many phenomena (e.g. Sheil 1996a) of which I only have space to present a few. Use of the data is complicated by many issues (e.g. Sheil 1995a). Note that the samples represent only five plots, and observations within plots are neither independent nor consistent in definition. The treatments performed on four of the five plots reduce the potential for generalisation from the subsequent growth data (see later).

In the 'overview' figures shown in this initial section those periods showing a discernible growth response following treatment are excluded (i.e. plot 2, 1960-69; plot 5, 1948-69; plot 6, 1944-65; plot 15, 1950-71 - note all the qualitative trends and differences shown in the figures are robust and also demonstrated in equivalent overviews using a) all the data, b) only the 'pre-treatment' data, and c) only periods when all species are recorded). Graphical summaries illustrate the general patterns despite a range of analytical limitations see Figures 1-6. Figure 1 provides an overview of the plot data showing how the general growth rate decline as composition matures (see table 1, Eggeling 1947a, and Sheil in press b for the background to this successional development). Figure 2 shows a typical hump backed variation in growth relating to stem sizes. Figure 3 shows the broad species specific data for more common species. Figure 4 shows how size variations differ amongst species.

The long-term growth patterns provide a remarkable overview of the data. Figure 5 shows the marked period to period changes in Dd distribution and Figure 6 shows that the shifts are even more marked in basal area. These shifts have considerable implications for any simple and naive forecasts derived from short-term data. The understanding of this pattern requires a more careful examination of the data.

Growth data measured as Dd have positively skewed frequency distributions. The Budongo data varies in its form of distribution. An exploratory examination was made of correlations between parameters of the Dd/Dt distributions [the mean, an upper and a lower 5th percentile (p5 and p95), the median, and the upper and lower quartile (q^{up} and q^{low})] against Dt. One distinct correlation was that the broad spread of growth measures (i.e. p95-p5) is inversely related to the census interval. This is best explained by the increasing proportion of Dd that is accounted for by measurement error as periods become shorter (Sheil 1995a). Other influences seem to have seasonal origins (see below).

The impact of arboricide treatments

The selective poisoning was intended to increase the growth of valuable timber stems, and also to encourage regeneration. The lack of precise knowledge about the silvicultural treatments, both how they were performed and the nature of their impact, has been a major limitation in using the data from plots 2,5,6, and 15 post-treatment. Various examinations indicate that the treatments had considerable influence. In addition to the growth by period figures already presented (Figure 5, 6) three graphical presentations are provided: the change in mean growth by species, the change in mean growth rate by size class, and the number of stems growing faster or slower in the period following treatment when compared to the preceding period (Figure 7, note appropriate period to period data for plot 15 is not available). The relatively small samples preclude extensive interpretation by species and stem size but the positive response to treatment appears general and most marked in the smaller stems.

Rainfall and seasonal influence

Comparisons of growth, where the measurement intervals do not cover an integral number of years, are potentially invalidated by the unknown influence of the partial year. As part of the initial data evaluation an analysis was performed to examine whether the variation in growth distributions between and amongst all the measurement intervals was influenced by seasonal factors and rainfall variations. The data are inadequate to examine seasonal aspects in satisfactory detail by direct observations. Measurement of incomplete years allows an indirect assessment and seasonal 'signals' in the growth data was readily confirmed (Sheil in press a). A more in depth investigation provided three tentative conclusions (Sheil in press a):

1) seasonality is having a significant impact on recorded growth, but is not a 'linear function of rainfall, and individual trees are affected in different ways. Those measurement periods that cover incomplete years will be systematically biased.
2) the slowest growing trees generally increase measured Dd/Dt when more moisture is available, but,
3) most stems show a general decline in Dd/Dt over 'wetter' seasonal periods.

The explanation for this strange behaviour is open to debate. I suggest that diurnal patterns of stem shrinkage and transpiration induced flexing are playing a dominant role. In wet season conditions most stems are in full leaf, but are usually measured in dry bright conditions, i.e. when transpiration rates are likely to be near maximum. In temperate trees a high transpiration demand can induce a considerable reduction in stem pressure causing girth constriction (e.g. Kozlowski et al. 1991). A flex hypothesis for the seasonal signal detected is indirectly supported by the fast growing (crown exposed) stems being the most effected by the transpiration deficit while the slowest (well shaded) stems are not as influenced but instead increase in growth under wet conditions. Estimation suggests that the size of this putative artefact is the same order of magnitude as a year's growth (Sheil in press a). Clearly a serious potential bias.

The 'flex hypothesis' is open to direct evaluation. Recently in Kibale forest, Uganda, I collaborated with Mr. Kofi Affum-Baffoe, (Forestry Department, Ghana) and Andrew Bakainaga (Makerere University, Uganda) to examine this question. We used Dawkin's (1965) method of multiple precise measures on each stem to evaluate diurnal girth changes over several consecutive days on selected trees. Marked daily changes of c. 0.2% of stem size were detected in each of eight large trees examined, even though the observation period was characterised by dull overcast weather (unpublished data).

The remarkable variation in basal area growth may, or may not, prove to be largely an artefact. The interaction of growth values with season, moisture, and measurement interval requires wider evaluation. The apparent influence of a variety of factors upon the growth distribution is summarised in Table 4.

Discussion

As outlined in Sheil (1995a) PSP studies can be considered in five main parts once the objective has been defined; 1) the establishment of plots via a defined sampling strategy; 2) the evaluation/measurement process; 3) the compilation of the data (checking and correcting); 4) analysis; and 5) interpretation. The limitations and assumptions intrinsic to each of these distinct stages have ramifications for the entire process. I have focused here on the second and fifth stage but have noted issues about the first. Assumptions artefacts and errors can occur at all stages. Once we can identify these difficulties we must next seek to characterise them so that we can, reduce, allow for, or even eliminate them.

Sheil (1995a) has listed numerous problems and issues associated with PSP studies when viewed from an ecologists perspective. These concerns translate readily to normal forestry practise. The problems that community ecologists face are increasingly shared with forest mangers, e.g. more general species identifications (biodiversity conservation and wider utilisation), volume estimation for difficult stem forms (while irrelevant for timber such forms feature in biomass and carbon sequestration).

Advances or lessons from the past

The expense of establishing and maintaining PSPs often limits replication and plot sizes are often small, thus leading directly to many of the statistical inadequacies that arise even in good data. These frustrations were realised very early in the history of Budongo, and various solutions were sought. Some PSPs were ambitious in scale, and included Budongo's plot 13, designed to 'smooth' out environmental heterogeneity with a transect approach being 15.24 x 6758 m (50 ft by 4.2 miles) giving 10.3 ha (=25.5 acres, measured 1937, 1940, 1943, 1948). Plot 12 took a similar approach (5 by 5100 feet, 5.85 acres, measured 1936, 1939, 1942, 1946, 1950, 1951, 1955). Plot 56 set the record for size, originally comprising a massive 405 ha (= 1000 acres, as an evaluation of silvicultural treatments in which only larger trees were measured, dates unknown as data lost). The problem of small samples for the dominant timber stems was solved by selecting individual trees rather than defining a plot, e.g. 'plot' 53 comprised 50 stems each of Khaya, Entandrophragma cylindrica, and Maesopsis (measured in 1955, 1956, 1960, 1964). Ultimately many of the enormous silvicultural experiments undertaken in Budongo frustrated their makers with the putative effects lost within data noise and related inter-plot and period to period variance (e.g. Dawkins 1957, Philip 1968).

Other plots: untapped riches?

Eggeling's seminal studies initiated an extensive PSP program in Uganda. Philip (1964) documented the 538 purely research PSPs established by the U.F.D. by the early 1960s. For several years numerous additional plots were established purely for management: two or more PSPs were set-up to monitor regrowth in every compartment felled (see Dawkins 1958 for a description of 'yield plots').

In 1992, with file records and local help, we succeeded in locating the five Eggeling PSPs that we looked for. In 1993 and 1994 we again located three large-scale long-term-experimental plots (50, 56, 441) which we were searching for (see Rukondo this meeting). These experiences, with 100% success in finding what we sought, encourage optimism about finding 'lost' plots, - at least if they were lost for less than 30 years. It should be noted that Uganda was not exceptional in its approach to forestry and numerous PSPs were also established elsewhere (e.g. Kenya, Tanzania, Ghana, and Nigeria). These plots represent a major resource.

Recommendations

Despite the many problems encountered progress is possible. Sheil (1995a, Table 4) makes a list of recommendations to which should be added the obvious need for well designed sufficiently large sampling programs, and adequate long-term commitment.

Long-term PSPs have great value but are not necessarily sufficient to answer many key questions. Clearly methodological and interpretational deficiencies can compromise the adequate interpretation and use of PSP data. Specific short-term evaluations are also required: 1) studies of diurnal and seasonal variation in flex and growth, 2) rapid replication of measurements can be used to identify and characterise patterns of methodological error.

The value of long-term data sets is such that all countries that possess PSPs should make a careful review. The following are basic considerations: Are the recorded data replicated and secure? Are the data well organised and can any serious problems or discrepancies be noted - if so what is needed for rectification? Can the plots be relocated? Do the plots still have any value (probably yes)? Do the plots require maintenance?

We clearly need to extract meaningful information from imperfect data by learning how to filter the signal from the noise. This is not a trivial or simple task but a challenge which will be better undertaken after further study and, of course, with the necessary long-term data sets.

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Appendix 1

Species recorded at all measurement dates and their six-letter codes.

ALBFER = *Albizia ferruginea* (Guill.& Perr.) Benth. Fabaceae subfam. Mimosoideae
ALBGRA = *Albizia grandibracteata* Taub. Fabaceae subfam. Mimosoideae
ALBGLA = *Albizia glaberrima* (Schumach. & Thonn.) Benth. Fabaceae subfam. Mimosoideae
ALBZYG = *Albizia zygia* (DC.) J.F.Macbr. Fabaceae subfam. Mimosoideae
ALSBOO = *Alstonia boonei* De Wild. Apocynaceae
ANIALT = *Aningeria altissima* (A.Chev.) Aubrev.& Pellegr. Sapotaceae
ANTTOX = *Antiaris toxicaria* Leschenault var. *usambarensis* (Engl.) C.C.Berg. Moraceae
BEQOBL = *Bequaertiodendron oblanceolatum* (S.Moore) Heine & Hemsley. Sapotaceae
CELAFR = *Celtis africana* Burm.f. Ulmaceae
CELDUR = *Celtis durandii* Engl. (Arguably = the Malagasy species *Celtis gomphophylla* Baker).Ulmaceae
CELMIL = *Celtis mildbraedii* Engl. Ulmaceae
CELWIG = *Celtis wightii* Planch. Ulmaceae
CELZEN = *Celtis zenkeri* Engl. Ulmaceae
CHLEXC = *Milicia excelsa* (Welw.) C.C.Berg [*Chlorophora excelsa* (Welw.) Benth.& Hook.f.].Moraceae
CHRALB = *Chrysophyllum albidum* G.Don. Sapotaceae
CHRMUE = *Chrysophyllum muerense* Engl. Sapotaceae
CHRPER = *Chrysophyllum perpulchrum* Mildbr. ex Hutch.& J.M.Dalz. Sapotaceae
COLGIG = *Cola gigantea* A.Chev. Sterculiaceae
CORMIL = *Cordia millenii* Bak. Boraginaceae
CROMAC = *Croton macrostachyus* Hochst. ex A.R.Delile. Euphorbiaceae
CROMEG = *Croton megalocarpus* Hutch. Euphorbiaceae
CROSYL = *Croton sylvaticus* Hochst. ex Krauss. Euphorbiaceae
CYNALE = *Cynometra alexandri* C.H.Wright. Fabaceae subfam. Caesalpinioidae
DRYUGA = *Drypetes ugandensis* (Rendle) Hutch. Euphorbiaceae
EKESEN = *Ekebergia senegalensis* A.Juss. Meliaceae
ENTANG = *Entandrophragma angolense* (Welw.) C.DC. Meliaceae
ENTCYL = *Entandrophragma cylindricum* (Sprague) Sprague. Meliaceae
ENTUTI = *Entandrophragma utile* (Dawe & Sprague) Sprague. Meliaceae
ERYSUA = *Erythrophleum suaveolens* (Guill.& Perr.). Fabaceae subfam. Caesalpinioidae
FAGANG = *Fagaropsis angolensis* (Engl.) Dale. Rutaceae
GUACED = *Guarea cedrata* (A.Chev.) Pellegrin. Meliaceae
HOLGRA = *Holoptelea grandis* (Hutsch.) Mildbr. Ulmaceae
KHAANT = *Khaya anthotheca* (Welw.) C.DC. Meliaceae
KHAGRA = *Khaya grandifoliola* C.DC. Meliaceae
LOVTRI = *Lovoa trichilioides* Harms. Meliaceae
MAEEMI = *Maesopsis eminii* Engl. Rhamnaceae
MILEXC = *Mildbraediodendron excelsum* Harms (& See CHLEXC). Fabaceae subfam. Caesalpinioidae
MORLAC = *Morus lactea* (Sim) Mildbr. Moraceae
OLEWEL = *Olea welwitschii* (Knobl.) Knobl. Oleaceae
PRUAFR = *Prunus africana* (Hook.f.) Kalkman. Rosaceae
PYCANG = *Pycnanthus angolensis* (Welw.) Exell. Myristicaceae
STRSCH = *Strombosia scheffleri* Engl. Olacaceae
TRIDRE = *Trichilia dregeana* Sond. Meliaceae
TRIMAR = *Trichilia martineaui* Aubrev.& Pellegrin. Meliaceae
TRIPRI = *Trichilia prieuriana* A.Juss. Meliaceae
TRIRUB = *Trichilia rubescens* Oliv. Meliaceae
ZANGOL = *Zanha golungensis* Hiern. Sapindaceae
ZANGIL = *Zanthoxylum gilletii* (De Wild.) Waterm. Rutaceae
ZANLEP = *Zanthoxylum leprieurii* Guill.& Perr. Rutaceae
ZANRUB = *Zanthoxylum rubescens* Hook.f. Rutaceae
ZANMIL = *Zanthoxylum mildbraedii* (Engl.) Waterm. Rutaceae

Tables

Table 1. Plots and vegetation types. Listed in order by Eggeling's successional interpretation. (Copied from Chapter 4, Table 4.1)

Plot	15	**1**	2	3	4	5	6	7	8	9	10	11
Year 1940	*Closing Terminalia grassland*	*Colonising (Woodland)*	*Colonising (Maesopsis)*		*Ecotone to Mixed*	*Mixed*		*Ecotone to Ironwood*		*Ironwood*		*Swamp forest*
Year 1992	*Mixed (Maesopsis)*	*?*	*Mixed*	*?*		*Mixed*		*Ecotone*	*?*	*?*	*?*	*?*

Unshaded are those plots for which later assessments including 1992 are recorded.

Table 2. Establishment, location and dimensions

Plot Established	**Location** **Lat.**	 **Long.**	**Location UTM**	**Elevation (m)**	**Dimensions (ft.)**[1]	**Area (ha)**	**Silvicultural reduction**[3]
PSP2 1940	1° 45'N	31° 28'E	330 194	1050	400 x 500	1.86	1960, 64 6-10 m^2ha^{-1}
PSP5 1940	1° 44'N	31° 28'E	331 192	1050	400 x 500	1.86	1954,55,60 25-30 m^2ha^{-1}
PSP6 1933	1° 44'N	31° 28'E	330 192	1070	400 x 600[2]	≈ 2.12[2]	1956,58,59 15-25 m^2ha^{-1}
PSP7 1939	1° 43'N	31° 30'E	334 190	1035	400 x 500	1.86	none
PSP15 1944	1° 43'N	31° 28'E	330 191	1080	400 x 500	1.86	1955,56,58 8-15 m^2ha^{-1}

[1] The plots were defined in feet.

[2] The plot is slightly skew

[3] Year and basal area reduction, which though not recorded, has been estimated from various graphical examinations - hence these ranges are wide and difficult to assess.

Table 3. Measurement history, and raw data quantities by plot.

Date[1,2,3]	Min d (cm)[3]	Stem N[4]	Meas N[5]	Δd N[6]	New[7]	Management & Notes
PSP 2						
1940.38	23.9	257	257			
1943.55	24.3	250	250	235	Yes	
1945.38	24.7	219	219	218	No	
* **1960.63**	10.2	131	131	79	Yes	Poisoned stems>9.7cm(8/60)
* **1963.21**	9.8	135	135	126	Yes	Poisoned stems>39cm(10/64)
* **1966.19**	9.7	141	141	134	Yes	
* **1969.08**	10.3	152	152	138	No	
* **1971.10**	10.4	145	146	141	Yes	
1992.73	9.7	985	1011	93	Yes	Mapped
PSP 5						
1940.38	21.3	259	259			
1943.38	24.3	273	273	255	Yes	
1948.46	16.6	448	507	248	Yes	
* **1963.22**	10.8	67	83	50	Yes	Poisoned stems>9.7cm(8/1960)
* **1966.20**	9.8	75	95	66	Yes	Poisoned stems>39cm(10/1964)
* **1969.48**	10.2	81	100	74	Yes	
* **1971.11**	10.2	83	102	78	Yes	
* **1976.06**	11.2	81	96	76	Yes	
1992.63	9.6	810	893	66	Yes	Mapped
PSP 6						
* **1933.80**	23.9	90	90			*Survivors till 1957* only
* **1944.88**	25.0	90	90	87	No	*Survivors till 1957* only
* **1957.33**	15.0	106	106	83	Yes	
* **1958.23**	10.8	112	112	96	Yes	Poisoned >9.7cm 11/1956 & 3/1958 & 3/1959
* **1965.16**	6.1	100	100	75	Yes	
* **1968.13**	8.2	99	99	95	No	
1992.66	9.6	849	948	73	Yes	Mapped
PSP 7						
1939.04	15.0	278	343			
1942.04	19.4	255	317	255	No	
1944.95	19.4	261	315	241	Yes	
1952.12	15.4	322	455	239	Yes	
* **1959.45**	9.9	250	251	149	Yes	
* **1960.45**	9.9	247	247	246	No	
* **1964.30**	8.3	273	274	245	Yes	
* **1971.22**	8.5	293	293	257	Yes	
* **1973.15**	8.3	287	287	285	No	
1976.17	8.7	988	991	281	Yes	
1978.28	8.8	982	982	961	No	
1992.69	10.0	1090	1312	836	Yes	
1993.32	10.0	1087	1307	1087	No	Mapped
PSP 15						
1944.56	9.7	425	427			
1950.80	9.7	761	764	298	Yes	Poisoning >19.4 cm, 1955,56,58
* **1971.11**	8.8	201	201	79	Yes	
1992.61	9.8	927	931	149	Yes	Mapped

[1] Date given in decimals of completed calendar year (*i.e.* year + [months-1]/12)

[2] * Signifies that only timber species were measured

[3] Min d = Smallest diameter measured.

[4] Stem N = Number of stems measured.

[5] Meas N = Number of measurements made (*i.e.* includes stem problems such as buttresses).

[6] Δd = Number of separate growth observations when coupled with previous date (1 per stem).

[7] New = If newly recruited stems were recorded.

' + ' implies a positive correlation while ' - ' signifies a negative correlation.

Table 4. Some influences operating on the distribution of growth values from PSPs.

	Mean	$p5$	q_{lower}	Median	q_{upper}	$p95$	Artefact or bias
Less careful first measurement	-	- -	-	-	-	-	✓
Less careful second measurement	+	+	+	+	+	+ +	✓
Shorter measurement interval	+?	- -	-	?	+	+ +	✓
Drier period before first measure and/or wetter before second	+		+	+	+ +	+ +	(✓)
Wetter period before first measure and/or dry before second	-	(+)	-	-	- -	- -	(✓)
Measurement period with extra seasonal rain	(+)?	+	(+)?	(+)?	?	?	X

Figures

Figure 1. Growth rates by plot (in order of implied successional stage). This shows a declining rate of growth with 'successional development'. In addition a decline in variation within the plots is shown, despite a greater occurrence of outliers in plots where buttressed stems are more common.

Notched box-and-whisker plots provide a convenient means of summarising and comparing data (McGill et al. 1978, Frigge et al. 1989). The box divides the data values into four areas of equal frequency: the line crossing the box is the median; the top and bottom of the box delimit the upper and lower interquartile values and thus the box holds the central 50% of data values. The lower whiskers are drawn from the base of the box to the lowest data value within 1.5 interquartile ranges and from the upper quartile to the highest data value within 1.5 interquartile ranges. The width of a box is proportional to $\sqrt{n}$, where n is the number of observations. Options for presentation exist : points beyond the range of the whiskers can either be plotted individually or excluded as "outliers"; also the mean can be shown by a point within the box. The top and bottom of the notch delimits the approximate 95% confidence limit on the position of the median, i.e. at $\pm [1.25 (q_{upper}-q_{low})/(1.35 \sqrt{n})](p50/2.5 + p50)/2$, where $(q_{upper}-q_{low})$ = the inter quartile range, and p50 is the median ('StatGraphics Plus' 1993). If comparisons between boxes show that these notches do not overlap the medians are significantly different in location.

Figure 2. Growth rates by stem size classes. This shows the uni-modal relation of growth against stem size. Smaller stems are suppressed in lower light conditions while old stems become senescent and moribund. While the pattern is potentially confounded by the variety of data origins and definitions, these features are supported in more specific examinations such as size-growth relations within plots and within periods.

Figure 3. Growth rates by species. This shows the growth rate distributions of those 37 species for which there are sufficient observations (outside of treatments). N ranges from 1344 for Celtis mildbraedii (CELMIL), to 20 for Terminalia glaucescens (TERGLA). Those species usually considered as 'pioneers' or early colonisers can be seen to have the highest growth rates, while small understory species are the slowest. 'Woodland species' (e.g. Terminalia and Acacia) have lower growth rates than forest pioneers, but are represented here chiefly by measures from senescent individuals. Major deviations characterise those species with more 'awkward to measure' stem forms. All inter-quartile ranges lie between -0.1 and +1.5 cm/year, and most median values lie between 0.1 and 0.4 cm/year. The six-letter species codes are listed in Appendix 1.

Figure 4. Growth rates, by species, by size class. This shows those 16 species that have provided 100 or more observations (outside of treatments) and grow to sizes more than 30 cm dbh. A unimodal form is apparent for several species. Species that possess buttresses generally show an additional Dd/Dt increase at very large stem sizes (and a marked increase in variation). Maesopsis also displays a pattern with Dd/Dt increasing markedly with larger stem sizes. Such a 'light-demander' only shows significant recruitment under open conditions and thus has good initial growth followed by a growth decrease as competition (probably canopy closure, but root competition also may be involved) increases; at larger sizes the species is taller than most competitors and its canopy exposure (of survivors) will generally be greater and most growth rates again increase. A similar relation is noted for Cynometra which may be in part explained by buttress growth, but 'aggressive' canopy species (i.e. species that can dominate locally) may perhaps show such a growth-size relation maximising advantages under asymmetric competition for canopy exposure.

Figure 5. An overview of stem growth over time for (updated) populations of large timber species (dbh ≥ 25 cm, except for plot 15 where dbh ≥ 10 cm), (horizontal lines denote value across a measurement interval). The distributions of growth values were non-normal (with significant skewness and kurtosis). Growth values are represented by using the median and the 95 and 5 percentiles (p95, p5), i.e. 5% of observations are excluded above and below these lines. The overall spread (p95-p5) is inversely related to time interval (see Sheil 1995a). The period to period growth changes in a seemingly irregular way. To examine if these 'steps' were 'significant' or might be

dismissed as 'noise' two null hypotheses were evaluated between each period: that a) that the location of the Dd value distribution does not change significantly between consecutive periods (asterisks above the line, Wilcoxon 2-sample test with continuity correction); and b) that for stems that have growth recorded in both periods the number of stems growing faster in the following period is no different than expected by chance: (asterisks below the line, binomial probability as sign-test), the results are signified on the graphs. The shifts in growth values are often highly significant, even without interventions (and across integral years), but the silvicultural interventions appear influential.

Figure 6. Basal area growth by plot, for stems over 25 cm dbh for timber stems, and where possible for all species. This figure is based only on stem growth for stems that are measured at the start and end of each measurement interval and does not include recruits as a source of gain.

Figure 7. An overview of girth change data in periods before and after silvicultural poisoning, from available data ('timber species only'). Plot 2 (a,b,c) uses the periods 1945-60 and 1960-63. Plot 5 (d,e,f) uses the periods 1948-63 and 1963-66. Plot 6 (g,h,i) uses the periods 1944-57 and 1958-65. The figures show changes in mean stem growth by species (a,d,g), the change in mean stem growth by size class (b,e,h, note also the right hand column gives the total stem mean difference), and the number of stems growing faster or slower in the period following treatment when compared to the preceding period, also by size class (c,f,i). The six-letter species codes are listed in Appendix 1.

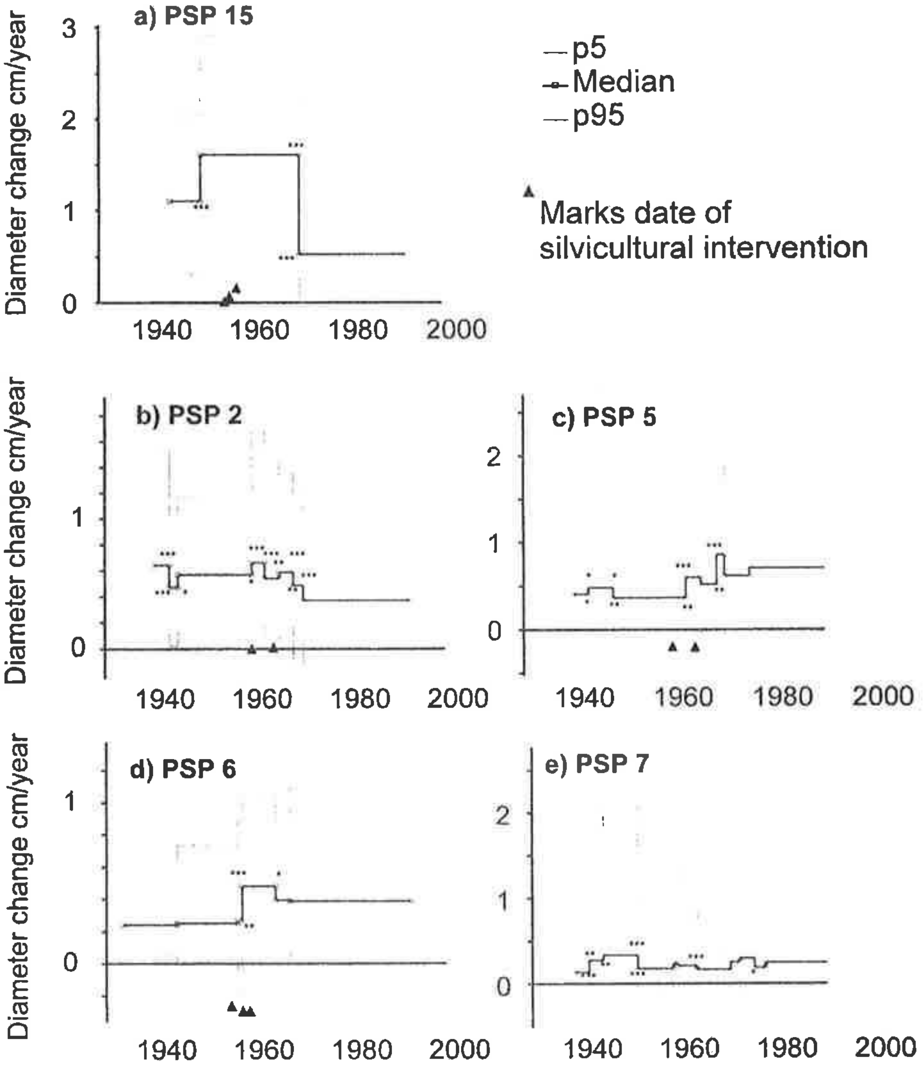
a) PSP 15
Diameter change cm/year
3
2
1
0
1940
1960
1980
2000
—p5
-●-Median
—p95
▲ Marks date of silvicultural intervention
b) PSP 2
Diameter change cm/year
1
0
1940
1960
1980
2000
c) PSP 5
2
1
0
1940
1960
1980
2000
d) PSP 6
Diameter change cm/year
1
0
1940
1960
1980
2000
e) PSP 7
2
1
0
1940
1960
1980
2000

Figure 5.

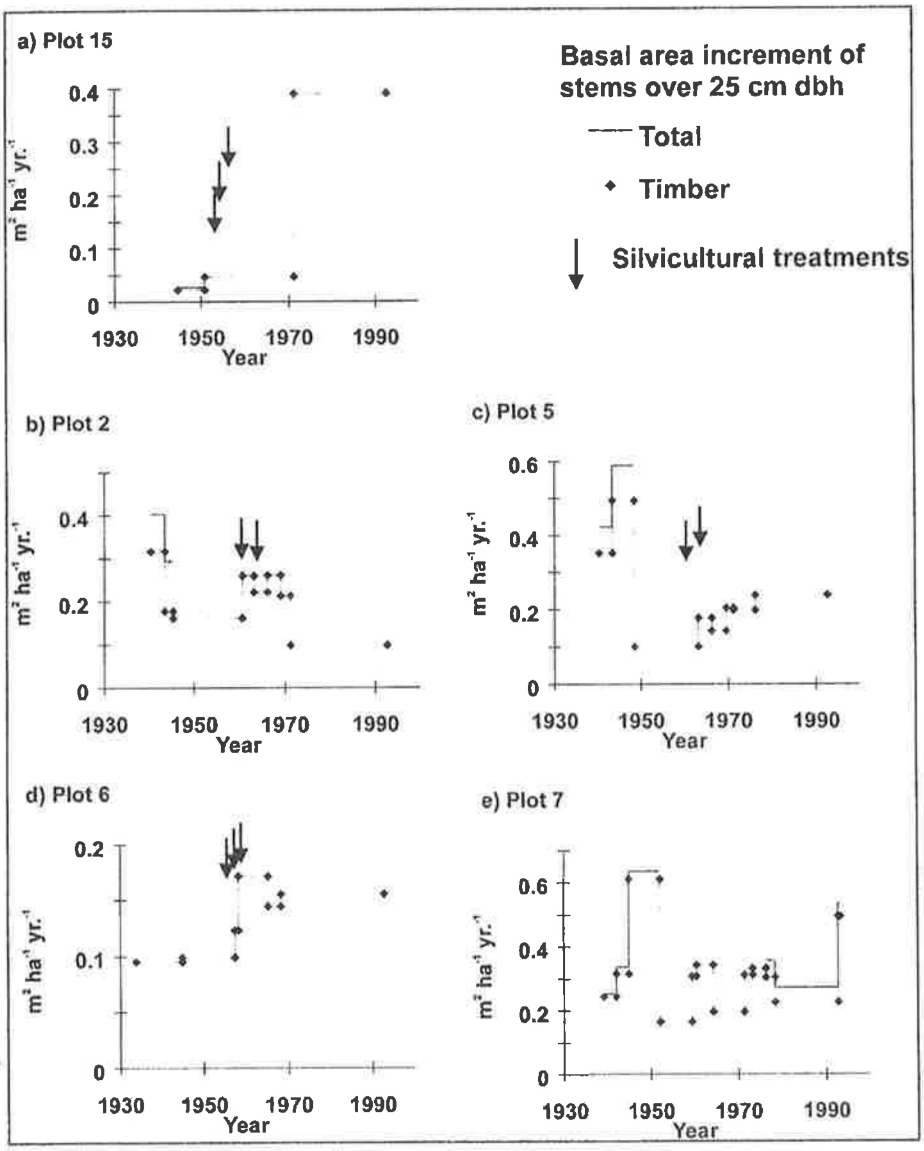
a) Plot 15
Basal area increment of stems over 25 cm dbh
Total
Timber
Silvicultural treatments
b) Plot 2
c) Plot 5
d) Plot 6
e) Plot 7
m² ha⁻¹ yr.⁻¹
Year
0
0.1
0.2
0.3
0.4
0.6
1930
1950
1970
1990

Figure 6

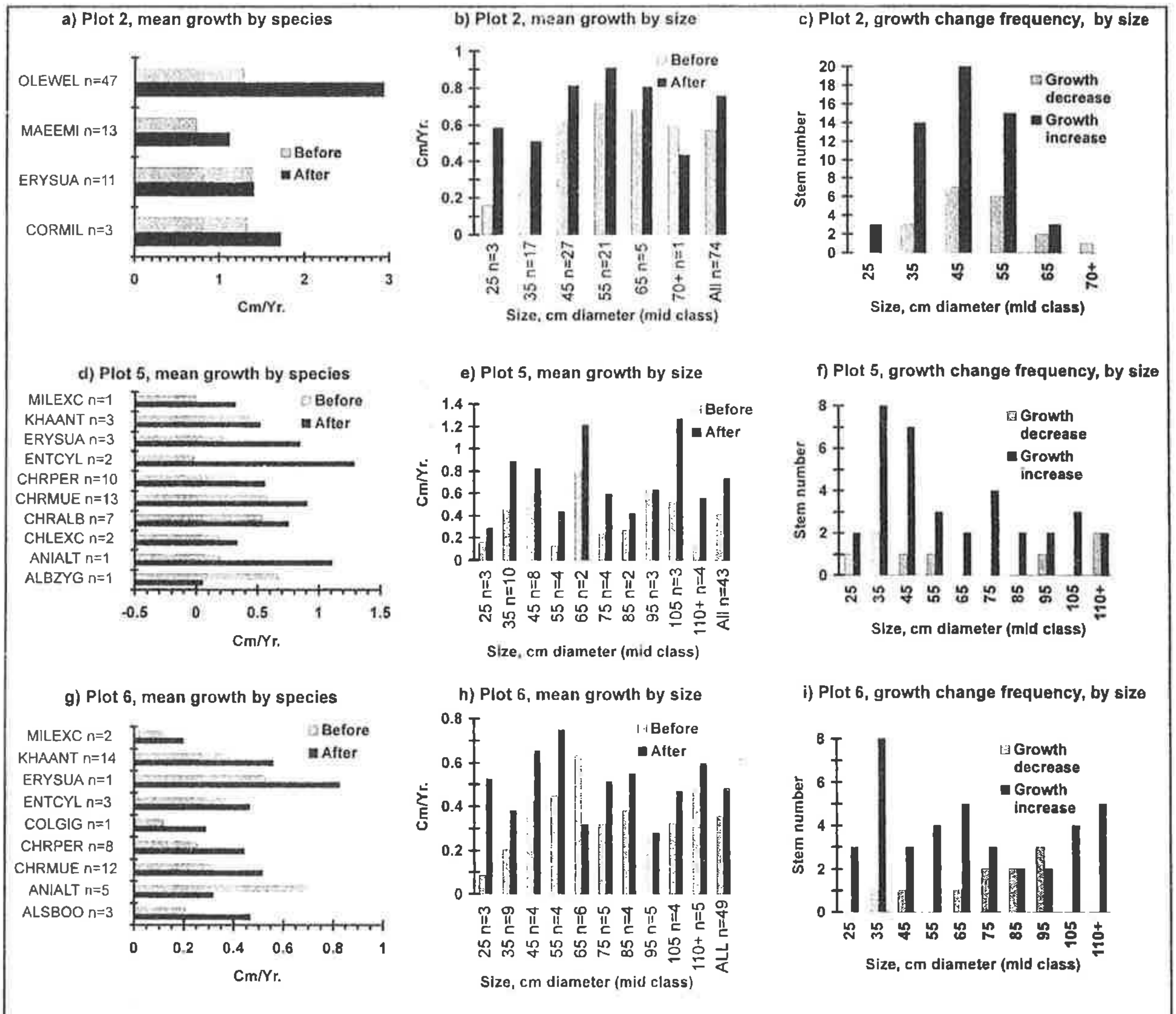
a) Plot 2, mean growth by species
OLEWEL n=47
MAEEMI n=13
ERYSUA n=11
CORMIL n=3
Before
After
0
1
2
3
Cm/Yr.
b) Plot 2, mean growth by size
Before
After
Cm/Yr.
1
0.8
0.6
0.4
0.2
0
25 n=3
35 n=17
45 n=27
55 n=21
65 n=5
70+ n=1
All n=74
Size, cm diameter (mid class)
c) Plot 2, growth change frequency, by size
Stem number
20
18
16
14
12
10
8
6
4
2
0
Growth decrease
Growth increase
25
35
45
55
65
70+
Size, cm diameter (mid class)
d) Plot 5, mean growth by species
MILEXC n=1
KHAANT n=3
ERYSUA n=3
ENTCYL n=2
CHRPER n=10
CHRMUE n=13
CHRALB n=7
CHLEXC n=2
ANIALT n=1
ALBZYG n=1
Before
After
-0.5
0
0.5
1
1.5
Cm/Yr.
e) Plot 5, mean growth by size
Before
After
Cm/Yr.
1.4
1.2
1
0.8
0.6
0.4
0.2
0
25 n=3
35 n=10
45 n=8
55 n=4
65 n=2
75 n=4
85 n=2
95 n=3
105 n=3
110+ n=4
All n=43
Size, cm diameter (mid class)
f) Plot 5, growth change frequency, by size
Stem number
8
6
4
2
0
Growth decrease
Growth increase
25
35
45
55
65
75
85
95
105
110+
Size, cm diameter (mid class)
g) Plot 6, mean growth by species
MILEXC n=2
KHAANT n=14
ERYSUA n=1
ENTCYL n=3
COLGIG n=1
CHRPER n=8
CHRMUE n=12
ANIALT n=5
ALSBOO n=3
Before
After
0
0.2
0.4
0.6
0.8
1
Cm/Yr.
h) Plot 6, mean growth by size
Before
After
Cm/Yr.
0.8
0.6
0.4
0.2
0
25 n=3
35 n=9
45 n=4
55 n=4
65 n=6
75 n=5
85 n=4
95 n=5
105 n=4
110+ n=5
ALL n=49
Size, cm diameter (mid class)
i) Plot 6, growth change frequency, by size
Stem number
8
6
4
2
0
Growth decrease
Growth increase
25
35
45
55
65
75
85
95
105
110+
Size, cm diameter (mid class)

Figure 7

Session II - Inventory methods

Chair: Dr. David Ladipo

Revised permanent sample plot procedures in Ghana.

Kofi Affum-Baffoe[1]

Abstract

One of the tools essential for good forest management, especially in the mixed tropical high forest, is the setting up of permanent sample plots to monitor dynamics of the forest. In Ghana, 600 one hectare permanent plots were established throughout the forest reserves within the high forest zone on a five year remeasurement cycle. An initial analysis of 66 remeasured plots revealed some inconsistencies arising primarily from faulty field and data processing procedures. This brought about a temporary suspension of the programme to enable a review and revision of procedures to be undertaken. The paper outlines the sources of error and the measures introduced to improve data quality, accuracy and the precision of data capture. Emphasis on the need for careful field procedures followed by vigorous data checking especially once the data has been entered on to the computer are stressed. Questions regarding the optimal number of plots to be maintained by the programme and the choice of plot sites, site characterisation and the possibility of using the preliminary results before sufficient data is available for full growth and yield analysis still remain open and advice and recommendations invited. The review will be complete after these issues are addressed.

Introduction

Good forest management requires information on general changes in forest status such as species growth rates, mortality rates and regeneration patterns over time. This information can conveniently be obtained by setting up Permanent Sample Plots (PSPs) to monitor these trends. Permanent plots represent the most reliable technique for estimating growth in all types of forest, especially mixed forests under selection management (Alder 1990). The need for careful field procedures followed by vigorous data checking to obtain good quality data are paramount if any meaningful and reliable projections are to be made from the information gathered.

Under a Forest Inventory and Management Project (FIMP) sponsored by the Overseas Development Administration (ODA) 600 one hectare plots were established between 1988 and 1994 covering the entire High Forest Zone. Following recommendations made by a forest growth consultant, PSP field activities were suspended to enable new field and modified data processing procedures to be developed. This paper documents a review of the PSP programme in the Ghana High Forest to date.

Justification

Bird and Sackey (1991), contended in their PSP manual of procedures that available knowledge was very fragmented and that the process should be improved upon as and when more information became available. After an initial analysis of 66 re-measured plots by Dr. Denis Alder (a forest growth consultant) several inconsistencies were detected. The re-measured plots constituted 11% of the total number and the fact that errors identified were quite significant called for an urgent review of the PSP programme.

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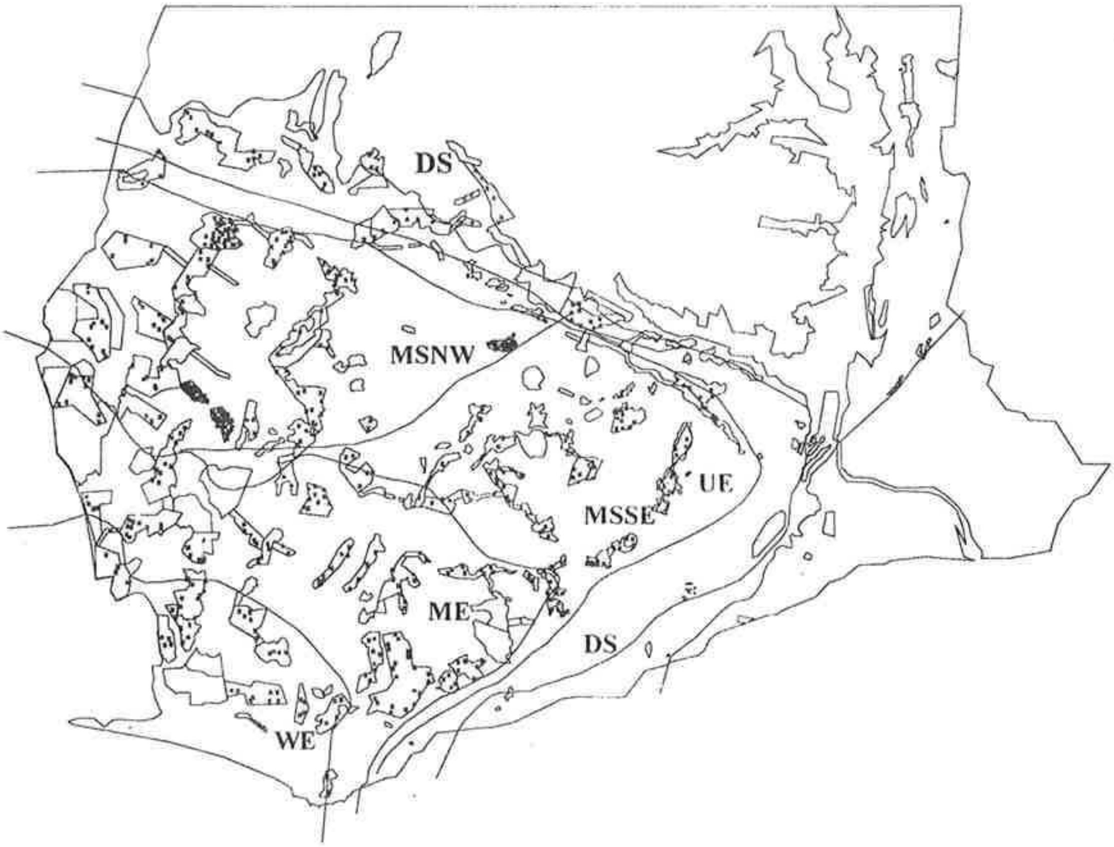
MAP SHOWING DISTRIBUTION OF PSPs IN GHANA HIGH FOREST ZONES



The table below shows errors identified by the consultant.

Description	Count	%
Clean Data - no errors	16,914	64.4
Tree position changed by over 5m	2,333	8.9
Different quadrats	462	1.8
Change of species code	4,122	15.7
Duplicate record- bad or missing data	1,206	4.6
Excessive change in diameter	1,215	4.6
Total	26,252	100%

Brief history of PSP in Ghana

The Permanent Sample Plot programme began in 1969. The aim of the programme was the estimation of tree increment of the then economic species (Sackey & Bird 1991). Two plots were randomly selected for every square mile. Plots measured 100 m on each side and each was subdivided into 25 quadrats.

The leading desirable (LD) concept was adopted to determine which trees to record in the PSPs. This was a procedure of nurturing any economic tree or seedling which was likely to be of most value at the next felling cycle. Two LDs were chosen per quadrat, hence 50 trees were measured per plot. Ghana forest Simulation(GHAFOSIM), a report that describes the development of a system for projecting future yields of natural forest in Ghana was obtained from this data.

Towards the end of 1988 PSP programme was revitalised under the ODA supported Forest Inventory Project . The LD concept was considered inappropriate for long term studies of forest dynamics since the economic value of tree species are liable to change over time and also tree recruitment, mortality and competition could only be fully understood when the entire tree population is monitored.

PSP programme under FIMP

Number Of Plots Established

Alder (1981) stated that there was no appropriate statistical method of determining the number of plots required for such a complex situation. It was agreed that 600 one hectare plots be established of which one third was to be made up of the then existing network of plots. The number was believed to be manageable in the long term and also sufficient enough to provide the required information. Within each Forest Management Unit (FMU), a minimum of 10 and a maximum of 20 plots (with the exception of the following : 108 plots in FMU 4, 22 plots in FMU 39 and 30 plots in FMU 17) were enumerated. A five year interval between successive plot measurement was also agreed and by the end of 1994 the target of 600 plots was achieved and reassessment began in 1995.

Distribution of PSPs by vegetation zone

Vegetation zone	Forest reserve area km^2	Number of PSPs
Wet Evergreen (WE)	1006.31	50
Moist Evergreen (ME)	4361.17	160
Moist Semi deciduous South East (MSSE)	2289.89	82
Moist Semi deciduous North West (MSNW)	4601.50	228
Upland Evergreen (UE)	258.70	10
Dry Semi deciduous (DS)	1991.00	60
Wet Evergreen/ Moist Evergreen (WE/ME)	472.40	10
OTHER	1360.03	0
TOTAL	16341.00	600

Mode of Plot Distribution

The high forest has been classified into a number of forest types by Hall and Swaine(1981) and this provided the framework for the distribution of PSPs. Plots were laid out in proportion to the area of forest reserves within each of the major forest types. The distribution of plots are linked to the Forest Management Units (Each FMU measures 50,000 ha approx.).

Plot size

Ghana's PSPs are of a standard size of 100 m by 100 m and subdivided into 25 quadrats. Each quadrat measuring 20 m by 20 m.

Tree measurement

Within each plot all tree species greater than or equal to 10 cm diameter at breast height (dbh) are measured. In each FMU, two subplots of size 60 m by 2 m are established in the middle of plots selected in which all saplings (between two and 10 cm) are measured.

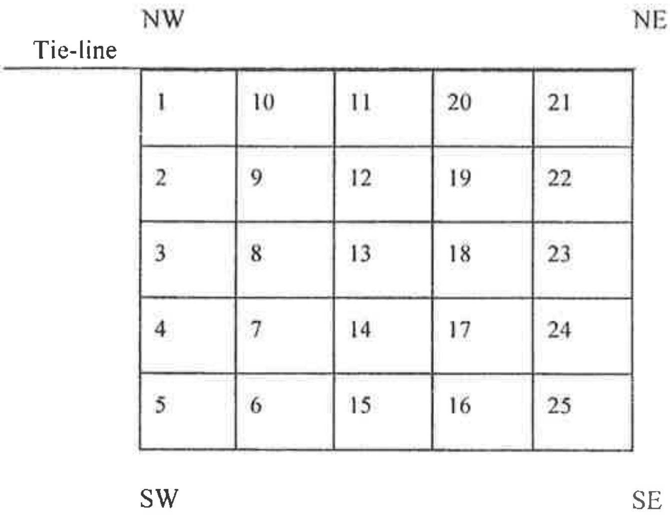


Figure 1: PSP layout

Special PSPs

In addition to the standard PSPs, three one-hectare plots in the Dry Semi-deciduous Forest type have been designated Fire PSPs to study the growth and dynamics of degraded, undegraded and moderately disturbed forest following surface fires. In these plots, which are established in 1992, all vascular plants including seedlings and saplings are enumerated.

Re-measurement of Trees are carried out by the Planning Branch PSP team and that of juveniles (<10 cm dbh) are undertaken by a special Ecology Unit field team since this requires greater expertise in identifying young plants. Poles and saplings are measured biennially and seedlings annually.

Brief description of field procedures

Plot demarcation precedes enumeration by one month and involves the use of machetes to cut lines, chains and meter tapes to measure distances and a compass for direction. A demarcation schedule containing information on plot location and a forest reserve map are used as a guide to the plots.

Enumeration of plots involves measuring all trees 10 cm dbh and above using girth tapes and diameter tapes. Large buttress trees are measured with relascopes while callipers are used for trees where climbers cannot be eased from the stem. Point of measurement (POM) is painted red for one third of the entire bole circumference. Aluminium tags with numbers to serve as tree numbers are then fastened to the tree below POM. A technician calls out the name of the tree, diameter, tree number , crown position. crown form, degree of strangulation and so on to the booker. Approximate location of each tree is recorded within each quadrat by measuring distances in the north-south and east-west directions along the edge of the quadrat. Field data is sent to the Computing Unit where the data is entered by trained data entry personnel.

Errors associated with demarcation

The modification of PSP field procedures affected enumeration greatly as against demarcation, however unreliable demarcation practices accounted for the following errors:

Missing species: Tree species missing from the second assessment during the merger of first and second data were attributed to poor demarcation practices. It was detected that plot boundaries were widely cleaned and in some cases inaccurate. The use of outmoded survey equipment such as chains also contributed.

Species in neighbouring quadrats: For the same reason outlined above, some species were found in different quadrats and at times outside the plot even though previously enumerated.

Damage by hunters and NTFP gatherers: In order to locate PSPs easily, District staff are assigned to clean all PSP tie-lines in their area of jurisdiction, this old system was very unsatisfactory in that the open tie-lines serve as pathways for hunters and NTFP gatherers resulting in plot damage such as loss of tree number tags, removal of nails, tree damage due to removal of bark and roots of some medicinal tree species etc.

Errors associated with enumeration

Tree numbering system: All trees are numbered with aluminium tags. These tags have four or five digits inscribed on them. These long tree numbers couple with their random sequence caused transcription errors making the sequence of work unclear and leading to first and second measurements being compiled in a different order. This resulted in some difficulty during comparison.

Nails and tags: The numbered tags were fastened to the trees below POM with nails. These tags and nails created problems such as theft and loss of tags, and callus growth around nails .

Measurement point: Point of measurement (POM) for buttressed trees and especially trees measured with relascope instrument are not recorded. POM is painted red but at times visibility and accuracy is hindered. This is partly due to the fact that about one third of the entire circumference is painted.

Girth tapes: The girth tapes used are not very accurate (±3 mm diameter). The 1 cm graduations are insufficient for increment measurement. Again the use of girth tapes and at times diameter tapes confused data entry staff for example girth measurements are entered in the diameter column and vice-versa. It was a source of error in calculation and created unnecessary complications in the database design.

Relascopes: Relascope usage for diameter measurements has its own problems, lack of enough light under close canopy to facilitate reading etc are some of the problems when considering accuracy, The relascopes used are too old and unable to give satisfactory readings.

Ladders: Insufficient ladders to measure and paint large buttressed trees create a lot of problems for the enumeration teams compelling field teams to use the relascope for most of the large buttressed trees when they could more appropriately use a ladder.

Double measurements: Double measurements are made for all trees with buttresses or with a potential to develop buttresses. This, however, is not appreciated by some field teams who carry out this procedure on non-buttress trees.

Field staff: Some field staff have too much to do and others too little, resulting in overwork or overcrowding in some field parties and incessant chatting in the latter which tends to confuse the Booker.

Errors in data processing

The record structure does not cope properly with double and multiple measurements. The data entry does not involve checks on the numbers of trees or checksums of any kind. The system was exposed to loss of records and data due to mistakes with Foxpro, power failures and/or casual re-booting of the computers. Many records and complete quadrat information disappeared as a result.

Measures introduced to reduce or eradicate these errors

Demarcation: As part of measures to improve the quality of PSP data, external and internal boundary cleaning should not exceed 70 and 50 cm respectively. Tie line-cleaning would only be done during reopening of plots prior to enumeration. This work would be done by a well trained demarcation team. The use of metal chains is being replaced by fibre glass survey tapes and new compasses have been acquired to enhance efficiency and accuracy.

Enumeration: The tree numbering system has changed. Trees are now numbered sequentially starting from quadrat one, the first measured tree is given the number 1, second 2, third 3 and so on. These numbers are written boldly using red paint below POM. Recruited trees are given a number after the last tree number in the previous measurement i.e. if the plot recorded 100 trees in the previous measurement then the first recruited tree measured is given the number 101, second 102 etc.

A well designed enumeration form including a selection of previous measurement data with old tree numbers, columns for new numbers, new diameters, diameter ranges of previous measurements and measurement methods are taken to the field together with a plot map produced from tree position co-ordinates. The sheets are also designed to include cells for checksums and species codes.

All POMs other than 1.3 m are properly recorded on the enumeration sheet. This will enable information to be acquired which will help resolve the problem of 'shrinking trees'.

The entire circumference of the tree at the POM is painted red to improve visibility and accuracy.

In order to reduce the work load and facilitate conscientious re-measuring of PSPs, the minimum measuring diameter has been changed from 10 to 20 cm dbh. Before the review, about 300 to 450 trees were measured per plot. The present system allows 100 - 150 trees (a reduction of about a third).

To decide on recruits, a go-no-go gauge comprising of wooden callipers with a fixed width of 19 cm has been introduced to make a quick check followed by of an inscription of a letter P in chalk to indicate those which qualify.

The use of 1 cm graduation tapes give diameter to the nearest 3 mm and this is unreliable in PSPs Diameter tapes graduated in millimetres are now in use instead of girth tapes To encourage the use of diameter tapes instead of relascope even at POM of 5m height, two sets of double section aluminium ladders are now taken to the field per enumeration team. The ladder also helps in reaching POM for painting to be made around the entire band of the tree and also to ensure that the tape is accurately aligned during measurement.

With regards to double measurement, the new instruction is that POM is changed only when there is significant lack of contact between the diameter tape and the bole. In such situation both old and new POMs are measured and recorded and in the next measurement only the upper band is measured.

Separate forms to cater for bearings and distances from the tree to the operator as well as the distance of POM from the ground has also been introduced for measurements that demand the use of a relascope.

Deciding the optimal number of plots, and choice of plot sites

It has been recommended that 200 core PSPs should be maintained for future measurement. The sampling of these plots should include completely undisturbed and heavily disturbed forest. Plots should be stratified according to vegetation type and should be spatially well distributed. The following procedures have been suggested and comments and contributions are invited:

All plots in the UE zone should be retained and that the 200 plots should be distributed evenly among the 5 zones (DS, MSNW, ME, WE, MSSE). We suggest that each zone have 40 plots plus 10 in the UE to arrive at a total of 210 PSPs.

With regards to choice of plot sites, the following are suggested:

1. Count the total number of PSPs currently in the zone
2. Calculate the basal area for each Plot, or it may be easier to use the sum of diameters as an alternative to BA.
3. Find the plots with maximum and minimum BAs.
4. Divide the BA range into 4 equal quarters.
5. Identify 10 plots within each quarter using random numbers. This will ensure that plots represent a spread of forest densities. FMUs should be selected at random first, then plots within FMUs to ensure spatial distribution of plots.

Data processing: The objective is to develop an integrated data entry and editing package with internal data validation and archival using a standard database package namely Foxpro. It also includes some preliminary processing for validation of re-measurements by comparison with earlier measurements.

The data processing procedures for the PSP have been developed into a single package via a menu system providing for the following:

- Data entry
- Report generation for field sheets and checksums
- easy access to programs for preliminary analysis for PSP data
- on-line error checking and validation

Other issues

Other pending issues such as what might be required for site characterisation, and possibility of using preliminary results as an interim measure in dealing with issues such as the AAC and the current yield formula until sufficient data is available for full growth and yield analysis still remain unresolved and comments and contributions are invited.

Conclusion

It is anticipated that with the new measures in place, more reliable information would be made available to address growth, recruitment and mortality issues so that the possibility of developing dynamic growth model for Ghana will be realised.

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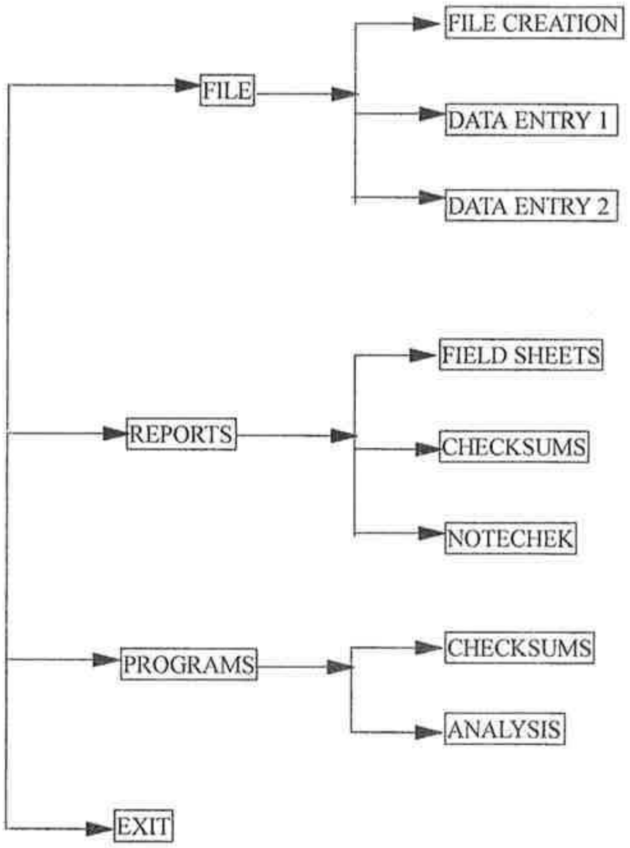

Figure 2: Menu for data entry procedures

Getting the most out of your permanent plot data

Jerome K. Vanclay
Center for International Forestry Research, Indonesia

Abstract

A catalogue of ideas for graphical analyses of growth data is presented, in the hope of stimulating the more imaginative analyses. Graphs can be particularly revealing, because the human eye is good at detecting patterns. Suggestions are given to make graphs more effective, and analyses more insightful.

Introduction

In this paper, I want to stimulate some more innovation in the analysis of permanent plot data. I was motivated to collate these suggestions recently after refereeing some manuscripts which I felt did not do justice to the data at hand. Analyses of permanent plot data should not merely follow accepted procedures copied from previously published work; rather it should involve careful consideration of the objectives of the study, and of the potential and limitations of the data at hand. In many cases, graphical approaches are the most revealing, and I urge greater use of such techniques, for preliminary screening of data, as a supplement to formal statistical tests, and as a convincing way to communicate findings. I will not comment on statistical procedures (these have been adequately dealt with elsewhere, e.g., Warren 1981, 1986), and I will confine my comments largely to graphical techniques for preliminary data exploration prior to more formal statistical analyses, and for illustrating findings in publications.

Revisiting objectives

Perhaps the first step in any analysis is to clarify the objectives. This applies to the analysis of any of any data, whether from temporary or permanent plots, experimental or passive monitoring plots (Vanclay 1994*a*). It applies to the objectives of the analysis in question, and to the objectives of the plot system.

Ideally, the objectives of the plot installation will be consistent with those of the planned analysis. This need not always be the case, and useful conclusions may be drawn from plots established for purposes disparate from the analyses in question, but careful consideration of possible outcomes is warranted if the objectives are not congruent. The critical questions are:

- to what extent may results be influenced by the design of the plot system?
- will results merely be artefacts, or can the plot data cast light on the issue at hand?
- are the available data sufficient to detect the phenomenon of interest, if it exists?

These questions impinge on both the plot system, and on the analysis at hand. It is appropriate to revisit the objectives of the plot system during any analysis of plot data, particularly since many plot systems are established with rather vague objectives. Clearly, care must be taken to ensure that any enhancements proposed for the plot system do not confound observations (Vanclay 1994*a*), but analyses of plot data may reveal forest types and conditions that warrant further sampling (e.g., Beetson *et al.* 1992), or may reveal additional attributes that should be measured on existing plots.

The analysis at hand should also reflect the objectives, not merely follow a standard proforma. This requires clear objectives, ideally, stated as testable hypotheses. I have addressed this issue before (Vanclay 1992, 1994*b*), as have many others (e.g., Lund *et al.* 1992, Rennolls and Gertner 1993), but it remains one of the greatest weaknesses in many analyses, so is worth revisiting.

Checking for errors

Deliberate analyses remain amongst the best ways to detect errors in a database, but a great deal of time may be lost in this way. It is preferable to commence an analysis with careful checks for errors; this avoids many pitfalls, including spurious results and wasted time. Doug Sheil (1995) recently presented an excellent review of procedures to detect errors and inconsistencies in long-term data from permanent plots in tropical moist forests. I make no attempt to summarize his work; I prefer that you consult the source.

Graphical analyses

Modern spreadsheets and other computer packages make it easy to graph data, and offer a many options to customize graphics. Unfortunately, these features are often abused, so that they detract from, rather than contribute towards a fuller understanding of the data. Edward Tufte (1983) devotes an entire book to this topic (a classic book, beautifully illustrated: I recommend it). However, his message is simple and well argued: maximize the information:ink ratio by focusing on the information and keeping the graphics simple. The object of a graphic is to stimulate the reader to think about the implication of the graphic (e.g., for forest management), not to wonder how the graphic was produced. Many of the special effects (e.g., 3-dimensional appearance, hatching, etc.) available in computer packages may produce the latter, rather than the former reaction. While the appearance of graphics is particularly important in the presentation of results, it is also an important consideration in the analysis, as too many "gimmicks" may conceal, rather than reveal information.

I am not proposing that graphical approaches should be used to the exclusion of other techniques. Rather, I propose that they offer an important supplement to standard statistical techniques, especially in the preliminary data exploration phase of analysis. One enduring advantage of graphical approaches is the ability to illustrate the shape of a relationship, and thus indicate suitable functional relationships and transformations for use in statistical models: this is why graphical inspection of raw data and residuals is a standard statistical technique (see e.g., Weisberg 1985, Vanclay 1994*a*). In addition to their role in supporting statistical analysis, graphs offer an efficient way to convey information to readers.

Examining a single set of data

What can be done to reveal the nature of a forest stand to the reader of a scientific paper? Summary tables with lots of numbers may appear rigorous, but are often tedious (and boring) to interpret, while sketches of the stand profile (see e.g., Oldeman 1990, for many examples) can be lively, but rather subjective. Fortunately, much quantitative data can be graphed to make it more accessible. With imagination, almost any aspect of a forest stand can be illustrated in a graphical way, but I shall confine my attention to two aspects: the species composition, and the stand structure.

Species richness, or biodiversity, is currently topical, but is not always meaningful (Hurlbert 1971, Vanclay 1996). Many indices have been proposed, but nearly all have some limitations (MacGurran 1988). Species counts appeal in their simplicity, but can be misleading as they reveal little about the sampling effort of local species distribution (Mawdsley 1996). Thus the presentation of information on the biodiversity of a site is not straight forward, and careful thought on the matter is warranted.

Pie charts are often used to illustrate the dominance of the most abundant species, commonly exhibiting stem numbers, basal areas, or "importance" (the mean of relative number and relative basal area), but the implication is not always clear, as the outcome may depend on sample size or placement. One way to offer supporting information regarding the sampling effort is to accompany pie charts with graphs showing cumulative species numbers plotted against sampling effort (e.g., area or number of trees sampled). Experiment by taking sub-plots or tree numbers in different orders, and see how this influences the shape of the relationships. Try scaling the axes or the data, to see if a square-root or logarithmic transformation suggests a straight-line relationship: this may support your contention that no asymptote has been reached, or may suggest mathematical relationships that may later be fitted to the data.

Stand structure is often quantified as a stand table showing the number of stems in each of several metric size classes (i.e., fixed-interval classes, e.g., 10-20, 20-30, ... cm dbh). The adequacy of such a summary depends much on the size of the sample and the number of classes. In many cases, it may be more appropriate to use deciles (i.e., 10% of total tree numbers in each class), rather than metric classes, but this may make it difficult to interpret graphs, and negates the utility of concepts such as de Liocourt's *q* (i.e., the ratio of numbers in successive classes; e.g., Philip 1994). Korsgaard (1992) argued that it is more informative to graph stand basal area (instead of stem numbers) within each size class. He observed that natural dipterocarp forests in Malaysia tend to maintain approximately equal basal areas in each class, and felt that the harvesting history of a stand could be inferred from the distribution of basal areas within size classes.

An efficient alternative may be to plot the cumulative numbers or basal areas of trees (commencing from the largest) against the tree size. This is analogous to the traditional stand table and Korsgaard's table of basal areas respectively, but is independent of class sizes and less dependent on sample size, so may have greater utility.

Another attribute often used to describe forests is the dominant height, often defined as the mean height of a specified number (e.g. 50/ha) of the fattest trees. However, the choice of the fattest rather than the tallest, and the arbitrary selection of a predefined number of trees (e.g. 50/ha), may influence results. A more informative alternative is to plot the running mean tree height against tree rank, where trees may be ranked by height or by diameter. This alternative may offer substantially more information, especially in mixed forests, as for example, stands with emergents will exhibit markedly different trends than trees with a more uniform canopy.

Finally, when examining commercial aspects such as timber volumes, think carefully about the quality of the various components contributing to the estimates. Some questions that should be considered include:

1. Do commercial species differ in form to such an extent that species-specific volume equations should be used, or can a general equation be used for all species?
2. Has sufficient account been taken of the various factors that may lead to a reduction in volume, including but not limited to inaccessible areas, buffer zones, logging damage, stem defects, etc.?
3. What volume is being predicted: phytomass, total stem volume, sawlog volume, veneer timber, etc?

It is inevitable that some approximations are needed in the analysis of tropical forest data, and this requires no apologies, but does demand clear descriptions of the assumptions made and the data presented.

Comparing data from different treatments or places

When more than one set of data is involved, the analysis may differ from the previous case in a number of ways, depending on the situation. Three situations are of interest, namely:

1. *replications*, where conditions are assumed comparable, and the variability of responses is of interest;
2. *treatments*, where conditions have been altered in a known way, and differences in mean responses are of interest;
3. *monitoring*, where differences in responses are observed, and inferences about changed conditions are of interest.

In the case of field forestry experiments, these three situations may represent an unattainable ideal, but they serve to illustrate the need to explore similarities and differences in the basic conditions underlying the data.

Replications should be identical in as many aspects as possible, and any factors that could vary should be investigated to see what contribution they make to the variance between replications. With treatments, a limited number of factors should be varied in a controlled way, while all other factors remain the same (as with replications). Of particular concern are factors not under experimental control that may vary with treatments, and thus *confound* the results (e.g., if insect defoliators are more prevalent in fertilized plots, no growth response may be visible, because it is obscured by the effect of defoliation). With monitoring systems, we need to know how all the conditions change, so that we can identify possible causes, and can be aware of possible confounding factors.

These caveats apply to all data comparisons, whether they relate to different treatments, different places or different years. The analyst has the responsibility to clarify what differences and what similarities exist, so that an objective assessment of the probable causes and possible confounding factors can be made. This may done using graphical and regression analyses, but it may also be useful to illustrate the distribution of the data in the data space defined by the two most influential factors. This is an analogue of the issue of supplementary sampling (e.g., Beetson *et al.* 1992), and the same exploratory techniques may be used. An alternative is to calculate the principal components (excluding the response variable), and to examine the distribution of data within the data space created by the first two principal components (PCs). If the first PC captures most of the variation (relative to the second PC), there is a real danger of confounding, and further investigation is warranted.

Clearly, it is important to understand the data, and to know how the various data subsets differ. One way to gain such an understanding is to graph all the data on a plot-by-plot basis (discussed above), and then to make graphs on pair-wise or group-wise basis to see how plots differ. Pair-wise graphs may be most useful in cases where stand-level data takes the form of distributions (e.g., stand tables), and the data from two or three plots may be included on the same graph using different symbols to indicate the origin of the data. Group-wise graphs may be most useful in cases where stand-level data can be summarized into a single number (e.g., site productivity, stand basal area, etc.), and may include data from many plots, especially when graphed against any of the factors that differ greatly among plots (e.g., graph site productivity against rainfall and elevation; stand basal area against time since last harvest, etc.). In both cases, visual impressions can be confirmed with standard statistical tests, such as F-tests on the residual variance about regressions (see any statistical text).

Comparing time series data

Time series data are analogous, since time, rather than place, has changed, but the also offer some particular challenges, since “everything is connected to everything else”. Take for instance, tree growth: changes in tree growth rates over time may be attributed to increased age, increased tree size, increased competition, to a combination of these factors, or to other factors. Amongst the other factors is the important question: how can one be sure that the changes observed are due to environmental change, not to procedural changes?

In even-aged single-species plantations, the stand-level changes in basal area and tree numbers are of some interest, but in the mixed tropical forest, individual tree characteristics may be easier to interpret. Three components of growth and change are of interest: diameter increment, mortality, and recruitment. Mortality and recruitment are difficult to deal with, since data are rarely of sufficient number or quality to provide good graphs of mean rates by stand density and by tree size (in the case of recruitment). However, it is worth experimenting with what data are available, and with graphs of the predicted values from statistical models fitted to the data.

There are several ways to appraise diameter increments. One useful way to gain an overall idea of growth relationships is to graph mean diameter increment within each of several species and size classes versus tree size (dbh) and stand basal area. These may be followed by graphs of individual tree increments versus tree size and stand basal area to gain more detailed insights.

Special considerations when several factors vary

As the number of variables increase, more care needs to be taken, as it becomes more and more difficult to understand possible interactions. One way to screen for possible confounding is to compile a scatterplot matrix (cf. correlation matrix). Another way is to examine the principal components of the regressor variables: if the data are orthogonal, all components will explain an equivalent share of the variance, but with non-orthogonal data, the amount of variance explained by a PC may diminish quickly with its rank.

Synthesis

My attempt to stimulate ideas for more imaginative analyses of data comprises three simple components

1. experiment with alternatives, especially visual ones, because the eye is good at detecting patterns;
2. keep it simple, so that the noise (and embellishment) does not detract from the signal;
3. supplement the graphics with statistical tests to confirm or reject what you see.

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Review of past inventories and prospects for long term monitoring for forest management and biodiversity conservation on Mt. Cameroon.

James Acworth*, Nouhou Ndam*, Peguy Tchouto*, Dr. Ian Edwards⌘ and Dr. John Proctor#

Summary

A total of six forest inventories have been carried out in the Mt. Cameroon region between 1989 and 1996. 178 x 0.25 ha plots have been established in different forest types to analyse their botanical composition and to provide a baseline for future monitoring of forest quality and tree growth. Size class distributions and basal areas for all areas inventories are similar to the pan tropical mean. More than 8,000 geo-referenced botanical collection records from the Mt. Cameroon region are now stored in the Herbarium and BRAHMS database, providing a powerful tool for management of biodiversity.

Additional analysis, including calculation of indices of species richness / diversity and ordination of the data will be completed to assist with the classification of forest types and identification/mapping of priority areas for biodiversity conservation.

Further ecological studies are ongoing. One set 5 x paired plots of 0.25ha were established in 1989 and re-measured in 1994-5 to analyse the altitudinal variation of vegetation on Mt. Cameroon. Results show no effect of altitude on size class distributions or basal areas, but illustrate a clear decrease in tree species diversity with altitude, However, the original data sets were not sufficiently accurate to calculate growth. Studies of regeneration after natural and anthropogenic disturbance have concentrated on the impact of tree fall gaps, shifting agriculture, lava flows and seedling ecology of the important medicinal tree Prunus africana. Preliminary results are reported.

Observations from the first phase of inventories high-light some of the difficulties surrounding the collection and analysis of adequate data for forest management in the short term, and particularly in those areas which are heavily used by the local community.

In preparation for developing plans for community-managed forests, a programme has been launched including rapid assessment methods to collect baseline biological data and to establish a set of plots for long-range monitoring of forest dynamics in areas of forest strongly affected by human disturbance. This programme is designed to take into account the problems realised during earlier inventories, and to provide management recommendations compatible with biodiversity conservation.

Key words: *Mount Cameroon, biodiversity conservation, participatory forest management, botanical survey, inventory, monitoring.*

Introduction to Mt. Cameroon and the Mt. Cameroon Project

Topography, Geology and soils

Mount Cameroon is the highest mountain in West and Central Africa (4095 m.). The main massif covers an area of approximately 1,500km^2. It is an active Hawaiian type of volcano of Quaternary origin, erupting about every 20 years. The slopes of Mt. Cameroon are steep and rugged almost down to sea level, marked by lava flows of various ages, notably the large 1922 lava flow on the north-western flank.

Mt. Cameroon is flanked on the south by Mt. Etinde (1,713m), geologically the oldest part of the mountain massif, characterised by a much older Tertiary lava, different in composition to the Holocene basalts of Mt. Cameroon (Payton 1993).

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Soils on the Mt. Cameroon massif are mostly of recent origin, on young volcanic rocks, and while generally fertile, they have poor moisture retention capacity (Hasselo 1961). The surrounding lowlands comprise a diverse mosaic of soil types including ferralitic clays formed by the weathering of igneous rocks, ash deposits, deposits of outwash material from conglomerates of water-worn rocks, and flat poorly drained plains of recent alluvium, sandy or silty in composition.

Climate

The climate is characterised by two main season, the wet season with heavy rains (June-October) and the dry season (November-May). At lower altitude, the annual rainfall ranges from about 10,000mm at Cape Debundscha to less than 2,000mm around Buea. In the cloud forest, mean annual rainfall decreases with altitude to approximately 4,000mm at 1,000m and to less than 3,000mm above 2,000m.

The air temperature at sea level varies seasonally from 27°C to 32°C and the temperature falls with increasing elevation at a rate of 0.6°C per 100m of ascent, to 4°C at the summit. The relative humidity is strongly influenced by the sea and remains at 75-85%. At mid elevation (1,200-2,000m), the mountain is characterised by semi-permanent mists and cloudiness (Payton 1993).

Vegetation

Mt. Cameroon is possibly the last mountain in West Africa where the continuum of natural vegetation remains largely unbroken from sea level to sub-alpine zone at the summit. Zonation is determined primarily by altitude, but is also affected by vulcanism and physical environment such as aspect, topography, geology, soils and climate (Hall 1973, Richards 1963, Letouzey 1985). Five distinct vegetation belts on the main massif have been described (Thomas & Cheek 1992, Tchouto 1995) on Mt. Cameroon including lowland evergreen forest (0-800m), sub-montane forest (800-1,700m), montane forest (1,600-1,800m), montane scrub (above 1,800m) and sub-alpine grassland (2,000-3,000m), but each comprises a mosaic of sub-variant plant communities.

In addition, the lowland forests surrounding Mt. Cameroon are clearly distinguished into three major types, including Atlantic Biafran Lowland Evergreen forest rich in *Caesalpiniaceae*, Coastal forest dominated by *Oubangia alata*, and Recent Second Growth Forest (Letouzey 1985).

Species diversity and conservation importance of Mt. Cameroon

The exceptional species diversity of Mount Cameroon is a result of the wide range of physical and climatic factors coupled with the fact that it corresponds to one of the two pleistocene forest refugia postulated for Africa (Hamilton 1976, Maley 1991). More than 42 strictly endemic species only occurring on Mt. Cameroon have been recorded of which 19 are restricted to the high altitude grassland (Cheek *et al.* 1996).

Because of its high endemism Mt. Cameroon has been identified as a national conservation priority and has been proposed as a Centre of Plant Diversity (IUCN/WWF 1994). Mt. Cameroon probably represent one of the highest priorities for the conservation of biodiversity within Africa (Watts & Akogo 1994).

Forest use by local community

The forests of Mt. Cameroon also support a large number of forest users, who exploit this wealth of biological resources for foods, medicines and materials for everyday life and for sale nationally and internationally. The value of the mountain to the local community is clearly reflected in the cultural importance they attach to the mountain as a whole (Jeanrenaud 1991).

However, it is now evident that the high population pressure is resulting in exploitation beyond the natural rate of recovery for many species. Without adequate protection, well planned and regulated exploitation, these resources can be considered seriously depleted in the short-term and some will be eliminated within the next two decades.

Mt. Cameroon Project

In 1988 a British-funded bilateral programme was initiated with the goal of identifying and protecting sites of biodiversity conservation priority. This project has evolved, now with three funding agencies (ODA, GTZ, GEF) working in collaboration with the Government of Cameroon.

It is expected that the goal of biodiversity conservation will be achieved through sustainable management of natural resources with the full participation of the local government and non-government institutions. Given the major involvement of the local community in both utilisation and the traditional control of forest exploitation, they are primary partners in the project.

Other key stakeholders include large commercial companies such as Cameroon Development Corporation, an industrial plantation parastatal company within whose leasehold priority forest conservation areas are presently located, and Plantecam, an international company who harvest medicinal plants for processing and export, in particular the tree *Prunus africana* Hook. f. Kalkman for which they have the sole exploitation permit for Mt. Cameroon. The bark of this pan-african montane forest tree is stripped and used for the extraction of medicinally active ingredient used internationally in the treatment of prostatic hyperplasia. Due to the high pressure of exploitation in many of the species' dispersed populations throughout the African continent *P. africana* has been listed in Appendix II of CITES.

Forest management issues on Mt. Cameroon

While the complex social environment surrounding Mt. Cameroon demands that local needs and community perceptions be taken fully into account in forest management planning, the identification of conservation priority areas and decisions about sustainable off-take of forest resources must still rely on scientific information from static inventories, ecological studies and long term monitoring. These will provide a better understanding of a range of natural features including :

- species distribution and abundance;
- stocks of exploitable species;
- dynamics in natural forest, (esp. exploited species such as *Prunus africana*);
- altitudinal variation of the structure and composition of vegetation;

and anthropogenic factors such as:

- impact of fire (semi-natural) on montane forest / savannah boundary;
- impact of selective logging and exploitation of other forest products;
- impact of partial clearance for shifting agriculture.

The Mount Cameroon Project, and associated researchers have established a large set of temporary, semi-permanent and permanent plots in the forests of Mt. Cameroon to study many of these factors.

Past inventory work on Mt. Cameroon

A series of inventories have been established by the Mount Cameroon Project, its predecessor (Limbe Botanic Garden & Rainforest Genetic Conservation Project) and associated visiting scientists. While many of the inventories share standard methods, they have been implemented with a range of objectives.

Forest Inventory and botanical survey

Objectives & methods

Forest inventories were implemented in four discrete forest areas: Mabeta-Moliwe (Cheek 1992a, Ndam 1993), Etinde (Cheek 1992b, Tchouto 1995), Onge (Thomas 1994a) and Mokoko (Thomas

1994b) to assess their structure, species composition and productive potential. The data will be compared to identify areas of conservation priority. The inventory design, plot size and results are summarised in Appendix 1.

Most of the inventories have been based on 0.25 ha. plots, located variously along transects, in clusters, or randomly scattered. Some are permanent, and other semi-permanent plots could be made permanent if re-measured and demarcated within the next two years. Some of the plots also include sub-plots for material <10cm dbh.

Results and Discussion

Tree plot data

For each of the four forest areas in turn, tree plot data have been analysed to provide information on species composition, diameter class distribution, basal areas and tree species numbers (see **Error! Reference source not found.**, Table 1). Diameter Class distributions compare similarly with the Pan-Tropical Mean (Dawkins 1958). Species Numbers are a subjective measure of diversity, since they are an artefact of the number of plots and sampling intensity of the inventory. Further analysis, including classification and ordination of the data set to identify vegetation groupings, and calculation of species diversity indices has been completed for the Etinde inventory only (Tchouto 1995).

This analysis will be completed for all data sets by June 1997 using a range of multivariate analysis tools such as unweighted pair-group method using arithmetic averages (UPGMA), two-way indicator species analysis (TWINSPAN) and Detrended Correspondence Analysis (DECORANA), but is awaiting an improved database structure for all data and confirmation of botanical identification of voucher specimens.

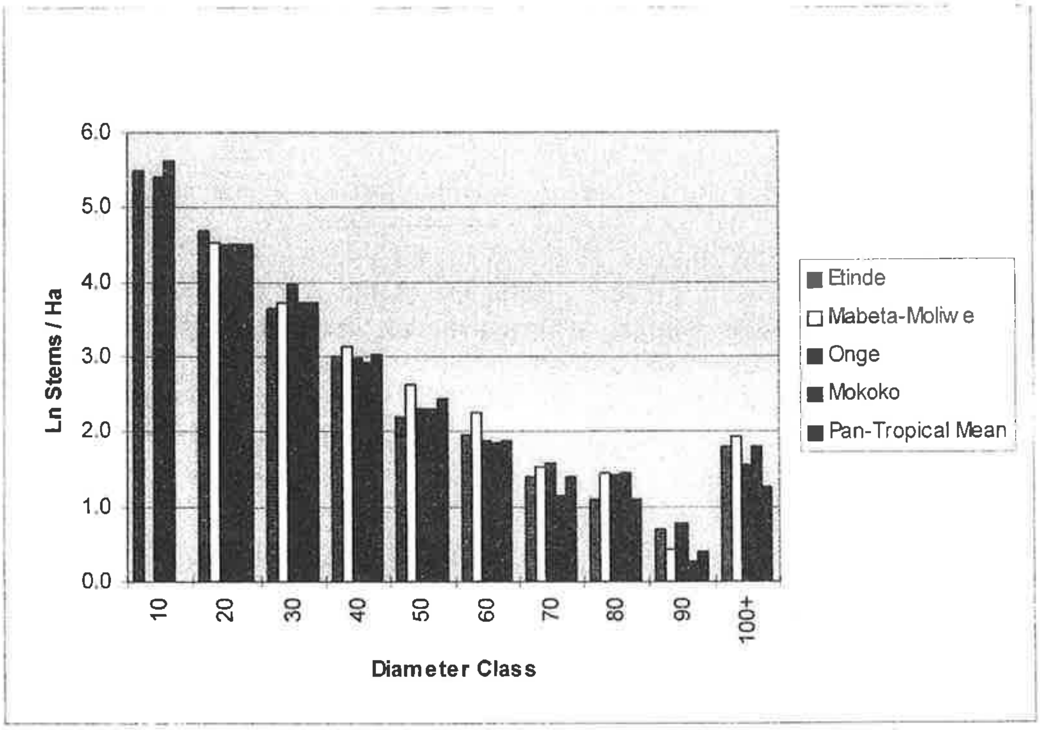

Figure 1. Ln of Stem Density (Stems/ha) for all forest inventories on Mt. Cameroon.

Table 1: **Mean No. Stems/ha, mean Basal Areas/ha, Tree Species Nos. for all inventories on Mt. Cameroon.**

Diameter Class	dbh range	Etinde	Mabeta-Moliwe	Onge	Mokoko	Pan-Tropical Mean
10	10-19	244.0	-	224.0	280.0	-
20	20-29	108.0	93.49	88.9	91.2	90.5
30	30-39	38.0	41.64	53.1	41.1	41.5
40	40-49	20.0	23.08	19.6	18.5	20.5
50	50-59	9.0	13.78	10.0	10.1	11.5
60	60-69	7.0	9.45	6.5	6.4	6.5
70	70-79	4.0	4.63	4.9	3.2	4.0
80	80-89	3.0	4.24	4.2	4.3	3.0
90	90-99	2.0	1.54	2.2	1.3	1.5
100+	100+	6.0	6.84	4.7	6.0	3.5
Total	Stems>10cm	441.0	n.a.	418.2	462.1	n.a.
	Stems>20cm	197.0	198.7	194.2	182.1	182.5
Mean Basal Area (m^2/ha)		*34.27*	*31.8*	*29.9*	*29.6*	*31.5*
Tree Species Nos.		*Smf[2]=113* *Mf[3]=36*	*245*	*261*	*286*	-

Allocation of weighted indices of conservation importance following the method of Hawthorne (1996) will be used to improve the identification of forest types and areas of conservation priority by December 1997. The stratification of vegetation in terms of forest type and conservation importance will be used to orientate future monitoring and management planning.

Botanical collection data

Botanical collections have been made alongside these forest inventories, including collection of voucher specimens from trees in main plots, collection of all specimens in sub-plots or general collection of fertile materials wherever they are encountered.

Approximately 10,000 botanical collections have been made on and around Mt. Cameroon and a replicate of all collections is stored in the Limbe Botanic Garden Herbarium. The collection data with geographical referencing is stored on the BRAHMS[4]. This database currently encompasses 3-4,000 species records from the South West Province of Cameroon and the neighbouring Cross River State, Nigeria. BRAHMS is a powerful tool for producing checklists by forest area, species distribution maps and to facilitate further vegetation analysis. In the near future, forest inventory (tree plot) data and botanical collection database will be made inter-connectable, so that all information for any one area or plot can be accessed and analysed.

Management Inventory of Mt. Cameroon

Objectives & Methods

A management inventory of commercial timber and medicinal plant species was conducted on Mt. Cameroon between June and August 1996 by ONADEF (Office National de Developpement des

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[2] *Smf* = Sub-montane forest in the proposed Etinde rainforest reserve

[3] *Mf* = Montane forest in proposed Etinde rainforest reserve.

[4] BRAHMS: Botanic Reference and Herbarium Management System. Developed jointly by Royal Botanic Garden, Kew and Oxford Forestry Institute.

Forêts). The objective was to establish an estimate of the stocks of priority productive resources on Mt. Cameroon, and to provide an assessment of the vegetation zonation as a result of natural and anthropogenic factors.

40 transects of 20m width, at 2km spacing (1% sampling intensity) were established perpendicular to the contours, from the forest/savannah boundary down to the lower limits of intact forest. A total area of 500 hectares was measured. In each transect, important timber species (about 35 species) over 30cm dbh were identified, measured and their quality was recorded. In addition, 13 medicinal plants species (small trees, shrubs, and lianas) were measured (species >10cm dbh) or tallied (species <10cm dbh)

The priority species for the inventory is *Prunus africana*, a medium to large tree growing between 500 and 2,000 metres altitude, whose bark is heavily exploited for medicinal use (see section 0), for which only preliminary estimates of stocks were available (Ebai *et al.* 1992).

Results and Discussion

At the time of writing, the data is still being analysed. The results will be presented as stand tables, volume tables and distribution / abundance maps for the medicinal plants.

In theory, it should be possible to project sustained yields from this inventory data, but in practice, the absence of any reliable growth data for the region and the unknown influence of altitude on growth rates will make it difficult to make any more than cautious estimates. Further, exploitation is heavily concentrated in the already degraded fringes of the lower slopes. Allocation of yield will have to take into account the gradation of intensity of forest use.

Finally, the accurate estimation of bark volumes, recovery rates and the sustained frequency of harvesting for *Prunus africana* is not possible without volume regression equations and information from long term monitoring of growth and recovery rates. A priority is therefore to collect yield and bark volume data for analysis.

Altitudinal variation of vegetation on Mt. Cameroon.

Objectives & Methods

In 1989, a set of five paired 0.25 hectare permanent plots were established at five different altitudes (300m, 600m, 1350m, 1,800m and 2,400m above sea level) on the southern slopes of Mt. Cameroon to compare the species composition, richness and vegetation structure as a function of altitude (Proctor & Edwards 1996, unpublished). Trees >10cm were tagged, measured and identified. These plots were re-measured in 1994-5 to confirm the original measurements and assess changes.

Results and Discussion

Altitude does not seem to affect either stem density (range 288-488 stems/ha.), basal area (range 24.9-50 m²/ha.) or size class distribution with any discernible pattern, once anomalies[5] have been removed.

The effect of altitude on species richness is significant: plots in the 300-1,100m range contained 14-18 tree families and 29-47 species compared to 7-10 families and 9-11 species in the plots above 1,800m altitude (see Figure 2 below) with dramatic corresponding falls in species diversity indices (Proctor & Edwards 1996 unpub.).

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[5] The presence of very large stranglers (*Schefflera* spp.) dramatically increased basal area and diameter class distributions of the plots where they occur. However, being hollow tubes rather than solid trunks, their influence is misleading and has been discounted.

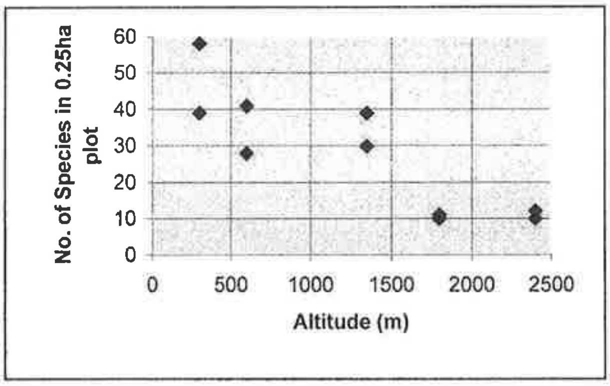

Figure 2. Species Diversity of trees & lianas > 10cm dbh. Operation Raleigh plots on Mt. Etinde (from Proctor & Edwards 1996 unpublished).

In the lower six plots (i.e. below 1,100m.) the species area curves show no tendency towards levelling off at 0.25ha many more species would have been included in the census if the plots had been larger. In the four plots above 1,800m species area curves do not continue to rise, suggesting that most species were sampled.

These conclusions correspond closely with the findings of (Tchouto 1995) for the Etinde inventory undertaken in the same area.

The re-measurement in 1994-5 revealed a number of errors in the first mensuration making it impossible to reach any detailed conclusions about forest dynamics. However, in one plot, very high mortality (44%) was observed, with no obvious explanation of the cause.

Regeneration after natural and man-made disturbance

A series of localised ecological studies are in progress (Ndam 1995) to investigate the successional patterns of tree recovery through changes in vegetation structure, species composition and species dominance in man-made and naturally disturbed sites of Mount Cameroon such as abandoned farms, tree cut and tree fall gaps, and recent lava flow areas.

Tree regeneration in gaps

Regeneration in gaps was studied by establishing plots in 11 gaps and 11 controls in lowland forest where selective logging is frequent. A total of 4 plots of 50 m x 50m, 143 plots of 1×5m, and 165 quadrats of 1m x 1m were established. All plants were tagged, vouchered when necessary, and height and diameter recorded for plants ≥10m dbh, ≥1m. Light was measured in each of the three zones (gap centre, gap edge and control or undisturbed).

Results show that species are indifferently located at undisturbed sites, gap centres and gap edges. Their numbers show little dependence to zone types, however various climbers were abundant in gap centres. High mortality was observed within plant population below 1 m tall. Seedling and sapling structure indicated that more than 50% of initial population died before reaching 1 cm dbh and about 10% reach the size of 5-10 cm dbh. A total of about 57 species have been identified so far and 4 of them are the commonest above 1 m layer of the forest under-storey.

Regeneration in agricultural fallows

In agricultural fallows, a total of 30 plots of 20×20m, containing 90 sub-plots of 4×5m were established between 800 m and 1,150 m altitude on Mount Cameroon. They were grouped into 5 age classes, according to the years since last farmed; 0-2, 3-5, 6-10, 11-30, and 30+ years. In each plot woody plants ≥2m tall were tagged, vouchered when necessary, and their height and diameter recorded. In each sub-plot a similar operation was conducted for woody seedlings ≥30cm and <1m tall.

Results indicate that the number of woody stems increases as the farm grows old (115-694 stems/ha.). Mortality was high during early years following abandonment when weeds were dominant. Recruitment was important at the very early time of abandonment or later after the weedy period (Ndam *et al.* 1996.)

Regeneration on lava flows

Two lava flows were studied: the 1922 lava flow at sea level, and the 1957 flow at its lowest extent (400m altitude). On both lava flows, a series of plots were established at 50m. intervals along a transect. In each 2x2m plot, the approximate percentage cover (abundance) of herbs, ferns, mosses and scramblers were recorded and in 2x5m plots the average height and maximum height were recorded for all trees, shrubs and climbers >1cm. Centre point plots were measured to record the identification, distance and dbh the first 11 trees >10cm dbh.

Results show that the earliest colonisers are Lichens, Mosses and Ferns, as seen on the 1957 Ekona lava flow, followed by gradual colonisation by trees, of which there are 4 dominant tree species: *Cecropia peltata, Hymenodictyon biafranum, Alchornea cordifolia* and *Chromolaena odorata.* as seen on the 1922 lava flow. In general, these species are also the tallest, suggesting that they were either the initial tree colonisers, and/or that they are aggressive species with rapid growth.

Regeneration of Prunus africana

The objective was to obtain information on the regeneration mechanisms and population dynamics of *Prunus africana,* (see sections 0 and 0), and to identify environmental or ecological variables influencing the success of its regeneration. Eighteen different sites were chosen, representing three habitat types (undisturbed forest, secondary forest and farm land). At each of these sites, two sets of six 2m x 1m plots were established, 1 set under the crowns of isolated trees, the other set under the common crowns of clustered mature trees giving a total of 216 plots (Ndam 1995).

Seedling densities were recorded over time after the fruiting season in two different years, and recruitment and mortality rates were compared between sites. Preliminary conclusions on the seedling ecology of Prunus africana indicate that the species prefers disturbed sites for successful seedling survival (Ndam 1995).

Future Inventory work in the Mt. Cameroon Region

Establishment of a set of PSPs.

Objectives.

Following the vegetation stratification produced from the first series of forest inventories, the next step is to establish a long-term monitoring system to provide information on forest dynamics.

A priority of the GEF (Global Environment Facility) funded component of the Project is to monitor the impact of forest use on biodiversity and to assess the success of the Project to achieve its goal of biodiversity conservation.

Methods

A selection of the existing 0.25 hectare semi-permanent and permanent plots set up in the first phase of inventories will be re-measured mapped and properly demarcated. New plots will be established in forest types which have not been adequately sampled. Plots will be stratified, and prioritised to lowland sites which are representative of a larger surrounding forest area, which is under immediate exploitation pressure. Another priority is to monitor the growth and recovery of *Prunus africana*, for which little or no management data exists.

In November 1996, the Smithsonian Institute/Man and Biosphere Program will establish one 1 hectare biodiversity monitoring plots in the lowland forest of Mabeta Moliwe (see **Error! Reference source not found.**). This will be the first of a network of additional plots around Mt. Cameroon and further afield in Cameroon which will provide data on species diversity and forest dynamics.

Participatory Resource Inventory

In spite of considerable efforts on the part of the Project to explain the objectives and results of past inventories in the area and to include local representatives in all stages of implementation, experience on Mt. Cameroon has shown that local communities are still highly suspicious of forest inventories. They fear they may either signal the creation of government owned forest reserves from which they will be excluded, or the imminent exploitation of valuable resources from their forests from which they will not benefit.

Emphasis put by the Project on community level management requires that communities understand fully the results and management implication of forest inventories. Their understanding of and collaboration in all inventories and in particular management inventories (targeted at specific forest resources) is crucial, if they are to accept and implement the resulting management recommendations.

The diverse mosaic of vegetation types implies that particular species are exploited in specific forest types. The nature of the products from species which require monitoring are equally diverse: timber, leaves, canes and bark. The intensity of forest utilisation varies as a function of distance from human settlement.

Future inventories must take into account the range of NTFPs that are utilised by the local community. Growth rates of bark (e.g. *Prunus africana),* herbs (e.g. *Afromomum spp.),* and lianas (e.g. *Laccosperma spp.)* may be economically more important than timber growth. Inventory methods will need to be adapted and simplified to allow full involvement of communities.

Due to the biological and socio-cultural complexity of the region, the planning and implementation of forest inventories, and the analysis of results will have to be done on a very localised basis, in close collaboration with the neighbouring communities.

Rapid Biodiversity Surveys

While the existing set of established plots have produced important information about biodiversity, this is not the most efficient means of surveying species distribution and abundance. In the next phase, the Project will initiate a programme of rapid biodiversity surveys, testing and comparing various methods developed elsewhere, including Hawthorne (1996) and Gentry (Stergios 1996) as rapid tools to survey species distribution and abundance and to identify conservation priority areas. These surveys will be implemented in areas inadequately or not yet sampled.

Issues to resolve for forest inventory and long-term monitoring

Extrapolation from management inventory data

The wide range of micro-climates and growing conditions within a small geographic area imply that no single growth rate can be applied for any one species to calculate sustained yields. Further, forest management units are inevitably small, reflecting the localised nature of communities of forest users. Development of a site class system, giving site specific forest growth data, would be optimal but is not feasible within current project limitations.

Problems with differential use of PSPs and Transects

Where PSPs are obviously demarcated or their locations known, local communities may be inclined to use them differentially, compared to the surrounding forest. Depending on the circumstances, plots may either be destroyed or left totally untouched, because of misconception and fears regarding their purpose.In the case of inventories on Mt. Cameroon, transects have become entry points for illegal exploiters. In another instance a regeneration plot was even carefully "relocated" to make way for farm expansion!

Disguising permanent plots has been recommended in some circumstances (Alder & Synnott 1992), but this complicates establishment and relocation. Further, any "secrecy" counter-acts the desire to involve the local community.

Management events are sporadic and not recorded

In forests utilised by local communities, exploitation of forest products does not follow definable cycles and the timing and extent of forest exploitation are often unknown. Sometimes one has to use visual indications of previous exploitation events, such as cut stumps, and where they are indiscernible, one must rely on oral history.

Information management

Mount Cameroon Project is fortunate to host large and diverse data sets from a wide range of sources:

- Botanical collections on BRAHMS
- Forest Inventories (178 x 0.25ha. semi-permanent and permanent forest inventory plots, 1,000 x 0.5 hectares management inventory plot data.)
- 690 x small regeneration and floristic plots (range 1-400m2)
- Wildlife surveys
- Geo-Climatic data from weather stations and soil surveys
- Socio-economic survey data

This data originates from many different sources, and is in a range of electronic and hard copy formats. Much of this data is geo-referenced. Efficient data management is vital to maximise the value of the information. Before embarking on further data collection, a priority of the project is to standardise database formats (e.g. habitat descriptions, geographical references,) and cross link the information. In the medium term this information will be integrated within a Geographical Information System.

Projects are short term, monitoring is long-term

Project cycles are rarely, if ever, longer than three years. This is inadequate time to establish and re-measure PSPs. The information they could generate to support management planning, is generally only available at the end of the project cycles, which means there is less incentive to establish them.

Conclusions

Mount Cameroon and its environs represent a complex site, in geo-physical, bio-climatic and socio-economic terms. There are a wide range of forest types with a diverse set of associated management issues to tackle. Amidst such complexity, an inventory program to identify forest types and species distribution, to quantify forest resources, and to monitor long term forest dynamics requires a high sampling intensity and a range of inventory methods. The Global Environment Facility is financing some of these biological surveys using specialist teams.

The Mt. Cameroon Project is primarily a management project and has elected to concentrate efforts of field staff on developing community level capacity to manage forest resources. The workload that this entails precludes the implementation of an inventory and research programme which is sufficiently comprehensive to answer all management questions. In spite of these limitations some very valuable forest inventories have been completed and a good network of permanent plots established, some of which will form the basis for longer term monitoring of forest dynamics.

The Mount Cameroon Project has therefore established a centre for biodiversity, with logistical (vehicles, equipment) and scientific support (herbarium, field staff), and is currently inviting interest from national and international research institutions, to collaborate and contribute in the collection and analysis of biological data which will help provide scientifically founded prescriptions for the sustained management of forest resources, compatible with the conservation of biodiversity in the Mt. Cameroon region.

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Appendix 1. Summary of Inventories on Mt. Cameroon. 1989-1996.

Forest Area	**Mabeta-Moliwe proposed forest reserve**	**Etinde: altitudinal variation studies**	**Proposed Etinde Rainforest Reserve**	**Onge River Forest area.**	**Mokoko River Forest Reserve**	**Management Inventory of Mt. Cameroon**
Forest Type	Lowland, Mangrove, Littoral	Lowland, Sub-Montane, Montane.	Lowland, Sub-Montane, Montane, grassland	Lowland	Lowland	Sub-montane, Montane
Inventory executor	LBGRGCP + Kew	Proctor, Edwards + Op. Raleigh	LBGRGCP + Kew	LBGRGCP, Kew + Thomas	LBGRGCP, + Thomas	ONADEF
Latitudinal range	3 58' - 4 02'	4 04 - 4 07'	3 57' - 4 27' N	4 15` - 4 25'	4 21' - 4 28' N	3 57' - 4 27' N
Longitudinal range	9 13' - 9 18'	9 03' - 9 10'	8 58' - 9 24' E	8 45 - 8 60'	8 59' - 9 07' E	8 58' - 9 24' E
Altitudinal range	0 - 300 m	300 - 2,400m	200 - 4095 m	200 - 300 m	100-400m	400 - 2,400m
Forest area	36 km sq.	n.a.	360 km sq.	180 km sq.	96 km sq.	500 km sq.
GPS: plot location	Pending	Pending	Partial	Yes	Yes	Partial
Inventory type	9 Systematic transects	Paired plots at 5 altitudes in different vegetation belts	15 stratified transects	6 systematic Transects	8 clusters of 4 plots, randomly located.	40 Transects perpendicular to contours. (total 250km length)
Main plots: Number, Size, type	83 x 0.25ha (50x50m) permanent, tagged	10 x 0.25ha (50x50m) permanent, tagged	32 x 0.25ha (50x50m), 26 temporary, 6 permanent.	22 x 0.25ha (50x50m) temporary, untagged	30 x 0.25ha (50x50m) semi-permanent, tagged	1,000 x 0.5ha (20x250m) temporary plots along transects
data collected.	all trees >20cm dbh	all trees >10cm dbh	all trees>10cm dbh	all trees>10cm dbh	all trees>10cm dbh	all trees >30cm dbh
First measured	May - Sept 1992	1989	Sept - Nov 1992	Oct - Nov 1993	May - June 1994	April-August 1996
Re-measured	Oct-96	1994	-	-	-	-
Current status of plots	Some transects recut Nov. 1996, plots lost	Require mapping/ remeasuring to set baseline.	Require mapping/ remeasuring to set baseline.	Require mapping/ remeasuring to set baseline.	Require mapping/ remeasuring to set baseline.	Transects still open & marked.
Sampling intensity	0.50%	n.a.	0.02%	0.03%	0.08%	1.00%
Botanical collections	Transects & intensively collected plots	All sterile material vouchered	Transects, paths & individual habitats: e.g. Lava flows, grassland.	Transects and individual habitats	Transects, enumeration plots & general collection	1,000 x (5x20m) floristic plots.
New species	18	n.a.	21-23	13-17	33	n.a.
Endemic/rare species	34	-	42	Pending identifications	Pending identifications	n.a.

Volume increment of natural tropical moist forest in Nigeria: An account of the High Forest Monitoring Plots Project.

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Abstract

A knowledge of the annual volume increment and structure of a forest is essential for calculating its sustainable yield. This study evolved efficient techniques for collecting data in natural lowland tropical moist forests, based on earlier practices in Nigeria, and wrote the software for storing and analysing this information using a micro-computer. Estimates were made of volume increments and of sustainable timber yields for five high forest reserves in different climatic/geographic regions of Nigeria. Permanent sample plots were established in natural forest, each measuring one hectare. Two plots were laid down in each square mile (2.59 km²), a sampling intensity of 0.772%. The dimensions of a plot were 40m x 250m; only the centre line down the long axis was demarcated. Data were recorded for trees of all species ≥ 5 cm DBH (Diameter at Breast Height), although the plot was subsampled to different distances from the centre line for trees under 40 cm DBH. Regeneration ≥ 1 m tall of exploitable species was also sampled and soil samples taken for laboratory analysis. Each plot could be located, demarcated and assessed by a team of eight men within 3 days, and thereafter reassessed in 1 day. The interval between assessments was normally 2 years. Ways to reduce plot edge-effect on including/excluding trees from the sample are discussed, as are ways to reduce the effects of errors in measuring bole diameter on volume estimates, especially for large trees.

Volumes were calculated using taper functions to estimate bole diameters for each tree. In drier high forests at Omo and Owan North Forest Reserves, the mean annual increment for standing bole volume was estimated to be about 5.0 ± 0.5 cu m/ha; and in wetter high forest at Sapoba Reserve, 6.5 ±1.3 cu m/ha. (The larger error at Sapoba may owe to inconsistencies in stratifying the samples). At Oban Group Reserve in the south-east of the country, on strongly-leached soils under relatively high rainfall in previously undisturbed forest, the mean annual increment was 4.2 ±1.0 cu m/ha. In the drier high forests, species utilisable for timber accounted for about half of total increment; in the moister forest at Sapoba about two-thirds; and at Oban about a quarter. In each case, about half of this utilisable increment was for veneer-quality species. Standing bole volumes in the plots ranged from 110 to 340 cu m/ha and standing basal areas from 16 to 37 m²/ha. Natural forest seemed to be robust: correlations between volume increment and standing bole volume were not significant at the 0.05 probability level. The results suggest that the forests could withstand removals from an annual coupe equivalent to 50 cu m/ha of the standing bole volume, without dilapidating the forest seriously, though the relative proportions of species may change.

Introduction

The High Forest Monitoring Plots Project in the Federal Department of Forestry operated during the years 1984-1989, funded by the Government of Nigeria and by the European Community. The aims were to develop methods for determining the growth of natural tropical moist forest, and to make preliminary estimates. It was a sequel to the 1972-1978 FAO/FDF High Forest Inventory Project in Nigeria, which had estimated the standing exploitable volume of timber within forest reserves but not the increment of the forest.

Knowledge of species composition and size class distribution in a forest, and of its annual increment, are essential to calculate sustainable yield. For natural tropical forest, such information scarcely existed. Reasons are the complexity of the forest structure, and ignorance of the silvicultural and growth characteristics of most of the numerous tree species present. In tropical forests, most trees do not produce recognisable annual growth rings in the wood, and hence their increment cannot be obtained by taking sample cores from tree boles. Formerly, estimates of total volume increment, and its composition, were more in the nature of "guesstimates" than precise evaluations of the forest re-growth together with attribution of error. Dubious methods, based on summating estimated "times of passage" through successive girth classes, had been employed to determine felling cycles, but made it difficult to calculate valid estimates of error - because trees without measurable growth during the period of observation have infinite times of passage. This impasse was avoided by including only trees that passed given girths within given periods of time; but then data are needed to determine for each species the extent to which increment rates persist over time. However observations usually lasted for an insufficient duration, and silvicultural information was inadequate for satisfactory assumptions to be made. Production from tropical forests was usually controlled by minimum girth limits for different species, or groups of species, without any real knowledge of their rates of re-growth, and sometimes without any precise inventory of the forest. Sustained yield management requires continuous monitoring of the forest in order to estimate its volume increment.

Methods

The first task was to develop efficient ways of laying down and assessing sample plots. The 1972-1978 inventory organised by Harold Sutter had relied on point sampling of the forest using a basal-area gauge (Relascope) - which was unsuitable for continuous inventory - although it served as a method of sub-sampling the forest. A large tree contributes proportionately more to the volume of wood in a forest than a small tree, and is also more difficult to measure accurately. Nevertheless small trees comprise far greater numbers of trees. Therefore, to obtain the volume of wood in a forest with sufficient precision to get increment (which is the difference between two volume estimates - both large in relation to increment) some system for sampling trees is required that will increase the ratio in numbers of large trees to small trees. Existing enumeration data for natural forest were scrutinised to get stem frequencies of trees down to 5 cm or 10 cm diameter at breast height (DBH), both from records for natural forest plots of the Forest Research Institute at Ibadan (FRIN), and from the forest inventory for Ghana (Anon 1982). It was not possible to design a method that could optimise both error and cost, because of inadequate information on numbers of trees in different size classes, their errors of measurement, and costs of the various field operations. It was therefore decided to use a system that would approximately equalise numbers of trees inventoried for three size classes: ≥5 to <20 cm, ≥20 to <40 cm, and ≥40 cm DBH.

In Nigeria the indicative inventory, carried out between 1972 and 1978, was based on point sampling in temporary plots. This did not allow for the repeated measurements needed to estimate tree increment. Therefore Dawkins (1980) recommended that a series of 1 ha permanent sample plots should be established throughout the reserved high forest estate, in order to monitor growth of the forest. He advocated that the plots should be demarcated clearly on the ground so they could be found afterwards, and so that trees measured on a previous occasion could be re-identified. The plots were to be square, and to be sub-sampled for smaller size classes of trees. However, it appeared excessively time-consuming to lay out plots in this manner, because of the need to demarcate all the boundaries. It was therefore decided to resort to a methodology formerly used in the Forest Research Department (now FRIN) to sample natural forest, and developed from the Malayan systems of milliacre and quarter-chain quadrats, in which only a transect line was marked on the ground. [The side of a milliacre quadrat approximates fairly closely to 2 metres and that of a quarter-chain quadrat to 5 metres]. The practice was to cut transects through the forest, laying poles at right-angles to the cut line. In the case of quarter-chain sampling, two poles 8.25 ft (c. 2½ m) long were laid either side the line. Three pairs of poles were employed at the same time, 16.5 ft apart down the line, and leapfrogged along it as sampling proceeded. It was also the practice to measure trees of exploitable sizes to a distance of 1 chain (c. 20 m) either side the line. This was because, generally speaking, 20 m is the greatest distance for more or less unobscured vision in natural tropical high forest.

During the late 1960s the author had developed methods for repeated sampling down fixed lines through natural forest (Bamgbala & Oguntala, 1973; Okorie & Olagunju, 1973). Trees ≥ 4 ft girth (c.40 cm DBH) were assessed to a distance of ½ chain (c.10 m) either side of the sampling line; trees ≥ 2 ft girth (c.20 cm DBH) to a distance of 1/8th chain (c.2½ m) either side the line; trees ≥1 ft girth (c.10 cm DBH) in every 4th ¼ chain quadrat; and established regeneration between ≥3 ft tall (c.1 m) and <6 ins girth (c.5 cm DBH) were sampled in milliacre quadrats to a distance of 0.1 chain on one side of the line. An advantage was that only the transect centre line need be demarcated, and only the DBH and/or distance of marginal trees from the centre line neeed be checked. Trees were recorded by species and by 1-inch girth classes (c.1 cm DBH) in ¼ chain (c.5 m) segments down the transect, and whether to the right or left of the line, so they could be re-identified during subsequent re-assessments. The boles were marked with scarlet paint at the point of measurement (usually breast height, i.e. 4 ft 3 ins or 1.3 m from the ground). Trees of listed (economic) species ≥ 2 ft girth (c.20 cm DBH) were also numbered in sequence with paint, and a stamped numbered aluminium tag, attached to a piece of galvanised wire, was nailed to each tree 3 ft (c.1 m) below the point of measurement. Inspection of these plots in 1984 showed that paint marks lasted at least 3 years, and the tags were mostly still in place after 20 years.

Field assessment

The dimensions adopted for monitoring plots were 40 m wide by 250 m long, that is 1 ha in area. Only the centre line was demarcated, by six concrete pillars at 50 m intervals along the line. The pillars were moulded in the forest, using sand from stream or river beds, and each measured 10 x 10x 50 cm. They were half-buried in the ground, capped with cement, and incised with numbers for the plot/sequence of the pillar down the line, e.g. for plot No.45 - [45/0], [45/1], [45/2], [45/3], [45/4], [45/5]. The cap was covered with a large leaf to protect it until the cement set. Plot stratification was based on the existing sub-division of reserved high forests into contiguous mile-square compartments (2.59 km^2) for the purposes of forest management in Ogun, Ondo, Oyo and Bendel States. Two plots were laid down in each compartment, at right angles to a base-line formed by the boundary between compartments. They were placed at intervals of 800 m (approximately ½ mile) down the base-line and offset 50 m from it. The position along the base-line of each plot was shown by a pillar capped with the plot number, e.g. [45]. The sampling intensity conformed with Synnott's (1979) recommendation of 0.772%. Systematic sampling was preferred to random sampling due to the need to find the plots for re-measurement at 2 or 3 year intervals after the forest may have been disturbed by exploitation. This still gives unbiassed estimates of stand volume and volume increment, and may be nearer the true value (i.e. smaller statistical error) than for random sampling - unless plots are positioned inadvertantly at spacings which coincide with some periodicity of the forest, e.g. for topography or felling cycle. [Today, random sampling may be more practicable because of the availability of hand-held instruments for ground positioning from satellites]. It is advantageous to stratify plots by compartments, as a compartment forms the unit for controlling exploitation.

During enumeration, a (specially manufactured) 50 m surveying chain was laid along each section of the plot centre-line sequentially[6]. Different diameter classes of trees were measured up to various distances from the centre-line, as follows:-

- ≥ 40 cm DBH to 20 m either side the centre-line
- ≥ 20 - <40 cm DBH to 5 m either side the centre-line

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[6] Because they are more robust, surveying chains were preferred to surveying bands.

- ≥ 5 - <20 cm DBH to 2.5 m either side the centre-line.

The 2.5 m and 5 m boundaries were determined by laying down 2.5 m poles at right-angles to the centre-line (see regeneration sampling below). The 20 m boundaries were not demarcated, but marginal trees were verified by offset from the centre-line using a measuring tape [See Fig. 1]. The DBH of the trees was measured to the completed cm using diameter tapes at 1.3 m from the ground (breast height); those buttressed above 1 m were measured at 2.5 m from the ground; and those buttressed to ≥ 2.5 m were measured at 30 cm above buttress. Trees too large, too misshapen or buttressed too high to permit satisfactory use of a diameter tape, were assessed with a standard Bitterlich relascope. Measurements of diameter at fixed heights were preferred as the author had previously shown a relationship to exist between diameters at fixed heights for individual species (Lowe, unpub.). A similar assumption is also made when constructing taper curves to calculate volume (see below). Bole heights were recorded in metres, and estimated by counting the number of 2 m sections to crown break.

The use of a strip plot, rather than a circular or square plot, increases the length of boundaries in relation to plot area, and hence also the numbers of marginal trees. In the present inventory, a tree is judged to be within the strip when the centre of the bole appears to fall on or within the margins of the strip. This can be deceptive, and if there is bias to include trees rather than to exclude them, wood volumes will be somewhat over-estimated. It has been suggested that more accurate results could be got if trees along the left-hand margins of the plot are only included where their boles (at breast height) fall entirely within the plot, and along the right-hand margins where any part of their bole (at breast height) is touched by the margin. This was not employed, because the area of the strip to the left of the centre line would then have been less than that to the right, as would also have been the relative numbers of trees contained either side of the centre line - which would have been inconvenient. The best system might be to include all trees (of the appropriate DBH classes) whose boles at breast height were touched at any point by either margin. This would, in effect, proportionately increase the area sampled for larger size classes - but this could easily be corrected by inserting appropriate correction factors for the various bole sizes into the plot calculations. However, this does not resolve the problem of root buttresses on the boles of larger trees, for species which have them. Buttresses were disregarded when deciding whether trees were inside or outside a plot. The plot margin should still touch the bole, though on such trees there is a tendency for the bole to taper from the top of the buttress downwards. However, the presence of buttresses was allowed for when making volume calculations.

Selected trees, less than 60 cm DBH and belonging to species in Sutter's utility classes 1, 2, 3, 4 or 5 (exploitable for timber[7]) and considered to be potential final crop trees, were measured more precisely with a steel tape to the completed mm of diameter. A few species in groups 7 and 8 were also included as selected trees, because they seem potentially exploitable; these include *Enantia chlorantha* and *Funtumia elastica*, which rarely exceed 40 cm DBH. All enumerated trees were marked with scarlet enamel paint, by means of a horizontal line at the point of measurement on the side of the tree facing the centre-line. Where diameter was estimated using a relascope, a diagonal cross was painted on the tree bole. In the case of selected trees, a sequence number was also painted on their boles at face height, and they were tagged with an aluminium label attached to 10 cm of galvanised wire, nailed to the bole 1 m below the point of measurement. This was marked with the

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[7] Utility classification (Sutter, 1979) --
A. Species utilised at present
1. Peelers and slicers for decorative veneers; 2. Peelers and slicers for utility plywood; 3. Saw wood for furniture and joinery; 4. Saw wood for heavy construction; 5. Saw wood for light construction; 6. Wood for handicrafts and specialised uses.
B. Species not utilised at present
7. Capable of reaching dimensions well over 40 cm DBH; 8. Rarely reaching dimensions over 40 cm DBH.

same number and also with the plot number, embossed using a hand-held "Dymo" machine. The wire was to allow for cambial growth.

Specially prepared field sheets were used for recording plot data. The information for each tree was entered on a separate line, both on the field sheets and in the computer files; trees were recorded sequentially in successive 5 m segments down the centre-line (numbered from 01 to 50).

The following convention indicated in which segment and sub-sampling strip a tree lay, and whether to the right or left of the line, regardless of diameter class :-

- 21 R 21st section, 5m to 20m strip, right side of centre line;
- (22 L 22nd section, 2.5 m to 5m strip, left side of centre line;
- (23)L 23rd section, 0m to 2.5 m strip, left side of centre line;

and so on. This facilitates identifying individual trees during subsequent reassessments. Each species was identified by a four-letter code, based on the generic and specific names, because it was less likely to give rise to booking errors than using numerical codes. [Experience showed that a more satisfactory range of codes could have been obtained with a six-letter alphabetic code, three for the initial letters of the genus and three for those of the species].

While a plot was being enumerated, the numbers of established regeneration for species in Sutter's utility classes 1 to 5 were recorded along the centre-line in contiguous 5x5 m quadrats, viz:- 1 or more regeneration

- 2 or more regeneration
- 5 or more regeneration
- 10 or more regeneration
- 50 or more regeneration.

Quadrats were demarcated by the 3 pairs of 2.5 m poles laid out at right-angles either side the centre-line, and at intervals of 5 m down the line, and leapfrogged along it as enumeration proceeded (Fig. 1). In each quadrat the species code was recorded for the sapling or pole considered most likely to reach final crop size. The regeneration was differentiated according to whether they were saplings ("sp") ≥1 m to <3 m high, or poles ("pl") ≥3 m high to <5 cm DBH. [It might be an improvement to lay quadrats entirely to one side of the centre-line, to reduce damage inflicted within the quadrat when the line was being cut through the undergrowth].

The slope of the centre-line, from pillar to pillar, was measured using a clinometer; sampling points were positioned at 25 m, 75 m, 125 m, 175 m and 225 m down the centre-line. At each point, standing basal areas were determined using a x2½ metric BAF prism, by counting all trees around the sampling point for which DBH equalled or exceeded the subtended angle. Soil samples were also taken at these points for laboratory analysis, using a standard Edelmann soil auger. The top soil was sampled from 0-15 cm, and the sub-soil down to 45 cm where this depth could be reached.

A team of 8 people could locate, demarcate and assess one plot in 3 days, or reassess a previously established plot in 1 day. Measurements proceeded down both sides of the centre-line simultaneously. Each enumeration team was composed as follows:-

- 1 booker
- 2 measurers
- 2 chain/offset men
- 2 paint men

- 1 tree marker/ladder man.

The ladder man carried a 2 m long aluminium ladder for measuring buttressed trees, and was also responsible for embossing and attaching tags to the selected trees. An expert tree identifier assisted with naming tree species, and collected specimens of doubtful species for identification in the herbarium. The size of the team was influenced by the amount of equipment, and the distances this had to be carried through the forest.

Plots were measured in the dry season (December-April) when tree cambia are less active. Plots were normally reassessed after a lapse of two years; paint marks were renewed at the same time, and pillars or tags that had disappeared were replaced. It is unwise to leave plots longer than 3 years between measurements, because progressive flaking of paint makes it more difficult to identify the trees or points of measurement - although it should still be possible to re-establish a plot if at least two cement pillars remain intact. Computer print-outs from the previous assessment were carried into the forest during re-assessment. The print-out is double-spaced so that the new information can be written by hand immediately above each line of the previous data. This enables the booker to verify re-measurements against the previous assessment. [The data were subsequently entered into a computer file in the office, as described below; but today the same software could probably be used for a hand-held computer in the field]. Instructions for establishing and assessing plots were described in a specially prepared field manual.

Computer processing

The project was provided with an ICL multi-user multi-tasking microcomputer which had 512K RAM, 20 Mbyte hard disk, floppy disk drive, 3 work-stations, with both a dot-matrix and a daisy-wheel printer, and a UPS giving up to 3 hours running time in the event of mains electricity failure.

Initially the data were entered directly from field forms into computer files, using the WORDSTAR word processor in non-documentary mode. Later, a program FIELD was specially written in FORTRAN 77 for data entry. This could also be used to edit plot files -- although in the case of those that had been entered with a word-processor, their record lengths had first to be standardised with another program called REGDATA. A program HIFOR was written that transcribed plot files into printing files with a more explicit format, which was used double-spaced to re-assess plots in the field.

FORTRAN was preferred to BASIC as the programming language, because it is compiled and ran about 15 times faster using the same logic and input data. Moreover, FORTRAN has the advantage of being more standardised than BASIC for different machines. Spreadsheets were found to run slower and to be less reliable and less easy to use than specifically written FORTRAN programs. Complex spreadsheets seemed to be a source of errors that were appreciable, but not large enough to be obvious. This seemed to be due to the ways that the cells in spreadsheets interact - but was overlooked especially when using a series of integrated spreadsheets. This was discovered when employing spreadsheets to anticipate and to verify programs. However, when the calculations were made with a programmable pocket calculator, FORTRAN was found to have given correct results. [The author has since found other persons with similar experience]. FORTRAN programs also have the merit of being very fast and compact, especially after condensing the operating programs with the software PKLITE. In fact, all the source and operating files for the programs listed below, fit on a single double-density (720K) diskette.

The programs that prepare stand tables (see below) are run serially by the batch file HFM. This took 5 hours to process the data for a single 1 ha plot on the project 1984 ICL machine, 1 hour on a 1988 Olivetti 8086 laptop, but only 1½ minutes on a 1994 Olivetti 486 machine using a 2 Mbytes virtual D: drive (installed in RAM to contain data, *.HFM and *.EXE files). These stand tables displayed respectively the data for stem numbers, basal areas, volumes and volume increments; each table was analysed by species (listed in order of utility class) and by 10 cm DBH classes. Also needed are the input files SPPLIST.HFM, which lists species names and codes by utility classes, and TAPERFNS.HFM, which contains the coefficients to estimate volumes from Sutter's taper curves; they are adjuncts to data analysis and are written as text files in ASCII.

Other FORTRAN programs were written to process the data into utility classes, and to carry out analysis of variance to obtain statistical error. CHEKPLOT compares the earlier and later assessments of a plot, so that (where possible) corrections may be made before computing volume increment.

Name	Description of program
FIELD	Inputs field data for each plot into a file on hard disk.
REGDATA	Standardises record lengths, so that a plot file entered in ASCII by word processor can be edited with program FIELD.
HIFOR	Transcribes a plot file into a printing file, with suitable format for printing out; used double-spaced in the field for plot re-assessment.
CHEKPLOT	Compares 2 data files from separate assessments of a plot; indicates possible errors and their sources. Precedes the use of other programs to analyse increment.
TREVOL	For an individual tree of given species, DBH and bole length, employs Sutter's taper functions to estimate its bole volume.

Operated with batch file HFM:-

STANDTAB	From a plot file, outputs a stand table that classifies tree numbers by species and DBH with totals. Also outputs species list PLOTSPP.INT needed for other stand table programs.
STANDBA	From a plot file, outputs stand table for basal areas per ha, classified and totalled by species and diameter classes.
STANDVOL	From a plot file, outputs a stand table for volumes per ha, classified and totalled by species and diameter classes.
INCRMENT	From files for 2 occasions of plot assessment, for selected trees, outputs distribution of diameter increment on dbh, and conducts regression analysis. Also indicates possible errors.
CLASINCR	From files for 2 occasions of plot assessment, outputs a stand table showing volume increment per ha, classified and totalled by species and diameter classes.
VOLINCR	From files for 2 occasions of plot assessment, outputs volume increment treated in different ways to mitigate errors of measurement.

Other programs

LISTSPP	Precursor of SUMTABLE, to amalgamate species lists from any number of plots, ordered into utility classes.
SUMTABLE	Amalgamates stand tables of basal area, volume or volume increment, by utility classes for any number of plots, with totals.

TABCONV	Converts stand tables of tree numbers to a format suitable for amalgamation by the program SUMTABLE (as for basal areas).
UTILTAB	For single-plot outputs from SUMTABLE, prepares a file
UTILTAB.DAT	required as input for STATANAL.
STATANAL	From inputted file UTILTAB.DAT, calculates confidence limits for utility classes 1-2, 1-5 and 1-8 for plots stratified in pairs; also outputs tables for util. classes v. diam. classes and plots v. util. classes.

During processing, where probable errors in volume increment are detected during stand table preparation, the later measurement is regarded as more likely correct and a figure is substituted for the earlier measurement. In order to set this figure appropriately, six different ways for limiting gross errors in DBH measurement were compared by a program VOLINCR written in FORTRAN 77. Six methods tried were as follows:-

Method	Restriction of error
1	Total plot volume at 2nd assessment minus total plot volume at 1st assessment.

Or, during calculating and summating tree volumes over a 2 year period

2	Minimum DBH growth is set at -1.0 cm, and maximum at +5.0 cm.
3	Trees with DBH growth outside range -1.0 to +5.0 cm are excluded.
4	Trees with DBH growth outside range 0.0 to +5.0 cm are excluded.
5	Trees with DBH growth outside range 0.0 to +2.0 cm are excluded.
6	Minimum DBH growth is set at -0.5 cm; maximum DBH growth is set as follows:-

+0.5 cm for any species of a tree >130 cm DBH

+1.0 cm for any species of a tree >100 cm DBH

+5.0 cm for *Anthocleista, Macaranga, Musanga, Ricinodendron, Trema.*

+3.0 cm *for Antiaris, Alstonia, Bombax, Ceiba, Canthium, Celtis, Cleistopholis, Cordia, Khaya, Mitragyna, Nauclea, Phyllanthus, Pycnanthus, Terminalia, Trichilia.*

+1.0 cm for *Diospyros, Garcinia, Scottellia, Staudtia, Strombosia.*

+2.0 cm for all other trees of other species.

All the methods gave relatively consistent results, except sometimes when increment was got by subtracting total plot volumes, especially where plots had been exploited in the interim. Method 6 seemed most satisfactory and was therefore used by program CLASINCR to get stand-tables of volume increment.

It is necessary to limit measurement errors because volume increment is calculated for each tree by subtracting the volume estimate on one occasion of measurement from that on a subsequent occasion, and individual tree increments are aggregated to obtain volume increment per unit area. However the volume estimates for a tree, on each occasion of measurement, are separately liable to error. Because the volume of a tree is usually large compared with its volume increment, the proportionate effects of volume errors on those of volume increment are greatly magnified. Moreover, large trees are more susceptible to gross errors of diameter measurement than small trees, usually upwards, and their effects on cumulative volume increment for all the trees in a plot may be considerable, because linear measure is cubed when calculating volume. Generally, diameter increment is not closely correlated with bole diameter, and thus it was possible to set probable maximum increments for the various species; these were determined from the increments got with the more precise measurements made on selected trees (using the INCRMENT program), and by reference to previous experience.

Trees do not normally shrink more than about 0.5 cm in diameter unless suffering from water stress; and where they shrink more than this they are usually dying, or there has been an error of measurement. This knowledge was used to set a figure also to limit shrinkage. Where diameter increment or shrinkage is found to exceed the limits set for the particular species, then the computer programs automatically fix it at the permissible maximum; a substitute for the earlier DBH measurement is obtained by subtracting this figure from the later DBH measurement. When estimating volume increment, the substitute DBH is used to calculate tree volume on the earlier occasion. Measurement errors in the field are more likely to be biased upwards than downwards, as a slack or deflected diameter tape is the most likely source of error; and the risk is much greater for large trees. It means, of course, that volumes per ha are more likely to be overestimated than underestimated. However, volume increments are less affected in this respect as they are obtained from the difference between two volume measurements. For the purposes of preparing the stand table for volume increment, when a tree moves from one diameter class into another during the period between assessments, it is always placed in a diameter class based on the earlier measurement of DBH (or its substitute if such had been made). Trees dying or recruited during the period are excluded from the increment calculations.

Volumes are calculated using Sutter's taper functions (Sutter 1979). Sutter provides 50 different formulae, each applicable to different tree genera. Given the DBH of a tree, these formulae are used to calculate stem diameters overbark at 1 m intervals up the tree bole, beginning at 1 m below breast height or, for buttressed trees, at 30 cm below the point of measurement. Volumes are calculated using Smalian's formula for each 1 m bole section up to a top diameter of 5 cm or to crown break (i.e. recorded bole length) whichever occurs first. The taper functions were estimated by Sutter from data for trees ≥20 cm DBH. However, for twelve different species using data from Omo and Owan North Forest Reserves, Kanu (unpub.) showed they were accurate for trees down to 5 cm DBH. He found that volumes obtained using taper functions accounted for more than 98% of the variance for volumes obtained by direct bole measurements. Sutter reports that taper functions are applicable to the same species regardless of the trees' geographic location in Nigeria, and Kanu's results appeared to support this contention. It is clear that they describe the shape of a tree extremely accurately, although a disadvantage is that they cannot easily be used to calculate tree volumes without the aid of a computer. [Multiple regressions may need to be prepared with a computer, but afterwards a hand calculator can be used to estimate tree volumes. However different regressions may be needed for the same species in different localities, as was found in the Ghana inventory].

Initially, basal areas and numbers of trees were calculated after adjusting plot areas to the horizontal. However, for steeply sloping plots, this was found to give estimates of basal areas/ha grossly in excess of what could be expected. For example, Plot No.5 at Omo gave a basal area of 26.51 m^2/ha, when based on the actual superficial area of the plot; but after correcting for slope this became 42.11 m^2/ha (cf. Dawkins' 1958, pan-tropical mean for high forest of 35 m^2/ha). It appears that trees on steep slopes benefit from side-light reaching their crowns, as well as overhead light! Due to this, and to other similar experiences, it was decided not to adjust for slope.

The data were stratified by square-mile compartments, with two (1 ha) plots in each compartment. Statistical analysis was carried out by calculating separately the sums of squares of deviations for each of three size classes (5-20 cm, 20-40 cm and ≥40 cm DBH) viz: $\sum(y_1 - y_2)^2/2$. The pooled variance for these was got by adding the results together and dividing by (n-L), where n is the total number of plots and L the number of strata (i.e. compartments). This is divided again by n, square rooted to get standard error of MAI, and multiplied by 't' to obtain confidence limits. As the layout is systematic rather than random, the actual error may be less than this.

Results

The funds provided were modest, and therefore the intention was mainly to develop the necessary techniques and at the same time to range across the main forest types in the country, to get some idea of actual potential yields from the forest. Field work began in the 1984/1985 dry season and the project ended in 1989. Altogether, 95 plots were established: at Omo Forest Reserve in the south-west, Owan North and Sapoba Forest Reserves in the south-centre, and Oban Group and Cross River South Forest Reserves in the south-east of the country. The results are summarised in Tables 1 and 2.

Omo Forest Reserve (Ogun State) contains drier high forest on soils derived from basement-complex rocks; the annual rainfall averages c.1600 mm. The terrain is rolling, with occasional rocky outliers, and dissected by streams flowing into the River Oni along the eastern boundary of the reserve. Altogether, 33 km² of forest were sampled and 152 tree species identified, averaging 45.1 ±6.2 (σ) per 1 ha plot. At the second assessment, standing basal area averaged 26.60 m²/ha, and ranged from 18.63 to 36.66 m²/ha. All compartments sampled had been exploited during the previous 20 years, most within 10 years, and log removals were said to average 33 cu m/ha (J. Ball, pers. comm.). Some plots were re-exploited during the interim between the two occasions of measurement. In the 1950s the Reserve received Tropical Shelterwood System (TSS) operations: treatments to natural forest to favour regeneration and growth of economic species, when climbers and undergrowth were cut and shade-casting trees of non-economic species were poisoned with sodium arsenite solution, normally during the 5 years before exploitation. (At that time, 17 species were listed as merchantable).

A mean annual increment (MAI) overbark was obtained of 4.869 ±0.433 cu m/ha/yr at the 95% confidence interval (ranging between 2.468 and 7.325 cu m/ha/yr). Species in utility classes 1,2,3,4 and 5 (i.e. exploitable for timber) accounted for 45% of the increment, including 22.5% for veneer quality species (classes 1 & 2) and 22% for saw-wood species (classes 3,4,5). For exploitable species only, the MAI of standing bole volume was 2.182 ±0.307 cu m/ha/yr at the 95% confidence interval.

Average standing bole volume for the plots at the second assessment was 198.68 cu m/ha (ranging from 114.0 to 298.1 cu m); of this 54.5% belonged to species exploitable for timber, including 26.5% for veneer quality species. The correlation between plot MAIs and plot standing volumes ($r = 0.1871$) was not significant at the 0.05 probability level. For trees ≥60 cm DBH, the average standing bole volume was 68.96 cu m/ha of which 76.25% belonged to species merchantable for timber, including 42.25% for veneer quality species. For trees of unexploited species (utility class 8) the average standing volume was 90.60 cu m/ha, nearly half belonging to species not commonly exceeding 40 cm DBH.

Owan North Forest Reserve (Bendel State) is to the north-east of Benin City and contains drier forest on sandy sedimentary soils underlain by basement-complex material. The terrain is exceptionally broken, and intersected by steep-sided ravines cutting down to the basement-complex. Owing to the difficult terrain, the forest has not received Tropical Shelterwood System treatments (see Sapoba) and is only now being exploited, so that most of the 14 km² sampled is probably primary forest. 135 tree species were identified, and averaged 48.0 species ±8.4 (σ) per 1 ha plot. The species composition resembled that at Sapoba (see below) with 105 species in common, though the forest at Owan is less diverse [cf. 89 species in common with those at Omo]. The main difference from Sapoba was the larger number of species in utility class 7 (i.e. unexploited species growing to sizes well over 40 cm DBH).

The average volume MAI was 4.204 ±0.839 cu m/ha/yr at the 95% confidence interval, of which 60% belonged to exploitable species (i.e. utility classes 1-5), including 27.25% veneer quality species (classes 1 & 2) and 32.5% saw-wood species (classes 3-5). The standard error of ±0.3427 is greater than for Omo (±0.2007) perhaps because fewer plots were sampled and due to inconsistencies in stratification because, although most compartments sampled were in primary forest, parts of more accessible compartments (e.g. plots 72, 61, 67) had been exploited. For exploitable species only, the MAI was 2.519 ±0.716 cu m/ha/yr at the 95% confidence interval. At the second assessment, the standing basal area for all plots averaged 27.46 m²/ha, and ranged from 17.83 m²/ha to 36.02 m²/ha. Despite less disturbance to the forest, the results resemble those for Omo.

Average standing bole volume was 223.43 cu m/ha from which 70.5% belonged to exploitable species, including 31% veneer quality species and 39.5% saw-wood species. The correlation between plot MAIs and standing volumes ($r = 0.5471$) was significant at the 0.10 probability level but not the 0.05 level. For trees ≥60 cm DBH, average standing volume was 123.10 cu m/ha of which 86% belonged to exploitable species, including 34.5% veneer quality species and 51.25% saw-wood species. For unexploited species (utility classes 6-8) the average standing volume was 66.03 cu m/ha, of which 40% belonged to species that rarely exceed 40 cm DBH.

Sapoba Forest Reserve (Bendel State) is south-east of Benin City, and contains relatively moist forest on deep sandy freely-draining soils derived from sedimentary materials; the annual rainfall is c.2000 mm. The terrain is exceptionally flat and devoid of surface streams, and hence is readily accessible. Consequently it has a history of commercial exploitation going back to about 1900, and has been heavily exploited and re-exploited during the past 50 years. At Sapoba, Redhead (1960) recorded log removals of 51 cu m/ha. The primary forest was formerly exceptionally rich in merchantable species, growing to large sizes, some attaining bole dimensions well above 200 cm DBH. The area is floristically rich: 162 tree species were identified by the project, averaging 56.4 ±9.9 (σ) species per 1 ha plot. In the 1950s, this part of the reserve received Tropical Shelterwood treatments. "Taungya" farms are encroaching into the area, where peasant cultivators clearfell and burn the natural forest for conversion to timber crop plantations. Initially the farmers raise arable crops for 2 or 3 years until the planted trees close canopy. Unfortunately, in many instances nowadays, the trees remain unplanted or fail due to neglect. Parts of the area were also vulnerable to illegal felling. The distribution of trees through the size classes is remarkably similar to that at Omo.

Average MAI was 6.498 cu m/ha/yr, made up of 62% exploitable species (i.e. utility classes 1-5), 31.5% veneer quality species (classes 1,2) and 30.5% saw-wood species (classes 3-5). The 95% confidence interval for average MAI was ±1.263 cu m/ha/yr; the standard error of ±0.5669 is high, perhaps due to inconsistences in stratification caused by "Taungya" encroaching into some compartments, to occasional gantry sites, or to destructive exploitation by illegal fellers in accessible forest. For exploitable species, the MAI was 4.036 ±0.885 cu m /ha/yr at the 95% confidence interval. At the second assessment, standing basal area of the plots averaged 24.94 m²/ha, and ranged from 13.52 to 34.47 m²/ha.

In 1988, average standing bole volume was 194.0 cu m/ ha, of which 65.25% belonged to exploitable species, including 30.5% veneer quality species and 34.25% saw-wood species. The correlation between MAI and total plot volumes ($r = -0.1587$) was not significant at the 0.10 level of probability. For trees ≥60 cm DBH, the average standing volume was 69.1 cu m/ha, from which 80% belonged to exploitable species, including 26% veneer quality species and 54% saw-wood species. For unexploited species (classes 6-8) the average standing volume was 65.73 cu m/ha of which 34.5% belonged to species that rarely exceed 40 cm DBH.

Oban Group and Cross River South Forest Reserves (Cross River State) are in the south-east of Nigeria, and were not easily accessible to the rest of the country until the 1970s, when bridges were constructed over the Cross River at Ikom and at Itu. Extensive exploitation began relatively recently: the initial concession in Cross River North reserve being awarded to Brandler & Rylke in 1958, and in Oban Group Reserve to Oban Timbers Ltd. in 1962. The Oban forests are also exploited by pit-sawyers, who remove larger and more valuable trees by converting logs at felling site, and head-loading the planks up to 5 km to the nearest motorable road. Unfortunately, nowadays, they also use chain saws to saw up logs, resulting in considerable wastage. None of these natural forests has received silvicultural treatment. At Oban the rainfall is high, c.3000 mm annually. Consequently the terrain is often deeply dissected with steep slopes, and the soils, which are mainly derived from basement-complex rocks, are strongly leached. The project sampled 12 km² of forest on the east side of the reserve near Oban town, and 12 km^2 on the west side near Ojor. 171 species were identified, with a mean of 66.6 ±5.8 (σ) per 1 ha plot. The species spectrum of the Oban forests differs from the forests in the south-west and south-central parts of the country; there are only 79 species in common with the Omo plots and 94 with those at Sapoba. Hall (1981) drew attention to the relative richness in species of the Oban forests, and to the high frequency of disjunctions in species distributions between Oban forests and those west of the River Niger.

On the west side of the reserve the MAI was 4.158 ±0.935 cu m/ha/yr, and ranged between 2.927 and 5.754 cu m/ha; 27«% belonged to exploitable species (classes 1-5) and included 11«% of veneer quality species (classes 1-2). The standing bole volumes on the first occasion averaged 239.77 cu m/ha and ranged from 110.9 to 313.0 cu m/ha. Trees of exploitable species comprised 34.25% of total standing volume, including 12.25% veneer quality species. Trees ≥60 cm DBH accounted for 138.2 cu m/ha, and in several plots exceeded 150 cu m/ha; of these 47% belonged to merchantable species including 17% veneer quality species; an average of 49.3 cu m/ha belonged to utility class 7, i.e. that can reach sizes well over 40 cm DBH. Average standing basal area of the forest was 30.08 m^2/ha, and ranged from 16.64 to 36.98 m^2/ha.

On the east side of the reserve, the MAI was 2.602 ±0.283 cu m/ha/yr at the 95% confidence interval, ranging between 2.023 and 3.153 cu m/ha, and included 17.25% exploitable species, with less than 7% for veneer quality species. Standing bole volumes averaged 167.73 cu m/ha and ranged from 144.6 to 202.3 m/ha. Trees of exploitable species comprised 19% of total standing volume, with 9% veneer quality species. These plots lacked especially the higher diameter classes, and trees ≥60 cm DBH were only 49.61 cu m/ha, of which 19.11 cu m belonged to utility class 7. The standing basal area of the forest averaged 25.32 m^2/ha and ranged from 23.24 to 29.33 m^2/ha. There was no significant correlation between MAI and total standing volume at either of the sites ($r = 0.2694$ and $r = -0.3929$ respectively).

Cross River South Forest Reserve is further north in drier forest, and an area of 6 km^2 of the reserve was sampled. 117 tree species were identified, with an average of 62.6 ±9.5 (σ) per 1 ha plot. There were 59 species in common with Omo Forest Reserve, 77 species with Sapoba and 78 species with Oban (west). The standing bole volume averaged 223.69 cu m/ha, and ranged from 160.2 to 338.8 cu m/ha. Exploitable species accounted for 54% of the standing bole volume, including 25% veneer quality species. Trees ≥60 cm DBH averaged 99.40 cu m/ha, of which 74% belonged to exploitable species, with 29.5% veneer quality species. Standing basal areas averaged 26.94 m^2/ha and ranged from 21.76 to 34.69 m^2/ha. It was not possible to re-measure these plots, and increment data are not available.

Discussion

In general, it appeared that mean annual increment (MAI) for standing bole volume of natural tropical high forest, was about 5 cu m/ha/year for all trees ≥5 cm diameter at breast height (DBH). A half of this (c. 2.5 cu m) belonged to species exploitable for timber, including a quarter (c. 1.2 cu m) for both decorative and utility veneer-quality species. The standing bole volume of the forests ranged from 110 cu m to 340 cu m per hectare and averaged 220 cu m per hectare if Oban (east) is excluded. The increment of this forest is much poorer, with total MAI of only 2.6 cu m/ha/yr, which may reflect nearness to the Kwa River, due to shallow soils with rocky outcrops, and accessibility to pit-sawyers. The forest at Sapoba was richer in recognised timber species than the other forests, with total MAI of 6.5 cu m/ha/yr of which 4.0 cu m belonged to species exploitable for timber and 2.0 cu m to veneer quality species. The forests at Omo and Sapoba had been disturbed by Tropical Shelterwood System (TSS) operations and by repeated exploitation for timber. For undisturbed forests, it is probable that average standing bole volumes range between 200 and 400 cu m/ha, and Dawkins (1958) gives the pantropical mean for standing basal area as 35 mý/ha, to which Nigerian forests formerly appeared to conform. In the present study, standing basal areas ranged from 16^2/ha to 37 m^2/ha, and averaged about 27.5 m^2/ha.

Merchantable species generally grow to large sizes, and are commoner than non-economic species growing to similar dimensions: exploitable species are a greater proportion of the standing volume for trees ≥60 cm DBH than for trees ≥5 cm DBH. In forests sampled in the south-western and south-central parts of the country, the volume for exploitable species ≥60 cm DBH was 82% of the total volume for all trees ≥60 cm DBH; but for trees of exploitable species ≥5 cm DBH the proportion was 63% of total volume. For veneer quality species, the proportions were 35% for trees ≥60 cm DBH compared with 29% for trees of all size classes. However, in the south-east of the country, the proportions were 47% for trees of exploitable species ≥60 cm DBH compared with 34% for trees of all size classes; and for veneer quality species, 17% for trees ≥60 cm DBH compared with 12% for trees of all size classes.

Conversely, the proportion that unexploited species form of standing bole volume (38%) is lower in the south-west and south-centre of the country than in the south-east (66%) - excluding Oban (east) where the proportion is 81%. This is partly because, until fairly recently, forests in the south-east were relatively inaccessible so that timber merchants are not familiar with many of the species, although in fact they may be suitable for timber. Moreover it may be observed in the south-east that a high proportion of standing volume (40%) is in utility class 7, i.e. unexploited but growing to sizes well over 40 cm DBH. This compares with 21% for forests sampled in the south-west and south-centre, which have longer histories of exploitation. Poga oleosa is a species in class 7 which is currently felled for timber in the Oban Reserve, although it is valued locally as a food source because of its oily nuts.

There was generally no significant correlation between volume increment and standing bole volume of the forest. This suggests that natural forest is robust, and has withstood well the previous intensities of exploitation, with log removals of about 35 cu m/ha, which may be equivalent to about 50 cu m/ha for standing bole volume[8]. It seems that reducing standing basal area (or volume) enhances the increment of the remaining trees, which compensates for the smaller number of trees on which growth can occur. For non-economic species, volume increment accounted for 44% of the total stand increment, whereas their bole volume is only 36% of the total standing bole volume. Exploitable species still amount to 66% of the total standing bole volume in the forest at Sapoba, and 54% at Omo, which is more than expected and gives little indication that, at historic felling intensities, the forests were being rapidly degraded by selective exploitation.

About 12% of the total standing bole volume at Sapoba, and 20% at Omo, consisted of smaller trees belonging to species that rarely exceed 40 cm DBH. These are generally either slow-growing such as *Diospyros, Picralima*, and *Xylopia*; or fast-growing but short-lived species such as *Macaranga, Musanga* and *Trema*. The former are to some extent cut or knocked down during exploitation, whereas the latter regenerate where exploitation (or farming encroachment) has drastically opened the forest. The fast-growing weed trees may persist for perhaps ten or fifteen years afterwards. Farming or excessive exploitation can also result in extensive thickets of the shrubby weed *Chromolaena odorata* (Eupatorium), an exotic which invaded the high forest zone in the 1960s, and which suppresses tree regeneration. Felling cycles should be long enough to allow senescence and shading out of fast-growing weeds - perhaps at least 20 years - but short enough so that exploitable trees are not lost due to over-maturity. Economic species are forest emergents and many of them, maybe a majority, have small or wind-dispersed seeds: e.g. *Terminalia, Triplochiton* and the mahoganies (except Guarea spp.) have winged seeds; and *Nauclea* and *Milicia* (syn. *Chlorophora*) have fine seeds which are dispersed by rodents, birds or bats, and germinate on exposed mineral soil. Small seeds contain little food reserves, and may need exposure to light to germinate, and therefore

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[8] Knuchel (1953) distinguishes the unit of standing volume as the "Silve" and reserves the term "cu metre" for actual felled volume removed as logs. This avoids confusion between the two measures.

depend on disturbance of the forest to regenerate. Formerly, subsistence agriculture with shifting cultivation could have been responsible for this, by causing small impermanent clearings in the forest (Lowe 1991). Controlled exploitation for timber could well have a similar effect.

Another question, is whether the forests at Omo and Sapoba benefited from TSS operations in the 1950s, which were not applied to forests in the south-east. This cannot be answered confidently, as silvicultural investigations at the time were designed unsatisfactorily (Lowe 1978). Furthermore, what may appear successful in an experimental plot can prove unsuitable on a management scale. The available information suggests that TSS treatments did improve the amount of regeneration, but insufficiently for potential economic returns to justify the expense. In the present study 104 species are listed as exploitable; but during the 1950s only 17 species were regarded as economic, and all other tree species were liable to be poisoned during TSS operations, or cut down if they were saplings or poles. Moreover field work was conducted by contract gangs, or by general forestry labour, who were also liable to poison or cut down economic species during the various silvicultural operations! At that time, the felling cycle had been fixed at 100 years, and TSS was intended primarily to promote the regeneration of economic species, rather than to enhance the growth of existing trees or of advance regeneration. Poisoning operations generally removed between a third and two-thirds of the standing basal area; and in an attempt to augment the quantity of regeneration, poisoning tended to become increasingly drastic. This resulted in proliferation of herbs and climbers, which swamped tree seedlings and formed climber towers on surviving trees. Today, it is doubtful if poisoning extensive areas of forest would be acceptable, especially with anything so lethal as sodium arsenite. Hormonal arboricides are less effective, more expensive, and nowadays also tend to be regarded with disfavour.

If the MAI for exploitable species is taken as 1.5 cu m/ha/yr at the lower confidence limit, then for sustainable yield it should theoretically be safe to fell up to 37.5 cu m/ha each year on a 25-year felling cycle. However sustainability depends on the existence of enough trees of merchantable sizes. If none are available then none can be removed. Again in theory, if this figure represents the entire stock of economic species of merchantable sizes within the annual coupe then, after felling them, the merchantable stocking would be reduced to zero. If it is the actual sustainable yield then, during the succeeding felling cycle, the stocking of merchantable trees is progressively restored to the original level of 37.5 cu m. In these circumstances, the average merchantable stocking for the whole forest is:- (0.0 + 1.5 + 3.0 + 4.5 + 6.0 + ... + 37.5)/25 = 37.5/2 = 18.7 cu m/ha. That is, the average exploitable yield for the whole forest would be a half of that found in the current annual coupe before exploitation. This assumes that the forest is "normal". If this is not the case, the other extreme is where merchantable trees are spread evenly over the whole forest, as might occur in previously undisturbed forest. In this situation the average standing bole volume of merchantable trees will be the same in the annual coupe as for the rest of the forest and it may be desirable to enlarge the size of the annual coupe, to raise minimum felling girths, and to allow a greater volume of log removals in order to reduce the risk of losing trees due to their becoming over-mature before they are scheduled for felling. It follows for most forests, especially where previous exploitation has been haphazard, that the volume of merchantable trees lies somewhere between the two extremes.

At Omo, the average standing bole volume for trees of exploitable species ≥60 cm DBH is 52.6 cu m/ha, at Owan North (mostly primary forest) 105.9 cu m/ha, at Sapoba 56.5 cu m/ha, and at Oban West 63.2 cu m/ha (but 112.5 cu m if class 7 species are added). However, allowance is not made for including over-mature trees. At Sapoba the MAI for exploitable species is 3.1 cu m/ha /yr at the lower confidence limit, and almost double the yields sustainable at Omo and Owan should be theoretically possible. The compartments sampled at Sapoba are close to the forestry camp, and either TSS operations were carried out more assiduously than elsewhere; or (very probably) it reflects the greater richness of merchantable species in this forest in former times.

It is possible to estimate the tree volumes currently available for exploitation. However, the permitted cut is more easily regulated by minimum DBH limits for exploitable trees, than by volume of logs removed or numbers of trees felled, which are much more difficult to inspect and control. Minimum DBHs may be set by calculations based on a detailed inventory of the forest prior to exploitation, and using the cumulative standing bole volumes of the larger trees. Nevertheless, it may be desirable to set absolute minimum DBH limits, below which felling is not permitted regardless of the estimated allowable cut. In species valued for their decorative woods, the heartwood is coloured whereas the sapwood is white; moreover sapwood is usually less durable than heartwood. Larger trees also put on proportionately more wood than smaller trees for the same diameter growth, and it is therefore preferable to exploit such trees at larger dimensions. This is true particularly for the mahoganies, where large trees may continue to grow quite fast, and large logs are relatively more valuable than logs of smaller diameters.

Existing forestry rules set the minimum exploitable DBH at 80 cm for species giving decorative veneers and cabinet woods, and 60 cm for most other species; however the regulations are often disregarded, and trees of valuable species may be felled down to 30-40 cm DBH. Species such as *Enantia chlorantha, Funtumia elastica* and *Strombosia pustulata* do not grow to large sizes, and require a lower minimum girth for exploitation of perhaps 40 cm DBH. Whether using different DBHs for different species, as indicated, or taking all trees of exploitable species ≥60 cm DBH, in both cases the calculations gave similar volumes available for exploitation at Omo. However small diameter logs require different equipment, such as frame (i.e. gang) saws, to saw them efficiently. These saws are more expensive to install than the band saws generally used to break down larger logs.

It appears, from the above, that the forests at Omo and Owan could sustain log removals from the annual coupe of up to 35 cu m/ha on a 25-year felling cycle. At Sapoba the forest could probably support heavier exploitation, perhaps 50 cu m on a 20-year felling cycle. In theory the forests might withstand removals of at least twice these amounts, but it is necessary to regulate felling so that damage is restricted and the capital base of the forest is not endangered. The regeneration of economic species is fostered by the presence of mother trees, and valuable increment may accrue on larger trees of exploitable species. Moreover the felling cycle must be long enough to suppress the growth of weed species. A compromise must be struck between what the forest is capable of yielding theoretically, and what is silviculturally practicable. This can only be resolved by continued monitoring of the forest, and by well-designed field investigations.

It is therefore tentatively recommended that selective exploitation of natural forest should be on a 25-year felling cycle, and that an average of not more than 50 cu m of the standing bole volume should be felled within the annual coupe. Pre-exploitation inventories should be carried out by the forest managers to set minimum DBH limits for exploiting the various utility classes of trees within the coupe. In the case of forests in the south-east, some of the species in utility class 7 ought to be reclassified on the basis of timber characteristics. It is not recommended that any purely silvicultural operations are carried out; but the condition of the forest should be continually monitored by means of 1 ha sample plots, and these extended to all forest reserves being managed for production, so that deterioration in merchantable content of the forest may be quickly detected. It is perhaps inevitable that, as a result of successive exploitations, progressive changes will occur in the composition of exploitable species, but this will have to be accepted. The present monitoring exercise appeared to show that, in the compartments sampled, Triplochiton scleroxylon had become relatively uncommon. Formerly it was the main source of export timber, and in the drier high forests was commoner than all other economic species together. Attempts to induce natural regeneration of Triplochiton have met with little success, though methods of artificial regeneration were developed by Howland & Bowen (1977). If it is desired to maintain production of this species, it may be necessary to grow it in timber crop plantations.

In Nigeria, the present situation is that none of the high forest reserves are being managed under working plans. Over-exploitation proceeds to an extent that destroys the recuperative capacity of the forests. This extends also to secondary forest produce, such as chew sticks, medicinal barks, wrapping leaves, spices etc. that are garnered in the forest. These are removed wholesale on a commercial basis, often with little restraint. Unless something is done fairly quickly there is a risk that the entire resource base of the forests will be destroyed. Whether or not it is an ecological disaster, for many people this would certainly be an economic catastrophe. The need to import materials for building and furnishing houses would be greatly increased, and would result in substantial rises in costs of house construction and rents. This eventuality is no longer remote, because the timber resources of the country are already near the brink of exhaustion.

Nevertheless, the proportion that exploitable species comprise of the total standing bole volume of natural tropical high forest, and their annual volume increment, are higher than the author had anticipated. Indeed the potential yield compares with that achieved by some forestry plantations.

The operations needed to manage natural forest on a sustainable basis are probably few and cheap, and therefore this resource would appear well worth preserving in a productive condition. Indeed, if $1\frac{1}{4}$ million ha of high forest reserves are available for exploitation, then a yield of 35 cu m/ha of logs on a 25-year felling cycle gives a global annual yield of 1.75 million cu m of roundwood. The most urgent needs are to prepare working plans for the proper control of forest exploitation and regeneration, and to revise land tenure and fiscal arrangements in order to promote the planting of forestry crops on lands outside forest reserves.

B. Growth Studies in Tropical Moist Forests

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B. Growth Studies in Tropical Moist Forests

Session III: *Chair: Mr. Chemist Gumbie*

Growth patterns and composition trends in mixed evergreen forests in South Africa

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Abstract

Thirteen long-term growth study sites were established since 1987 in seven forest areas throughout the distribution range of mixed evergreen forest in South Africa. The forest areas covered a latitudinal gradient from 23°S to 34°S. In each area, one to four plots were established along a local altitudinal or soil gradient. Actual plot shape ranged from a triangle to a rectangle, and plot size from 0,48 to 2,86 ha. Each plot was sub-divided into 10 m x 10 m sub-plots. The species and diameter at breast height (DBH), of all stems ≥ 5 cm DBH, were recorded for each sub-plot during establishment of a plot. All plots have been remeasured after five years and a start has been made with the second cycle of remeasurement. Data of all plots have been analysed for species richness per sub-plot and plot; stand basal area and stem diameter distribution per plot; diameter and basal area growth, ingrowth from regeneration and mortality. Annual basal area increment ranged from 0,7% to 1,9% of stand basal area. Two approaches were followed in attempts to model growth response. The first approach was to relate statistically the gross increment at a site to abiotic site factors (GROdays - an index of plant water availability; and GROtemp - an index of physiological temperature). Basal area growth was not related to the availability of water to the stand, or to the mean growing-period temperature, or to soil parent material. The second approach was to apply a Lefkovitch matrix method to project the demographic trends in stem size. The simulation showed that the size-class distribution of the stands was very nearly in steady state. The intention is to apply results of this exercise to forest inventory data to do yield regulation and stand development projections for sustainable timber harvesting from the forests.

Keywords: *Biodiversity, forest, growth, modelling, structure.*

1. Introduction

Regulation of timber yields requires reliable estimates of growth of stands and species to keep the timber harvesting levels at or below the production potential of the forest. In the mixed evergreen forests yield regulation also requires an understanding of initial species composition, natural changes in growing stock due to growth, ingrowth and mortality, and community processes of disturbance and recovery. In South Africa, the indigenous forest resource is extremely small, i.e. a mere 3 000 km^2 or about 0.08% of the land surface. The forests are therefore principally managed for their conservation value, and very valuable timbers are harvested only from small areas. A conservative single-tree selection system is practised to harvest the timber from the southern and eastern Cape forests (Seydack 1996; Seydack et al 1996).

A set of long-term study sites were established in the South African indigenous forests since 1987.

The objectives of the plots were i) to provide data on recruitment, growth and mortality in order to improve the yield regulation for sustainable timber harvesting; ii) to develop an understanding of forest dynamics for practical application, such as comparative growth rate and mortality of individual species over diameter classes in different areas, and of the potential sizes of species in different areas; iii) to enable modelling of forest change; and iv) to develop scenarios on the impacts on the forest of different resource management systems. Several papers and reports described the composition of the plots, results from the first remeasurement after five years, and results of specific analyses (Geldenhuys 1993, 1994a,b, in press; Geldenhuys & Rathogwa 1995a,b,c; Geldenhuys & Van Daalen 1992; Van Daalen 1991, 1993a,b,c; Van Daalen & Shugart 1989).

Most often forest inventory data are used to calculate only the standing growing stock (volume/ha) of useful species. I believe that resource utilisation and biotic diversity of the forests can be sustained if the products and values are utilised in relation to the growth potential of the site, and the essential ecological processes of disturbance and recruitment to which the component species are adapted. The inventory data can be used to determine the species composition of the communities. The form of the stem diameter distribution of individual species across the communities can indicate the ecological behaviour of a species in relation to the typical disturbance regime of each forest community (see Figure 1). I have shown elsewhere that appropriately collected forest inventory data can give a good first approximation for development of a silvicultural system which is in tune with the requirements of the dominant species (Geldenhuys 1996). For example, analysis of the forest inventory data showed that mixed evergreen forest on the coastal platform in the southern Cape is fine-grained, i.e. the composition of the canopy and regeneration is very similar. By contrast, mountain forest is coarse-grained, with the canopy consisting of species responding to larger disturbances for regeneration, and the regeneration composed of several shade-tolerant species of the canopy of mature forest. Stem diameter distributions of the more common canopy species showed typical inverse J-shaped curves for those dominating the fine-grained forest, i.e. the curves are typical for shade-tolerant species expanding their population size in closed forest. The two common canopy species in the mountain forests have bell-shaped diameter distributions, indicative of a pioneering population in maturing regrowth forest. The preferred management system would be a single-tree selection system with small gaps for the coastal platform forest, and a group selection system with large gaps for the mountain forests.

The next step in development of a suitable forest management system is to base yield regulation on the growth and mortality patterns of the population stem diameter distributions of the important tree species.

The objectives of this paper are to:

i) describe the procedures used in the establishment and maintenance of the plots;
ii) summarise results obtained from the routine data analyses of the first remeasurements;
iii) present results from the initial approaches to modelling growth of the forest and to indicate the needs for future developments.

In the context of this study the following terminology will be used with reference to the location of the study:

Forest area:	a forest complex with a specific species composition in a specific landscape;
Site:	a relatively uniform area in terms of soils, aspect and slope in a particular forest community;
Stand:	A stand of trees of a particular forest community occurring on a uniform site;
Plot:	The demarcated area on a particular site on which the trees are measured;
Sub-plot:	A 10 m x 10 m sub-division of the plot (see Methods).

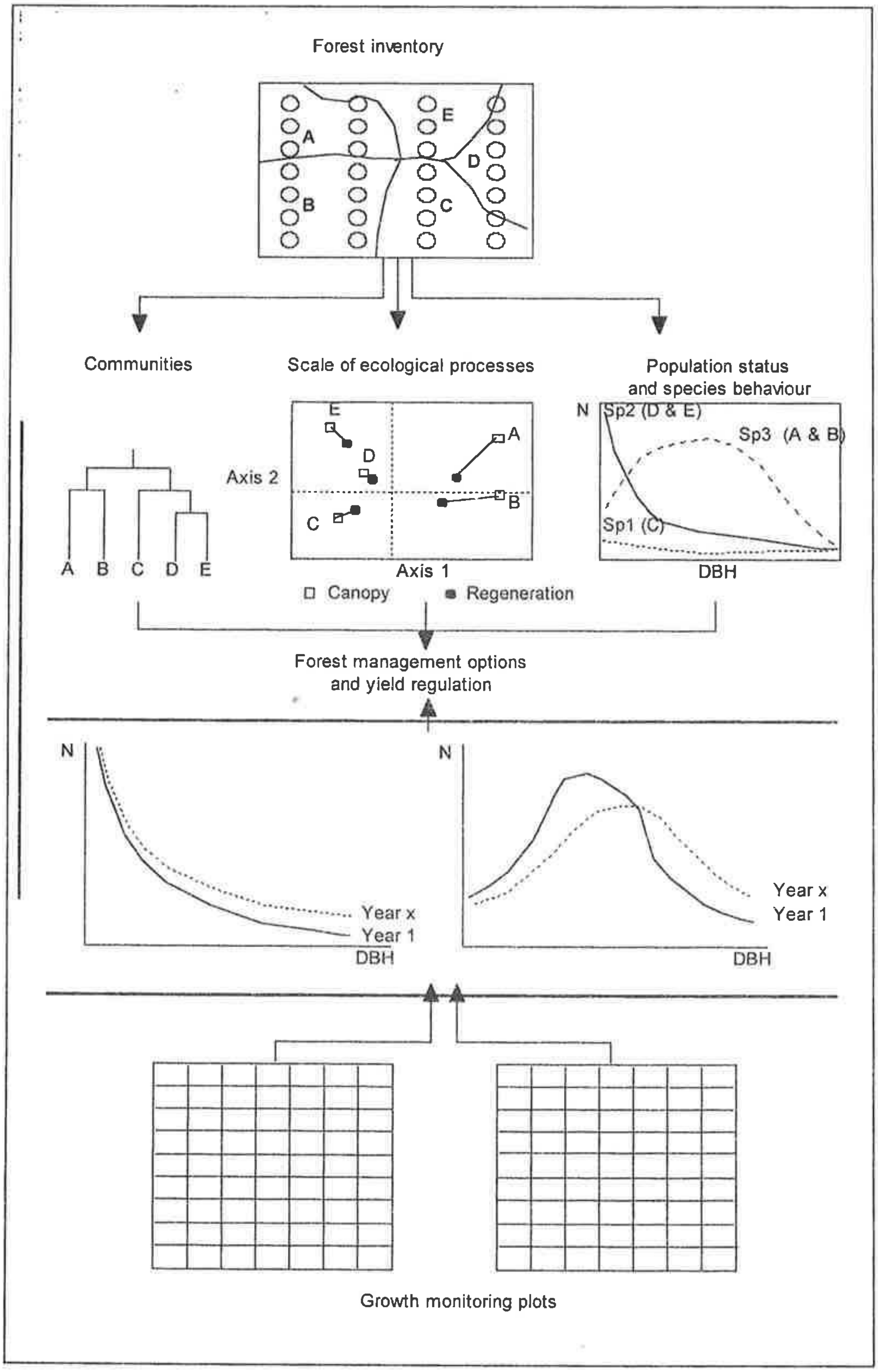

Figure 1: Relationship between information that could be obtained from a forest inventory and the growth patterns of important species to develop forest management systems and yield regulation options.

2. Study area

Mixed evergreen forests in South Africa occur in a narrow, disjunct zone along the eastern escarpment and the Indian Ocean coast line, from the Cape Peninsula at 34oS and 150 m above mean sea level [a.s.l.] to about 23oS and 1 380 m a.s.l. in the Soutpansberg mountains and 27oS along the KwaZulu/Natal coast. Annual rainfall (mm/annum) varies from about 2 000 and summer rain in the Soutpansberg, to about 1 200 and all-year rain along the southern Cape coast, to about 1 400 and winter rain in the south-western Cape. Forests still occur in areas with annual rainfall down to 700 mm in the summer rainfall areas, and 500 mm in the all-year and winter rainfall areas. Seven forest areas were selected for the study to cover this latitudinal gradient from the Cape Peninsula to the northern Transvaal (Table 1).

3. Methods

3.1 Plot layout

Between 1987 and 1989, 13 long-term plots were demarcated in the seven forest areas (Table 1): Cape Peninsula, southern Cape and Tsitsikamma coastal platform, Amatole Mountains, Transkei coast, North-eastern Transvaal Escarpment, and Soutpansberg Mountain. In each area one to four sites were selected to cover a local altitudinal gradient.

Ideally a square plot of 80 m x 80 m (0.64 ha) had to be established in each site, in a generally homogenous stand. However, the shape and size of some plots were adjusted to fit local homogenous site conditions, or to provide for specific additional studies. Actual plot shape ranges from a triangle to a rectangle, and plot size from 0.48 to 2.86 ha. For example, the Orange Kloof plot shape was determined by the small uniform area and absence of forest above the slope. The Diepwalle plot was much larger and sampled in more detail to study the effects of competition on tree growth (Van Daalen 1993a). Each plot was sub-divided into 10 m x 10 m sub-plots, each identifiable by a unique alpha-numeric number.

3.2 Data collection

On each sub-plot all stems ≥ 5 cm DBH (diameter at breast height, i.e. 1.3 m above ground level) were given a number and a painted band for repeated measurement. In the case of multi-stemmed trees, each individual stem ≥ 5 cm DBH was marked and measured. The following parameters were recorded for each stem: sub-plot, stem number, species, DBH.

During the second re-measurement, as in the case of the 1996 re-measurement of the Amatole plots, the crown position of each tree is indicated according to the following scoring system:

1	No direct light. Crown entirely shaded vertically and laterally
2	Some side light. Crown shaded vertically, but some direct side light (from gap or edge)
3	Full or partial overhead light. Crown adjacent to other crowns and partly to fully exposed vertically.
4	Emergent. Crown fully exposed vertically, and free from lateral competition from other crowns.

Table 1 List of plots for the long-term study of diameter growth, ingrowth and mortality in mixed, evergreen forest in South Africa. The forest areas (A - G) are indicated for each plot

Site	Grid reference	Altitude m	Rainfall mm season	Geology	Aspect & slope	Forest description	Plot size, ha	Date	
								Established	Remeasured
Orange Kloof- Cape Peninsula (A)	34°00'S, 18°24'E	150	1350 winter	Granite	Gentle, southerly	Species poor (14 tree species), regrowth forest, dominated by Cassine peragua, Olinia ventosa, Olea capensis subsp. capensis, Canthium inerme, Rapanea melanophloeos, Diospyros whyteana and Olea europaea subsp. africana. Open understorey. Canopy 12 to 18 m high.	0.52	12/1988	12/1993
Diepwalle - Knysna (B)	33°56'S, 23°09'E	300	1220 all-year	Quartzite	Gentle, northerly	Mixed forest (27 tree species), dominated by Olea capensis subsp. macrocarpa, Podocarpus latifolius and Curtisia dentata in the canopy, and Gonioma kamassi and Cassine papillosa in the sub-canopy. Dense, 4 m high understorey of Trichocladus crinitus. Canopy 18 to 22 m high.	2.86	05/1987	09/1992
Koomansbos - Tsitsikamma (C)	34°01'S, 24°03'E	190	1030 all-year	Shale	Flat, plateau	Mixed forest (33 tree species), dominated by Olea capensis subsp. macrocarpa, Podocarpus latifolius, Brachylaena glabra, Pterocelastrus tricuspidatus, Olea capensis subsp. capensis and Apodytes dimidiata in the canopy, and *Gonioma kamassi* and Burchellia bubalina in the sub-canopy. Sparse, 4 m high understorey of Trichocladus crinitus. Canopy 18 to 22 m high.	0.65	08/1988	08/1993
Witelsbos - Tsitsikamma (C)	33°59'S, 24°06'E	220	1165 all-year	Quartzite	Flat, plateau	Mixed forest (25 tree species), dominated by Platylophus trifoliatus, Ocotea bullata and Podocarpus latifolius in the canopy, and Gonioma kamassi in the sub-canopy. Sparse to dense, 2 to 3 m high understorey of Trichocladus crinitus. Canopy 20 to 24 m high, with gaps.	0.64	08/1988	08/1993
Pirie - Amatole (D)	32°44'S, 27°17'E	580	890 summer	Mudstone, shale & sandstone with dolerite intrusion	Flat, valley bottom	Mixed forest (43 tree species), dominated by Olea capensis subsp. macrocarpa, Podocarpus falcatus, Mimusops obovata and Nuxia floribunda in the canopy, and Trichocladus ellipticus and Canthium inerme in the sub-canopy. Open understorey. Canopy 17 to 22 m high	0.64	02/1987	10/1991 10/1996
Isidenge - Amatole (D)	32°40'S, 27°16'E	920	1035 summer		Flat, valley bottom	Mixed forest (37 tree species), dominated by Rhus chirindensis, Olea capensis subsp. macrocarpa and Xymalos monospora in the canopy, and Trichocladus ellipticus and Diospyros whyteana in the sub-canopy. Open understorey. Canopy 20 to 25 m high	0.64	02/1987	10/1991 10/1996
Sandile Kop - Amatole (D)	32°38'S, 27°16'E	1160	1100 summer		Gentle, ridge top	Mixed forest (38 tree species), dominated by Olea capensis subsp. macrocarpa, Scolopia mundii, Xymalos monospora and Podocarpus latifolius in the canopy, and Trichocladus ellipticus, Diospyros whyteana and Maytenus heterophylla in the sub-canopy. Grassy understorey. Canopy 20 to 25 m high.	0.46	02/1987	10/1991 10/1996
Kologha - Amatole (D)	32°32'S, 27°21'E	990	965 summer		Gentle, southerly	Mixed forest (36 tree species), dominated by Olea capensis subsp. macrocarpa, Rapanea melanophloeos and Vepris undulata in the canopy and Trichocladus ellipticus, Diospyros whyteana and Maytenus heterophylla in the sub-canopy. Open understorey. Canopy 18 to 25 m high.	0.80	02/1987	10/1991 10/1996
Manubi - Transkei (E)	32°25'S, 28°30'E	275	1220 summer	Dolorite	Gentle, northerly, on plateau	Mixed forest (44 species), dominated by Chionanthus peglerae, Strychnos mitis, Drypetes gerrardii, Olea capensis subsp. macrocarpa, Vepris lanceolata and Syzygium guineense subsp. gerrardii in the canopy, and Bequartiodendron natalensis, Allophylus dregeana, Diospyros natalensis and Tricalysia lanceolata in the sub-canopy. Dense to sparse understorey of tall Trichocladus crinitus. Canopy 20 to 25 m high	0,64	10/1988	10/1995
Patatasbos - N-eastern Tvl escarpment (F)	23°51'S, 30°00'E	1480	1215 summer	Granite-gneiss	Gentle, easterly	Mixed forest (28 tree species), dominated by Syzygium guineense subsp. gerrardii, Xymalos monospora, Cryptocarya liebertiana and Cassipourea malosana in the canopy, and Tricalysia capensis in the sub-canopy. Open understorey, with scattered clumps of bamboo Prosphytochloa prehensilis. Canopy is 20 to 24 m high	0.64	07/1989	07/1994
Hellschebos - N-eastern Tvl escarpment (F)	23°48'S, 30°00'E	1350	1695 summer		Steep, easterly	Mixed forest (25 tree species), dominated by Xymalos monospora, Cassipourea malosana, Combretum kraussii, Cryptocarya liebertiana and Ficus craterostoma in the canopy, and Rinorea angustifolia, Rothmannia capensis and Ochna arborea subsp. oconnorii in the sub-canopy. Open understorey. Canopy 15 to 25 m high with gaps.	0.64	07/1989	07/1994
Grootbos - N-eastern Tvl escarpment (F)	23°44'S, 30°02'E	1580	1780 summer		Gentle, easterly, ridge top	Mixed forest (26 tree species), dominated by Xymalos monospora, Cassipourea malosana, Syzygium guineense subsp. gerrardii and Nuxia congesta in the canopy, and Oxyanthus gerrardii, Ochna arborea subsp. oconnorii, Dovyalis lucida and Peddiea africana in the sub-canopy. Open understorey. Canopy 18 to 24 m high with gaps.	0.64	07/1989	07/1994
Matiwabos - Soutpansberg (G)	22°59'S, 30°17'E	1380	1960 summer	Quartzite	Gentle, easterly, ridge top	Mixed forest (33 tree species), dominated by Xymalos monospora, Cassipourea malosana and Olea capensis subsp. macrocarpa in the canopy, and Chionanthus foveolata subsp. major, Rothmannia capensis and Pavetta lanceolata in the sub-canopy. Dense, 2 to 3 m high understorey of multi-stemmed shrub Mackaya bella. Canopy 20 to 26 m high.	0.64	07/1989	07/1994

In 1987 each sub-plot in the Diepwalle plot was temporarily sub-divided into 2 m x 2 m sub-sub-plots to facilitate determination of the location co-ordinates of each tree. This procedure was used to study the effects of competition on tree growth (Van Daalen 1993). A start has been made to determine the exact location of each tree in the other plots. From the mid-point of each sub-plot the distance and compass bearing to each tree in the sub-plot are recorded. This data will be used to generate a 'tree map' for each plot, using a GIS procedure. A start has been made to collect the data for the Isidenge plot (Amatole).

The trees were re-measured after five years, and the Amatole plots were remeasured for a second time (see Table 1). During remeasurement all stems new to the 5+ cm DBH class were given a number and recorded as ingrowth. All dead trees and those damaged severely by windfalls or other means were recorded as mortality.

3.3 Routine data analyses

The following standard analyses were done for each of the plots:

- Importance value (IV) of a species, based on data of the first measurement, i.e. including mortality but excluding ingrowth, to describe the composition of each plot. IV was calculated as follows:

  $IV = (RF + RD + RBA)/3$ where

  RF = relative frequency, calculated as the percentage of sub-plots in a plot in which the species was present;

  RD = relative density, calculated as the stem density of a species in a plot and expressed as a percentage of all stems of all species in the plot;

  RBA = relative basal area, calculated as the basal area (horizontal surface area of a stem at 1.3 m above ground level) of a species in a plot and expressed as a percentage of total basal area of all species in the plot.
- The distribution of individual tree species within the plot, based on the mapping of initial measurement data, to visually assess the distribution patterns of the species.
- Growing stock of each plot in terms of stand density, mean stem diameter and basal area.
- Mean diameter growth, ingrowth and mortality by species and diameter classes, and the relation of these factors with other stand variables.

3.4 Modelling

Two simple modelling approaches were applied. The first approach was to relate statistically the gross increment at a site (in other words, the stem basal area increment plus the ingrowth) to site abiotic drivers. The drivers chosen were an index of plant water availability (GROdays) which can be thought of as the number of days per year when plant growth is not limited by water supply and an index of physiological temperature (GROtemp), which is the mean daily temperature on days when water is not limiting. These indices were calculated using monthly mean rainfall and temperature data and a simple water balance model.

The second approach was to apply a Lefkovitch matrix method to project the demographic trends in stem size (after Osho 1991). The stems of a single species, or group of functionally and structurally similar species in the case of rarer species, were classified into size classes such that each class contained at least 15 stems and no stem grew through a class in a single time interval. The fraction of stems remaining in each class during a time interval was calculated, and forms the diagonal of the Lefkovitch matrix (survivorship). The fraction graduating to the next interval forms the subdiagonal. The contribution per tree to the number of new recruits (ingrowth) is calculated by distributing the observed total recruitment among the sexually mature trees in proportion to their basal area, and forms the top row of the matrix. When this matrix is multiplied by the vector containing the number of individuals in each size class at time one, the result is a projection of the number of individuals in each size class at time two. This process can be repeated to get projections at successive times. However, since many crucial processes such as the effects of competition on growth, mortality and recruitment are not considered, projections more than a few time intervals beyond the measured data are not reliable. The main purpose of the exercise is to determine whether the observed recruitment and growth is sufficient to compensate for the observed mortality - in other words, is the population increasing, decreasing or stable in the long term. An example of the plant population matrix for input into the demographic model is shown in Table 2.

Table 2. Example of a plant population matrix for input into the Lefkovitch demographic model.

Plot size (ha)	0.65						
Starting year: 1st sampling year	1989						
Time step (yrs): Interval between 2 sampling years	5						
Number of size classes	7						
Lower size limit: cm DBH	5.0	7.1	10.1	15.1	30.1	50.1	100.1
Upper size limit: cm DBH	7.0	10.0	15.0	30.0	50.0	100.0	156.0
Mean stem diameter: cm DBH	6.0	8.5	12.0	20.0	42.0	77.0	119.0
Initial tree number: Number of trees in the first sampling year	163	137	92	119	100	33	8
Proportion moving: Proportion of individuals which grew sufficiently to move into the next size class	0.26	0.24	0.12	0.04	0.01	0.0	0.0
Survival rate: proportion of the individuals, present in the first sampling year, which survived to 1994	0.96	0.93	0.97	0.89	0.93	0.94	1.0
Mean seedlings/plant: number of seedlings contributed by each individual in the class	0.0	0.0	0.05	0.04	0.04	0.13	0.55

4. Results

4.1 Species richness and growing stock

Stand composition and species richness patterns across the plots are summarised in Table 3 and discussed elsewhere (Geldenhuys in press). The growing stock, as expressed in terms of stem density in different diameter classes, mean DBH and stem basal area, is shown in Table 3. Stem density shows a wide range, from a high density (2600 to 1900 stems/ha) in the regrowth forests at Orange Kloof, Pirie and Kologha, to a low density in the old growth forests of Witelsbos and the Transvaal sites. The development stage of a stand is also reflected in the percentage stems in the different diameter classes. In the regrowth stands of Pirie and Kologha the stems <10 cm DBH represent >60% of all stems, except for Orange Kloof where this smallest class contains fewer stems than the next class. In the old growth forest such as Witelsbos and the Transvaal, the plots have a lower percentage stems in the lower diameter classes, and a higher percentage stems in the 30 to 49.9 cm diameter class than in the two adjacent classes. The mean DBH per stand is below 15 cm in Orange Kloof, Diepwalle and Koomansbos, and generally around 20 cm DBH in most of the other stands.

Basal area gives an estimate of stand biomass. In general the mean stand basal area is relatively high, with the highest values in the Transvaal plots, in Sandile Kop and Orange Kloof. Isidenge, Kologha and Diepwalle have much lower basal areas. The range and frequency distribution (Figure 2) in basal area per sub-plot show different patterns. The regrowth stands have a relatively narrow range with a general bell-shaped frequency distribution. The old-growth stands have a wide range with some very high values due to some large trees, and the frequency distributions are rather flat with a number of low peaks, and many plots with very low or no basal area, and a high frequency for sub-plots with >80 m^2/ha.

4.2 Growth and mortality patterns

Nett growth of a stand is the end result of the growth of individual trees, the ingrowth into the lowest diameter class of stems from below the lower limit (in this case 5 cm DBH), and mortality of trees in stems above 5 cm DBH (Table 3).

4.2.1 Ingrowth and mortality

In the original reports for each site ingrowth was expressed in number of stems per ha per year for each stand as a whole, and for individual species. Here ingrowth is only indicated for the total number of stems. Ingrowth is generally low in all sites except for the Koomansbos site. Ingrowth included only a fraction of the species present in the site, i.e. from 11% to 64%, and of these only a few were canopy trees. Ingrowth by stems could be related to stand basal area in the particular area, and the successional status of the species occurring there, i.e. they contributed to a better understanding of the dynamics of the forest.

Mortality was expressed in a very similar way, except that it also included stems of a range of diameter classes. It was expressed in both number of stems and basal area. In some stands (Koomansbos, Sandile Kop and Hellschebos) mortality due to windfalls and trees dying standing, in particular of only a few large trees, resulted in a negative nett change in basal area over the study period.

4.2.2 Stand growth

Net stand growth was generally very low, i.e. between -0.2% and 4.4% of the original stand basal area per year. Basal area growth, for trees which were measured during the first measurement and still alive at time of the second measurement, showed a significant relationship with initial stand basal area, as indicated for the Amatole forest stands (Figure 3). It shows that the bigger the stand basal area, the larger is the annual basal area growth. However, relative growth rate showed no relationship with the initial stand basal area, and varied between 0.7% to 1.9% of the initial basal area per year.

Neither total basal area (of live, measured trees of the two measurement periods) nor the relative growth rate showed any relationship with GROdays, GROtemp or the soil parent material (Figure 4). The standing crop on the sites, as indexed by the stem basal area, was remarkably consistent across the sites, despite the climate and soil range that they occupied. There is a suggestion of a slight depression in stem basal area at sites with a moisture index of less than 220 'growth days' per year.

Table 3: Number of species, number of stems by diameter classes, stand basal area, ingrowth, mortality and nett basal area growth for the 13 long-term growth study plots in mixed evergreen forest in South Africa

Variable	Orange Kloof	Diepwalle	Koomansbos	Witelsbos	Pirie	Isidenge	Sandile Kop	Kologha	Manubi	Patatasbos	Hellschebos	Grootbos	Matiwabos
Number of sub-plots	52	268	65	64	64	64	46	80	64	64	64	64	64
Number species: stems ≥5 cm DBH	14	26	33	25	43	37	38	36	44	28	25	25	33
Number species with IV≥10%	7	10	14	7	11	9	12	10	10	5	8	8	4
Number species/ sub-plot: mean	5.1	7.2	8.7	4.4	6.5	6.2	6.8	6.5	7.0	5.2	5.2	5.1	4.7
Number species/ sub-plot: maximum	7	14	14	7	12	11	11	12	12	10	9	10	10
Number species per DBH class													
5.0-9.9 cm DBH	14	24	29	21	34	29	31	31	30	26	20	21	25
10.0-29.9 cm DBH	13	25	28	21	34	28	25	29	31	23	21	21	21
30.0-49.9 cm DBH	7	13	15	13	16	11	12	10	21	8	13	16	17
50.0 + cm DBH	4	8	5	11	7	10	5	8	8	9	11	8	10
Stems/ha ≥5 cm DBH	2640	1382	1600	773	2116	1689	1387	1910	1369	1033	1302	1009	784
Stems 5.0-9.9 cm DBH % of total	31.5	48.9	48.1	40.6	61.7	52.0	45.4	64.3	46.8	40.1	44.2	44.7	32.5
Stems 10.0-19.9 cm DBH % of total	44.7	30.7	27.8	29.7	23.0	29.4	26.7	24.8	31.9	26.0	30.9	21.2	27.1
Stems 20.0-29.9 cm DBH % of total	17.7	9.5	13.0	7.8	7.7	9.8	12.0	6.0	14.1	11.2	12.7	12.2	13.7
Stems 30.0-49.9 cm DBH % of total	5.8	8.3	9.9	12.4	6.4	6.1	11.4	3.5	5.7	16.0	7.2	15.6	18.7
Stems 50.0+ cm DBH % of total	0.3	2.6	1.1	9.5	1.2	2.7	4.4	1.4	1.5	6.7	5.0	6.3	8.0
Mean DBH cm	14.9	14.7	14.7	20.0	21.7	20.6	22.0	22.1	14.3	19.6	17.0	19.7	21.7
Basal area m^2/ha: mean	58.8	38.7	42.8	45.9	43.7	24.5	57.4	32.2	33.3	54.1	55.9	60.7	48.3
Basal area m^2/ha: maximum/sub-plot	122.6	102.9	99.8	284.5	126.7	151.0	179.5	112.4	94.9	146.4	258.5	208.8	228.1
Basal area m^2/ha: minimum/sub-plot	16.0	0.0	10.6	0.0	8.8	8.7	9.9	2.0	5.9	0.5	3.7	0.6	0.9
Ingrowth, stems/ha/year	5.8	8.5	25.2	6.9	6.4	3.7	7.0	7.8	13.4	1.3	2.8	6.9	6.9
Mortality, stems/ha/year	18.1	8.8	29.2	8.4	18.2	7.4	7.5	9.4	22.3	13.1	17.8	12.5	6.9
Mortality, m^2/ha/year	0.12	0.22	0.56	0.35	0.72	0.15	0.67	0.30	0.64	0.48	0.51	0.65	0.25
Net basal area growth, m^2/ha/yr	0.65	0.35	-0.08	0.05	0.05	1.09	-0.42	0.00	-0.10	0.06	-0.08	0.19	0.29
Basal area change, % of initial stand basal area	1.1	0.9	-0.2	0.1	0.1	4.4	-0.7	0.0	-0.3	0.1	-0.1	0.3	0.6

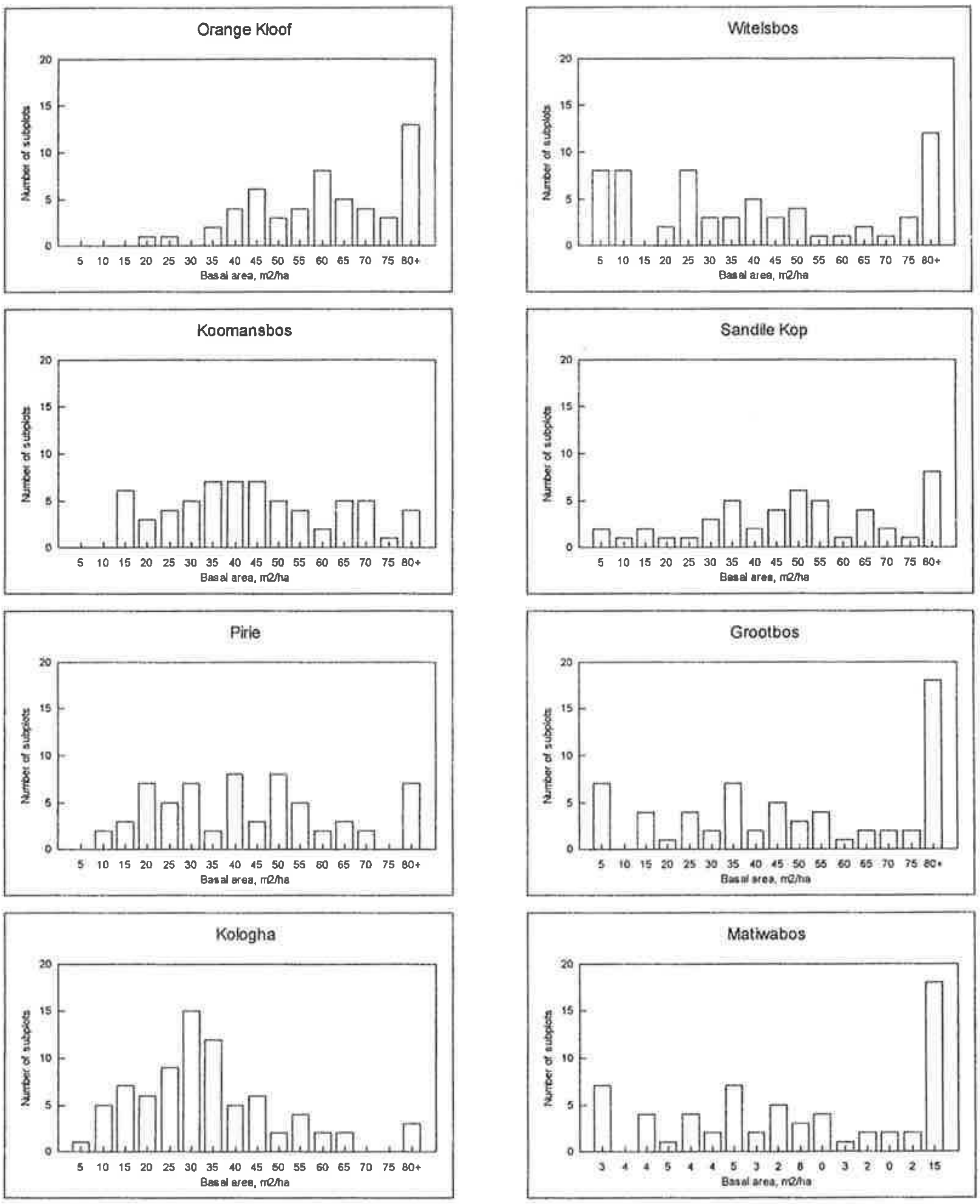

Figure 2: Frequency distribution of stem basal area per sub-plot in a selected number of forest growth study sites.

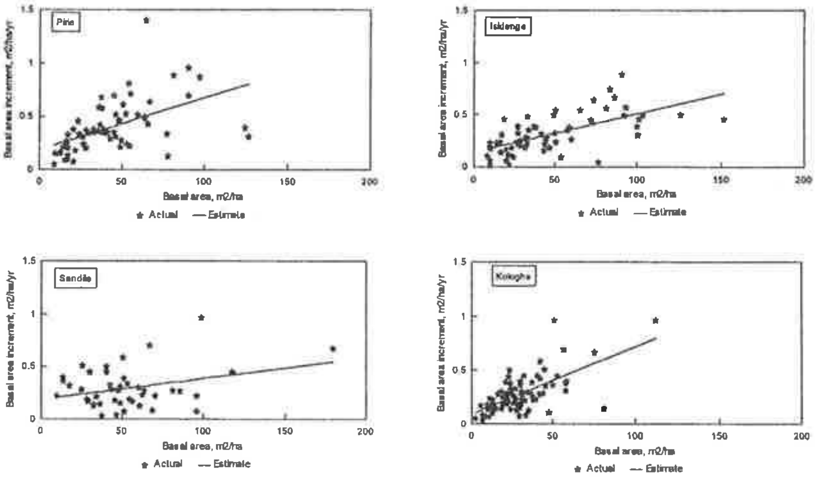

Figure 3: Relationship between basal area growth and initial stand basal area for the individual Amatole forest growth study sites.

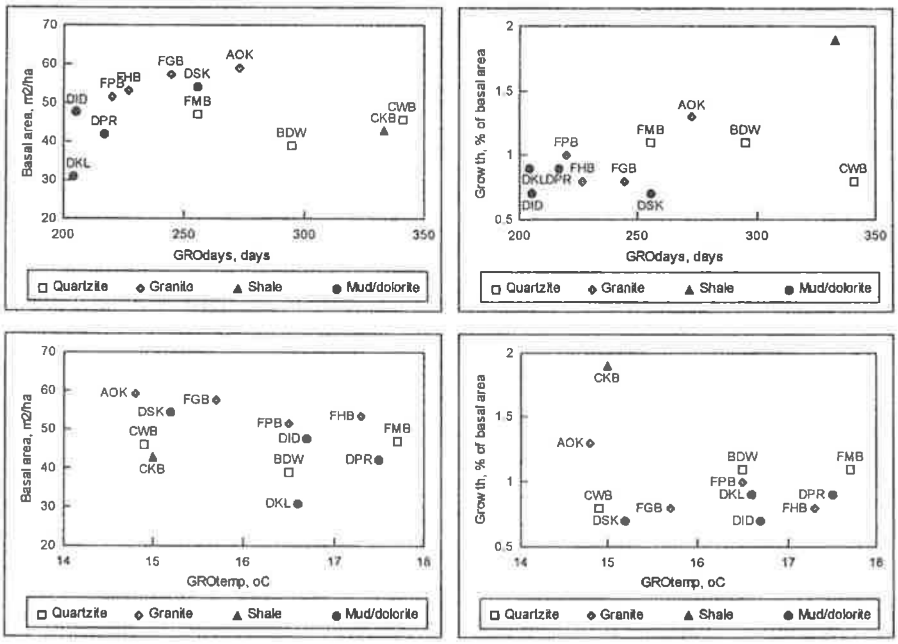

Figure 4: The relationship between either initial basal area of the stands or growth as a percentage of initial basal area, with moisture index, temperature or the broad categories of soil parent material. The relationships were all non-significant. The plot symbols have the following meaning: 1st digit indicates the forest area (see Table 1); 2nd and 3rd digits indicate OK = Orange Kloof, DW = Diepwalle, KB = Koomansbos, WB = Witelsbos, PR = Pirie, ID = Isindenge, SK = Sandile Kop, KL = Kologha, PB = Patatasbos, HB = Hellschebos, GB = Grootbos, MB = Matiwabos. Manubi forest was not included in this analysis.

4.3 Growth rate of tree species

The number of stems measured, initial mean DBH, and mean diameter growth for individual species have been calculated for each site. In this paper an example of such a table is given for the Amatole plots (Table 4). In addition, mean diameter growth together with the coefficient of variation (CV%), were calculated for the stems in each 5 cm wide DBH class. For many species only a few stems were included in a particular site, and even fewer for individual 5 cm DBH classes. The growth data do give an indication of the relative growth rate of individual species, and of the variation in growth of a species between different diameter classes within a site and between the different sites.

Table 4 Mean DBH (1987) and mean annual growth rate for each species with at least 20 stems in one of the Amatole forest plots. Trees of the ingrowth and mortality categories were excluded from the analyses

Species	Pirie			Isidenge			Sandile Kop			Kologha		
	No of stems	DBH cm 1987	Growth cm/yr	No of stems	DBH cm 1987	Growth cm/yr	No of stems	DBH cm 1987	Growth cm/yr	No of stems	DBH cm 1987	Growth cm/yr
Podocarpus falcatus	48	17.0	0.129	15	48.3	0.166	12	29.2	0.116	7	12.3	0.071
Podocarpus latifolius	7	11.3	0.055	12	36.0	0.103	39	42.6	0.122	19	39.3	0.096
Xymalos monospora	2	8.1	0.011	188	18.2	0.049	175	20.3	0.096	47	21.3	0.037
Trichocladus ellipticus	606	7.5	0.033	455	9.0	0.043	57	7.7	0.080	498	7.3	0.047
Vepris undulata	19	23.9	0.084	47	24.0	0.149	18	19.6	0.190	103	21.7	0.081
Protorhus longifolia	28	36.8	0.237	1	7.1	0.300	-	-	-	-	-	-
Rhus chirindensis	40	25.1	0.127	29	33.2	0.157	4	26.6	0.123	55	22.3	0.146
Maytenus heterophylla	8	6.8	0.023	34	9.5	0.014	57	8.2	0.036	150	7.8	0.014
Cassine papillosa	17	10.2	0.021	20	11.9	0.045	5	16.8	0.154	4	11.3	0.029
Scolopia mundii	6	21.9	0.150	9	19.6	0.067	32	14.5	0.128	16	22.6	0.168
Curtisia dentata	8	22.9	0.112	4	33.6	0.134	28	22.8	0.124	2	10.1	0.021
Rapanea melanophloeos	-	-	-	24	17.8	0.075	18	15.8	-	52	18.1	0.142
Mimusops obovata	113	12.7	0.063	12	14.7	0.091	-	-	0.060	2	30.3	0.161
Diospyros whyteana	25	9.8	0.036	38	9.1	0.035	56	8.5	0.021	301	9.7	0.067
Olea capensis subsp. macrocarpa	107	14.8	0.129	65	17.9	0.087	39	13.8	0.032	57	10.4	0.095
Nuxia floribunda	69	21.6	0.075	1	5.1	0.021	-	-	-	-	-	-
Hyperacanthus amoenus	16	6.6	0.068	3	6.9	0.007	-	-	-	33	6.8	0.015
Canthium inerme	64	17.1	0.065	1	33.1	0.000	5	10.2	0.026	2	12.1	0.096
Psydrax obovata	2	9.3	0.064	2	17.8	0.032	3	6.4	0.000	20	10.7	0.032

Application of the Lefkovitch matrix demographic model to the total stand data showed that the size-class distribution of the stands was very nearly in a steady state. However, its application to single species gave results which seemed to be illogical for the species tested, and was, for the interim, not included here.

5. Discussion

Results presented here and in Geldenhuys (in press) showed that the study sites provide a wide range of useful information on the composition and dynamics of the forests. There is however much unexplained variability in the data. It is therefore necessary that in future analyses, an attempt should be made to separate the variability in growth into components which, if could be explained, will contribute to a better control over the growth of the forests.

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Models for basal area dynamics of mixed tropical forest: Neo-tropical experience and prospects for application in Ghana

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Abstract

Stand projection which is not corrected for stand-level increment and mortality tends to overestimate achievable yields in natural forest. Two recent models, SIRENA and CAFOGROM.XLS, for Costa Rica and Brazil respectively, are discussed. The stand basal area increment, mortality, and recruitment functions for SIRENA are illustrated, and various simulation trials with CAFOGROM shown. The modelling system uses a pre-processor, CIMIR, for raw permanent plot data, and can be operated by non-programmers, but its application under current institutional arrangements in Ghana would be controversial, as each specific forest would need local management regimes to achive optimal results.

Introduction

Since the earliest models of tropical forest growth were proposed by Brandeis in 1856, it has been an implicit assumption of the *stand projection* approach that it is possible to determine the growth of a forest by analysis of individual tree increments (Brasnett 1953; Husch et al. 1982). Stand projection may be defined as a type of forest model in which trees are grouped into diameter classes and transition probabilities calculated between diameter classes to project changes over time. In more recent times such models have often been formulated as Markov or Usher-matrix type models (Buongiorno & Michie 1980;Usher 1966).

However, the underlying assumption, that empirical regressions on tree increments can be summed to give reasonable dynamic responses for the forest as a whole do not appear to hold up well in practice. Over the past few years the author has developed several growth models for natural tropical forests in different localities. GHAFOSIM was the first of this group (Alder 1990, 1995). This was constructed as a classical stand projection model using individual tree increment data from permanent plots established in Ghana between 1968 and 1983 (Baidoe 1968). GHAFOSIM was characterised by a tendency to linear response that lead to exaggerated estimates of yield over the longer term.

In Brazil in 1994 another model was developed called CAFOGROM.C (CPATU[9] Amazon Forest Growth Model, C version). This was designed on the basis of work by Vanclay relating to the North Queensland forest growth model (Vanclay 1989, 1994), as a cohort rather than diameter class model. It was based on a much stronger data set (Silva & Lopes 1984, Silva *et al.* 1994), and for moderate conditions of management, gave realistic responses over the long-term, with stands tending to achieve a basal area of around 40 m^2/ha and then fluctuate at around that level. However, when drastic interventions such as clear felling were applied, basal area would rise during recovery to levels or around 80 m^2/ha. These would eventually revert to lower figures over time, but would typically stabilise at unnaturally high levels of around 60m^2/ha (Alder 1995).

Both GHAFOSIM and CAFOGROM.C were based primarily on the modelling of individual trees by empirical regressions of tree increment on tree diameter, with different regressions for crown classes. There was no implicit control in the model for the maximum achievable basal area for the stand, or for basal area increment at stand level. However, it was clear that the absence of this stand-level analysis of basal area dynamics was a general weakness for empirical models constructed from individual tree increments.

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[9] CPATU is an acronym for *Centro de Pesquisa Agroflorestal da Amazonia Oriental.*

SIRENA: A model driven by stand basal area dynamics

Subsequent modelling efforts sought to address these problems by developing empirical regressions for the basal area dynamics of the stand as a whole. SIRENA (*Simulacion del rendimiento de bosque natural*) was the first model developed by the author of this type (Alder 1996a). It is written in Visual Basic for Applications (VBA) and runs under Microsoft Excel 5.

SIRENA was developed on the basis of a relatively limited set of data from forests in Northern Costa Rica. This comprised 26 1-ha plots and 27 ¼-ha plots managed by Tecnoforest del Norte SA and CODEFORSA[10] and measured at that time over a single interval of 2-3 years. The 16 Tecnoforest plots were all of 1-ha and occurred in a forest type characterised by significant proportions of *Carapa guianensis*. Undisturbed plots typically had basal areas in the region of 28-32 m^2/ha. The CODEFORSA plots comprised 9 plots of 1 ha, and 27 of ¼ ha. These were mainly in forests characterised by the presence of *Vochysia* and *Dipteryx* species and absence of *Carapa*, and were typically of lower basal areas, of 20-25 m^2/ha.

For each plot, increment on live standing trees was calculated as standing basal area increment (SBAI) in m^2/ha/yr. This included all trees over 10 cm dbh. Mortality basal area (MBA) was calculated as the basal area of trees recorded as dead or lost, excluding those marked as harvested or treated for liberation thinning. This periodic figure was divided by the measurement interval to give an annualised rate of losses through mortality in m^2/ha/yr. Recruitment basal area (RBA) was calculated as the basal area of trees observed on the second measurement but not at the first. This was annualised by dividing by the measurement interval to give recruitment in m^2/ha/yr.

Figure 1 shows the data and regression function for basal area increment. Two outliers have been omitted from the regression, which is a logarithmic equation with the form:

$$\text{SBAI} = 0.0419\ \text{SBA}^{0.8449} \qquad \{\text{eqn 1}\}$$

where SBAI is stand basal area increment and SBA is stand basal area. The R^2 was 0.336 with 48 degrees of freedom, which is statistically highly significant[11].

Examination of the data points suggests that the CODEFORSA and Tecnoforest plots probably follow different regressions. The Tecnoforest plots (triangles) show a very weak, non-significant regression, and have a mean SBAI of about 0.65 m^2/ha/yr over a range of stand densities. This almost certainly reflects differences between the forest types, but is not necessarily purely biological in origin. In order to simplify the model however, the two data sets have been aggregated within the version of SIRENA described in this paper.

Similar data can be plotted for mortality and recruitment basal area, as shown in the graphs in Figures 2 and 3. For mortality, the regression is very weak, and with an R^2 of only 0.0931. However, with 52 data points, this is statistically significant[12]. The separate regression considering only the 1-ha CODEFORSA plots shows a much steeper slope.

The recruitment function shows a much clearer relation than that for mortality. It is modelled by an exponential equation, which has the desirable properties that:

- Recruitment tends to a positive constant as basal area tends to zero.
- Recruitment tends to zero as basal area becomes large and the stand increasingly dense.

The equation fitted is:

$$\text{RBA} = 2.053\ \exp(-0.0994\ \text{SBA}) \qquad \{\text{eqn. 2}\}$$

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[10] Comisión para el Desarollo Forestal de San Carlos

[11] *Highly significant:* That is, there is a probability of less than 0.01 that this degree of correlation could occur by chance.

[12] The correlation coefficient is 0.305. The critical value at P=0.95 is 0.235 with 50 d.f., and at P=0.99 it is 0.328. The regression is thus significant but not highly significant using conventional terminology.

where RBA is recruitment basal area and SBA is standing basal area as previously defined. The R^2 is 0.413, which is highly significant with 52 data points.

These three functions completely define the development of stand basal area, and are used in SIRENA in this form. SIRENA uses species and size dependent functions of diameter increment and mortality, but then adjusts the individual cohort estimates proportionately to ensure that the stand-level estimates of growth are respected.

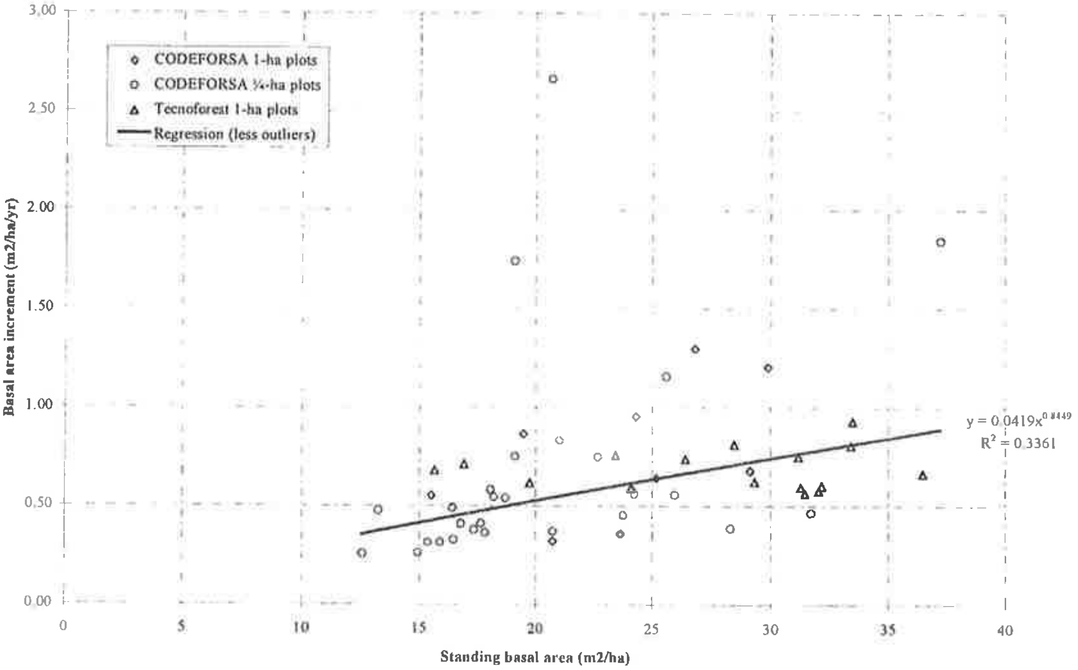

Figure 1: Basal area increment for sample plots in northern Costa Rica

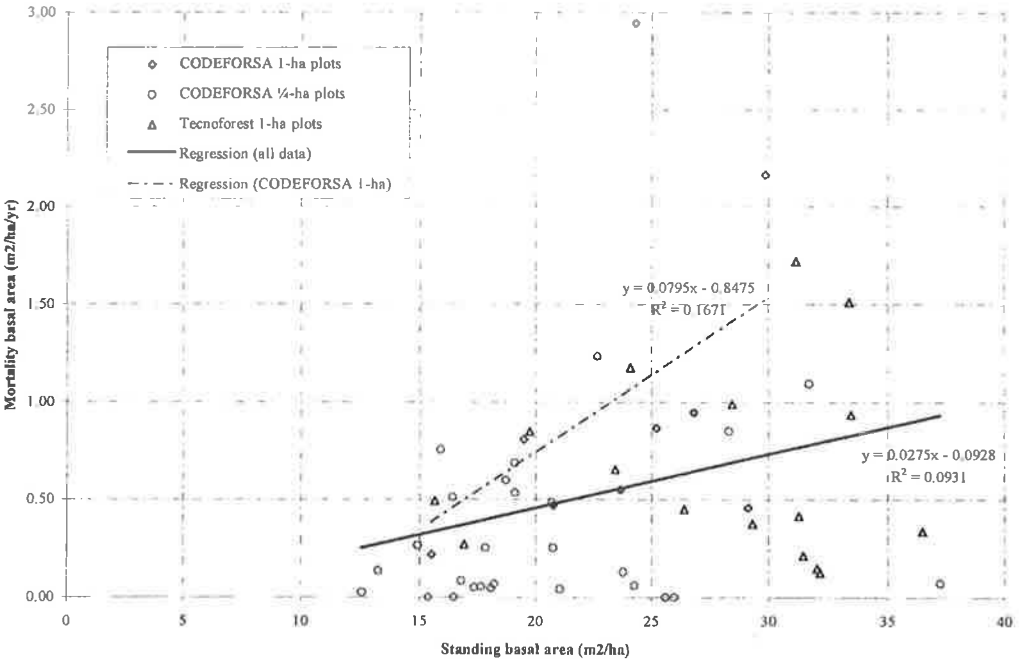

Figure 2 Mortality basal area for sample plots in northern Costa Rica

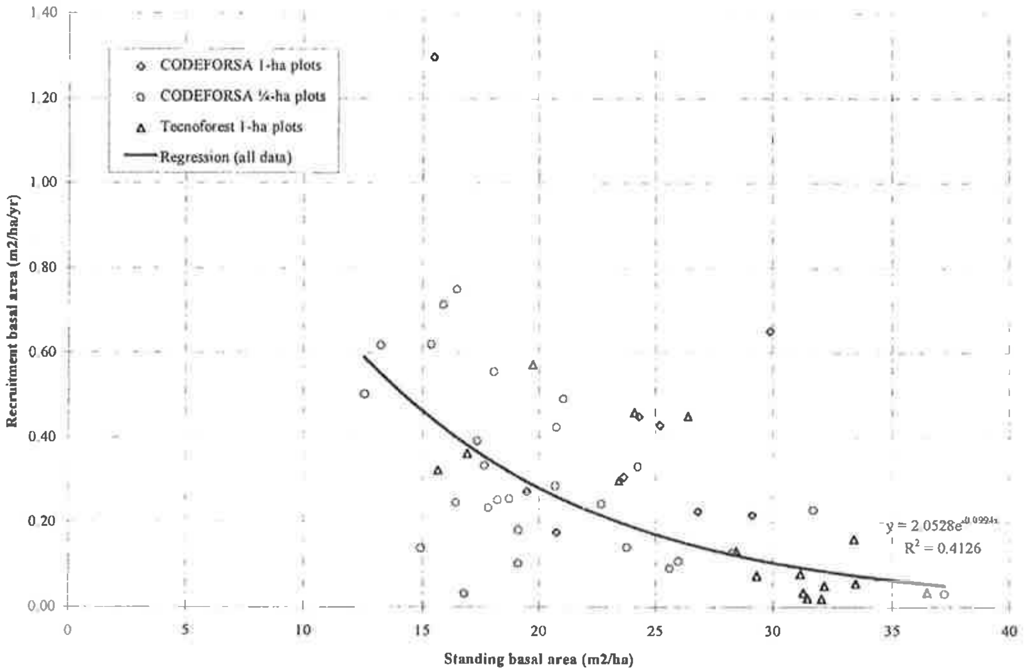

Figure 3: Basal area of recruits above 10-cm for sample plots in Northern Costa Rica

Basal area dynamics in CAFOGROM.XLS

The SIRENA model was based on a limited set of data from a single remeasurement of permanent plots in Costa Rica. The CAFOGROM model was based on much stronger data. During May and June 1986 the author had the opportunity to revise and improve that model (Alder 1996b). It was completely re-written in VBA to run under Excel 5, and was correspondingly supplied with a better user interface than the original program. The model was extended to automate the analysis process as much as possible, with a pre-processor program called CIMIR[13].

In terms of basal area dynamics, it was found that, as with the Costa Rica data, the Brazilian plots showed reasonable correlations between standing basal area and basal area increment or recruitment basal area. Mortality basal area showed a correlation, but was too weak to be directly useful. The existence of several measurement periods, or experimental treatments, and of different plot sizes on different experimental areas allowed several points to be noted during analysis. These included:

- The correlation of recruitment with initial standing basal area was strongest 2-4 years after logging. This included recruitment above 5 cm dbh.
- Basal area data from 1-ha plots gave better correlations than from ¼-ha plots. This applied especially to logging damage effects.

As with SIRENA, CAFOGROM.XLS uses individual tree functions for diameter increment and mortality. The mortality functions are not regulated at the stand level. The increment function is however limited for conformity with the stand basal area increment function. This ensures that the model performs in a reasonable manner even under extreme scenarios such as clear felling. The performance of the model was found to be sensitive to the way in which the stand basal area increment was allocated to individual trees. In SIRENA, a simple proportional adjustment was used for each cohort increment. However, with the better data available for the CAFOGROM revision, it was found that this method tended to overestimate the increment of small trees, and resulted in unrealistic stand structures over long periods. A different method was used to allocate basal area increment which gave long-term projections with stand structures similar to those found in real undisturbed stands. This involved the following logic:

- Increment was added first to the undamaged trees in the upper canopy, using the species-size tree increment function.
- Increment was then added to the understorey and damaged trees.
- Both phases were executed from largest to smallest tree in each category, and were terminated if the total basal area increment exceeded the stand increment function.

Thus, when increment is limited by stand density, large, canopy trees continue to grow. Smaller trees, those in the understorey, or damaged trees will show no diameter increment.

Both SIRENA and the revised CAFOGROM apply the recruitment function in the same way, involving several steps. During analysis, different species lists are built up for recruitment at different levels of stand disturbance. These contain two statistics for each species: The proportion of total recruitment by numbers for that species, and the mean diameter of recruit trees. The stand-level recruitment function is used to calculate recruitment basal area. This is used to determine the disturbance class, with high levels of recruitment being indicators of high disturbance. The appropriate list is selected according to the disturbance class. The basal area is then allocated proportionately to the species on the basis of their numbers and mean diameters.

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[13] CIMIR is an acronym for Calculation of Increment, Mortality, and Recruitment.

Logging damage as a component of basal area dynamics

Both SIRENA and CAFOGROM incorporate empirical functions for logging damage. For the SIRENA model, a specialised study was carried out by CODEFORSA (Gordon 1995). This involved detailed sampling on six study areas before and after normal logging operations. From this data, the graph and functions shown in Figure 4 were produced.

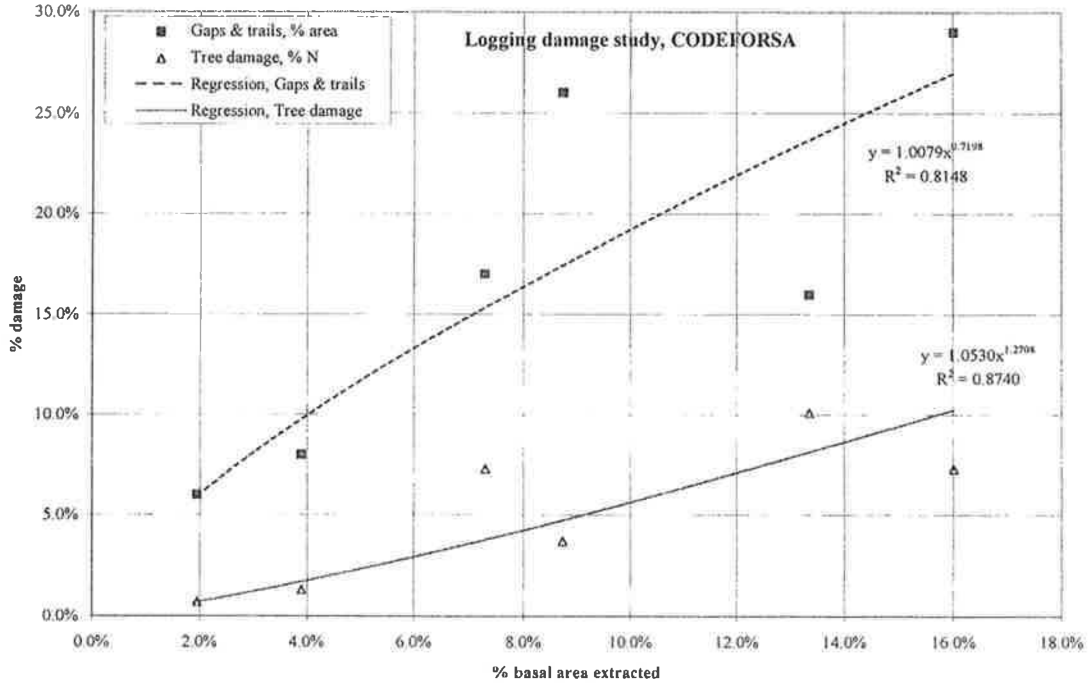


Figure 4: Basal area damage from the CODEFORSA logging study

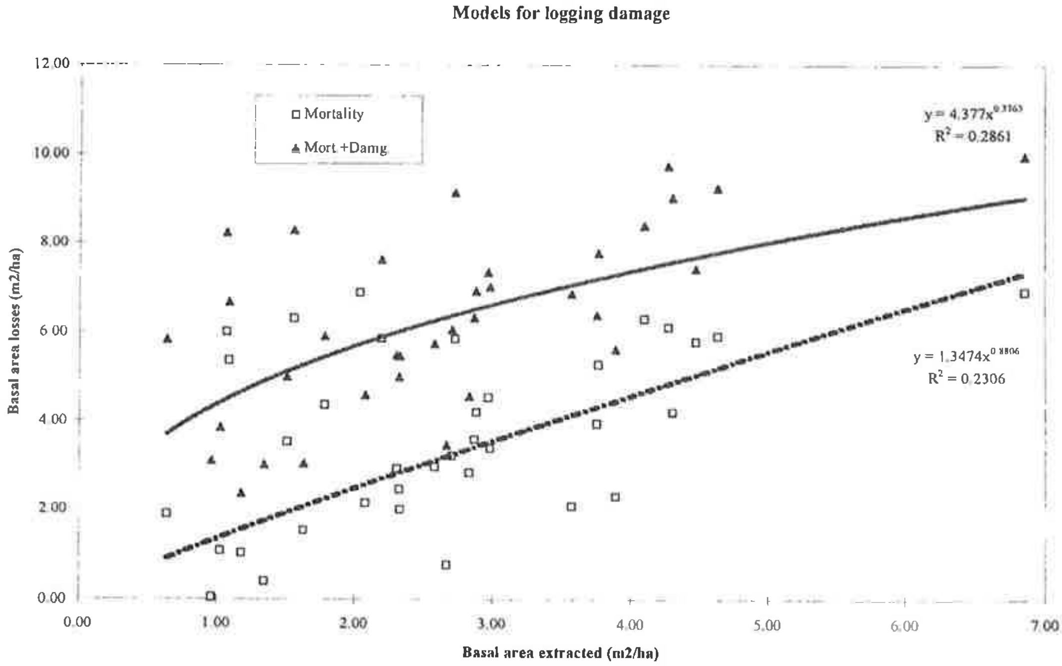


Figure 5: Logging damage data from CPATU plots near Jarí, Brazil

These show logging in terms of the percentage of basal area extracted, and range from 2 to 16%. In terms of actual basal areas extracted, the heaviest logging comprised about 3 m²/ha removed.

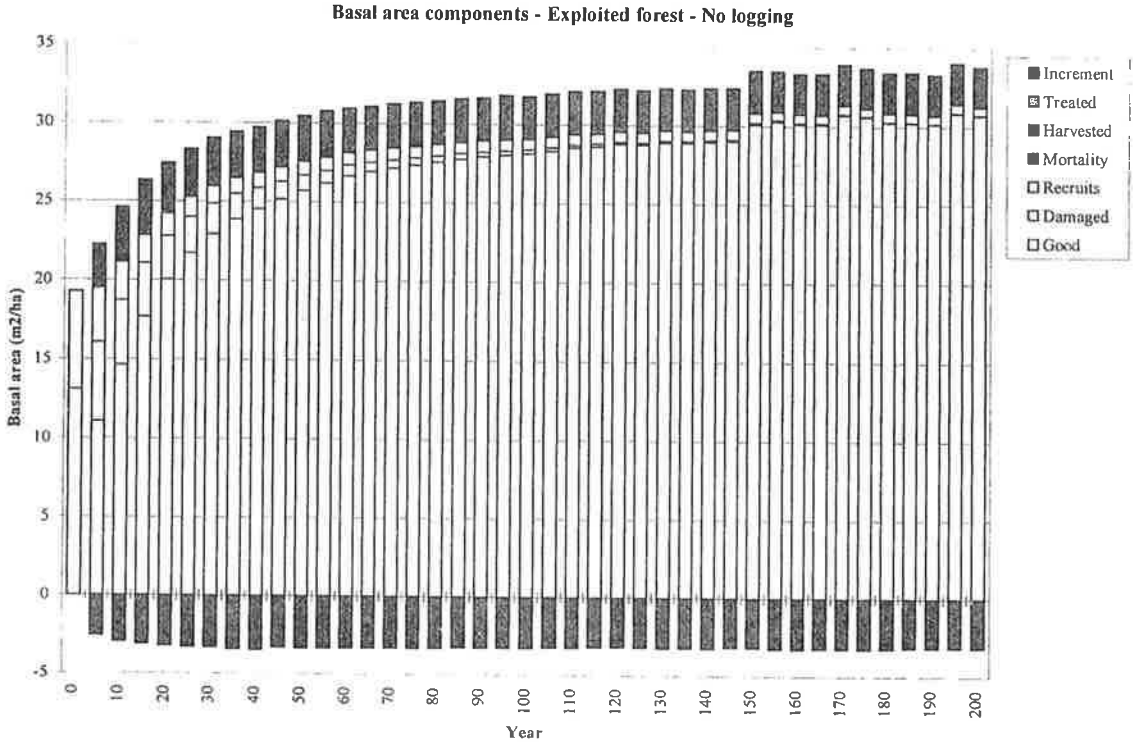
SIRENA has separate functions for trees severely damaged and for areas lost to skid trails and gaps. The area losses are applied only to trees below 20 cm, on the assumption that the tractor driver will avoid destroying larger trees. The tree damage function is applied through all sizes, with severely damaged trees being assumed to die during the period. The data exists from the study for a more detailed analysis of damage by size classes, and additional data is now being gathered by CODEFORSA to strengthen this information. It is likely that future revisions of SIRENA will therefore incorporate a more sophisticated approach.

CAFOGROM is, unlike SIRENA, not based on fixed pre-calculated functions, but develops the functions dynamically from the data set supplied, and is therefore both more flexible, and less easy to characterise in a simple way. Figure 5 however shows some typical logging damage data from the 1-ha experimental plots near Jarí. Two functions are developed. The lower line shows mortality during the measurement period following logging in terms of basal area. The upper line shows the combined losses from mortality and severe damage.

In CAFOGROM, the mortality function following logging is applied instead of the natural mortality function when a simulated logging has been carried out. The damage function is used to create cohorts of trees which are marked as severely damaged. Separate analysis carried out during model parameterization will typically show mortality rates for these damaged trees that are approximately double those of undamaged stems. The damaged cohorts are also retarded in their diameter increment.

Both the CODEFORSA and CPATU data show a similar story. For each unit of basal area extracted, a similar quantity will be lost through damage or mortality. Thus the CODEFORSA function shows that with 16% logging, 10% of the remaining trees will be severely damaged, and 27% of the forest area will be damaged by skid trails or felling gaps. The CPATU data in the example shows that with 6 m^2/ha extracted (about 20% of the basal area), 6 m^2/ha will die during the following 2-year period and a further 2 m^2/ha are severely damaged. It may be noted that neither of these situations are 'worst-case' logging scenarios. Forest owners in the CODEFORSA area use low impact methods based on agricultural tractors and cable extraction, whilst the CPATU plots are in an experimental area felled under supervision.

Figure 6: CAFOGROM simulation of recovering logged forest over 200 years



Trial simulations with CAFOGROM

Some aspects of the dynamics of mixed stands can be illustrated with trial simulations using the CAFOGROM model. Figure 6 shows the *Basal area components* diagram produced by the model for a run based on a heavily logged Amazonian forest (Tapajos km 67, as described in Silva 1989). The simulation has no logging, and is run for 200 years, in order to indicate the equilibrium behaviour. The diagram shows the standing basal area, and mortality, increment and recruitment over each 5-year step. The stand moves towards a long-term equilibrium of about 32-35 m^2/ha. In the equilibrium condition, net increment is approximately zero, but both mortality and growth remain active processes, with about 2.5 m^2/ha growth over a 5-year period, 0.6 m^2/ha recruitment, and 3.1 m^2/ha mortality.

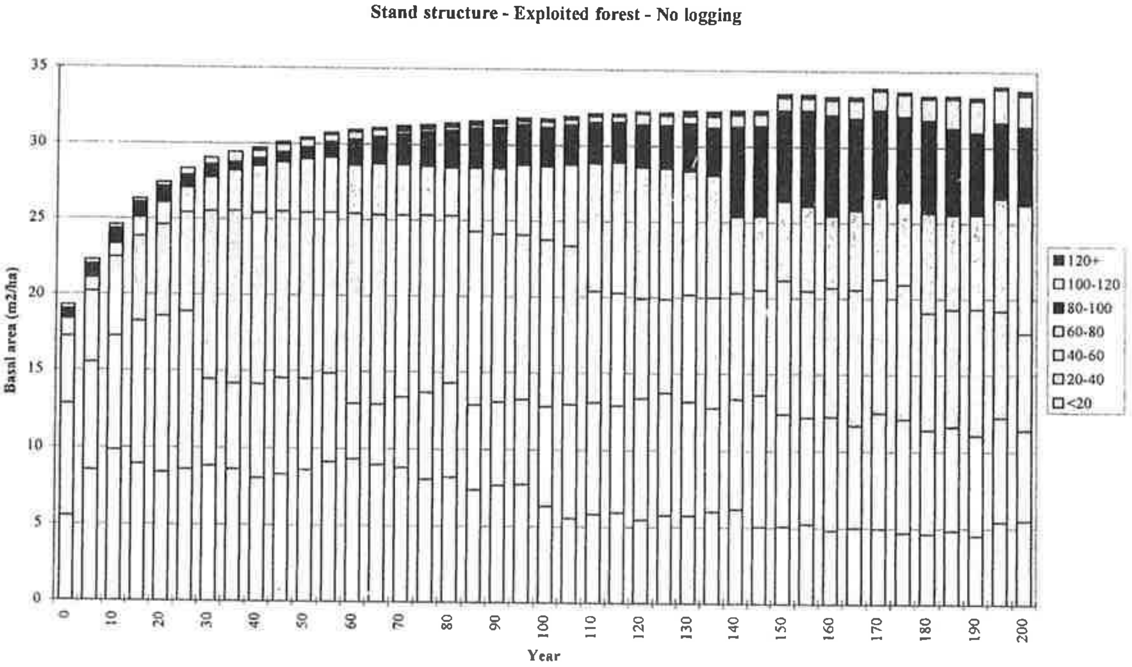


Figure 7: CAFOGROM stand structure diagram for 200 year simulation without logging

Figure 7 shows another output from the same simulation run. This is called the *stand structure diagram*. For each 5-year period it shows the basal area categorized by size classes. It can be seen that although total basal area remains more or less constant after the first 60 years of recovery from logging, there is a progression in terms of size classes. After 200 years, basal area is more or less evenly split into the 20-cm classes. This corresponds to the pattern for undisturbed primary forest in the same locality.

Figure 8 shows a more complex simulation of the same forest. In this, felling is specified under basal area control, with all commercial trees over 50 cm dbh being eligible for harvesting. However, felling is limited to a maximum basal area for extraction of 3 m^2/ha, and the model does not harvest trees which are severely damaged or of bad form. A thinning is specified 5 years after harvesting to remove up to 3 m^2/ha of non-commercial trees over 40 cm dbh, and also to remove relict commercial trees which are severely damaged or of bad form. In this basal area diagram, the removals through harvesting and thinning can be seen in the lower portion of the graph. Mortality can also be seen to be much higher during the 5-year period in which the logging is performed. Felling frequency is controlled purely by basal area, being permitted whenever the stand recovers to 25 m^2/ha.

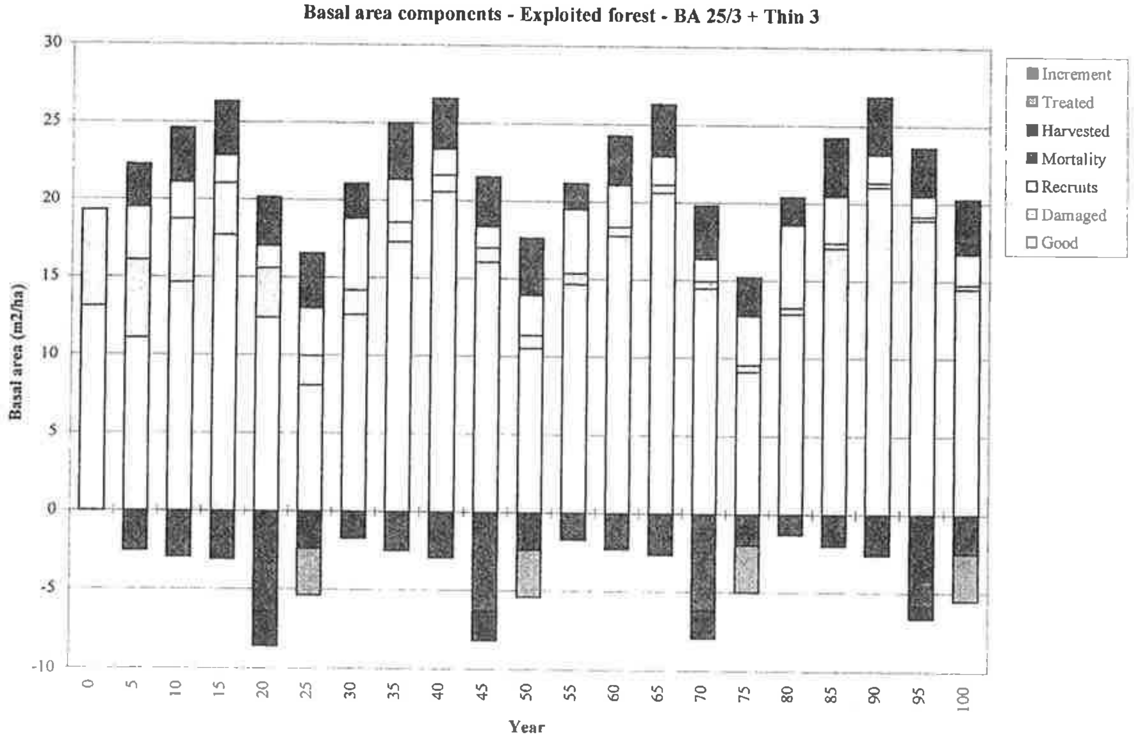


Figure 8: Simulation with felling under basal area control and post-harvest treatment

CAFOGROM has two other types of graphical output: A volume graph showing components of volume by species group, and a comparisons graph allowing one of the volume components to be compared between successive runs. The volume components graph is shown corresponding to the above regime in Figure 9. In this case, the four lines have been defined to show commercial and non-commercial volumes above 50 cm dbh, and for all trees above 5 cm dbh. The effect of the thinning in reducing the level of non-commercial volume can be seen clearly.

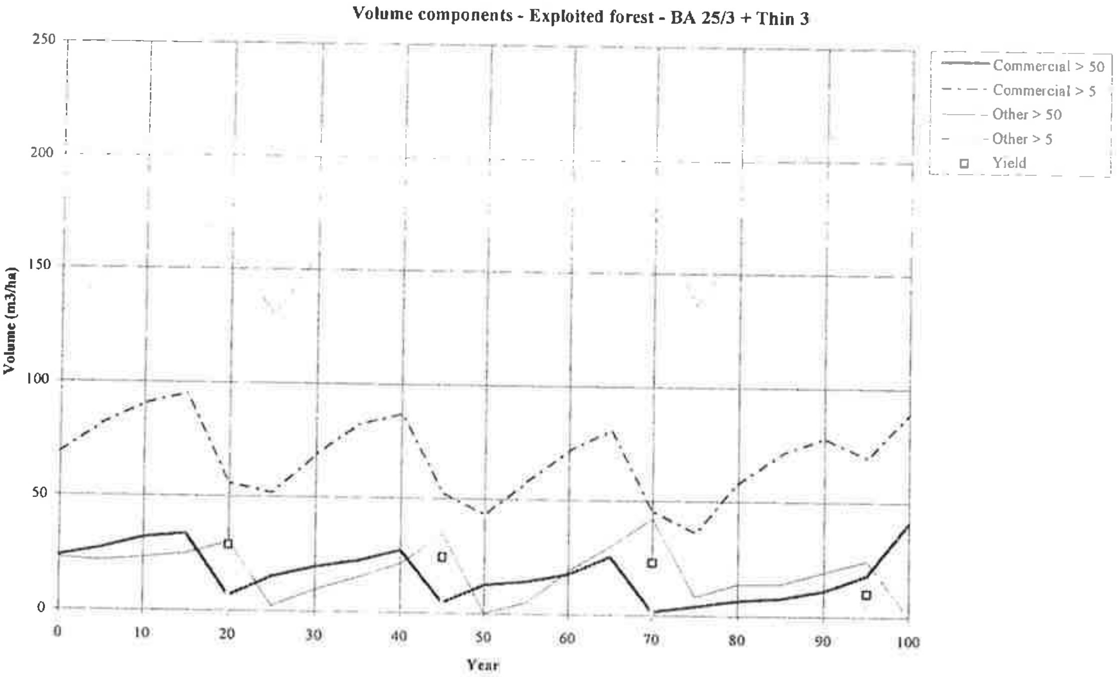


Figure 9: Volume components for a simulation with felling and thinning under basal area control

Figure 10 shows the *comparison of simulations* graph from CAFOGROM. In this up to five successive runs can be compared, using the first defined volume component. In this case, this is the volume of commercial trees above 50 cm dbh. The three lines show a forest recovering from logging over a 100 year period, the same forest logged under basal area control, and logging plus thinning under basal area control. The basal area control is specified to permit the extraction of 3 m^2/ha when the stand reaches 25 m^2/ha. Thinning is applied under the same regime 5 years after felling to remove a further 3 m^2/ha of non-commercial species and relict trees of commercial species. The thinning undoubtedly increases commercial yields, although whether it thereby constitutes a feasible economic or political proposition is another question.

These examples illustrate the main outputs of CAFOGROM and the related SIRENA model. SIRENA is being used for management planning in Costa Rica by CODEFORSA. In their situation, questions of short-cycle low impact logging are of great importance, as are questions relating to thinning. CAFOGROM is primarily a test-bed for research concepts in relation to the Amazonian rainforest, but it has been designed to evolve into a management tool over the next two or three years.

Conclusion: Prospects for application in Ghana

Given the quality of data that is potentially available from Ghana's permanent sample plot system, a CAFOGROM-type model could be readily adapted to the needs of forest planning. Associated with CAFOGROM is a pre-processor program, CIMIR, which can undertake all the required analyses directly from raw plot measurements. The system has been designed so that specialised computer programming skills are not required. However, the users would need a reasonably good knowledge of statistics and forest dynamics, as well as general computer skills[14].

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[14] Another feature of CAFOGROM interface is that it has been designed from the outset as a multilingual system. Currently it operates with English and Brazilian Portuguese menus, captions, and messages, but the system is open, and additional languages can be added readily.

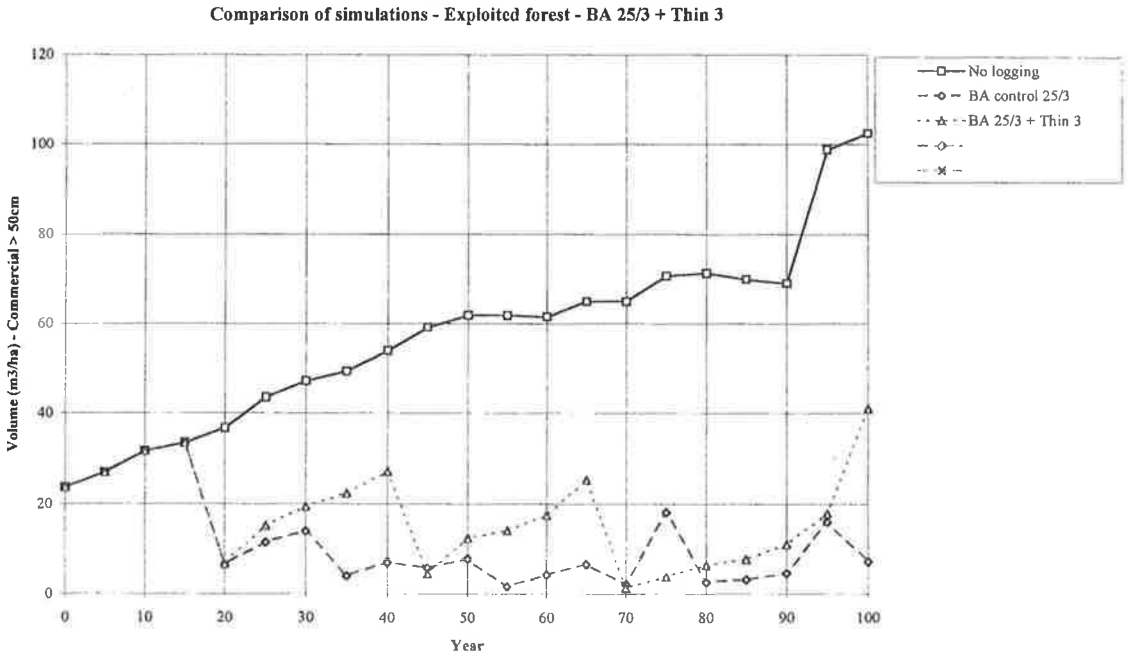

Figure 10: Comparison of three simulation runs: Unlogged, logged, and logging plus thinning

The institutional arrangements for using a model of this type need to be carefully considered. In Costa Rica and Brazil, effective forest management is primarily a matter for the private sector, with the state imposing only a requirement for sustainable management to be demonstrated. In this context, a model is very useful, as when applied to a particular growing stock and with specific species and size requirements, it can be used to justify a particular management regime.

In Ghana, on the other hand, forest management has so far been a top-down affair, with a single regime being imposed nationally on all high forests. This embraces several forest types, a great variety of species compositions, different industrial demands, and a great variety of exploitation histories. A model would show that for many situations, the general regulations might not be appropriate. But what then should be the next step? In the author's opinion, there is a need for a more flexible and localized approach to forest planning, with a greater participation of the private sector in the planning process. In this context a model can be very useful in helping to develop management plans and tailor felling regulations to local situations.

The basic thesis of this paper has been to show that forest models must incorporate whole stand information if accurate simulations are to be achieved. Analysis of individual tree data in terms of empirical coefficients is driven too much by the coincidental combinations of species, size classes and increments that occur in the data set. Empirical models developed on this basis cannot be reliably generalized to different management situations without some overall regulation or feedback at the forest level. This control can be applied empirically from models of stand basal area dynamics, or it could be derived from a more process-related approach. The latter would be very interesting to explore, and in the author's opinion should constitute the most fertile field for future research.

Acknowledgements

The SIRENA and CAFOGROM models have been developed on the basis of data provided by CODEFORSA and Tecnoforest del Norte SA in Costa Rica, and CPATU in Belém, Brazil. Many people participated in collecting data and designing systems for these situations, but I would like to thank especially those I have worked closely with, including Dr. J. Natalino M. Silva and R. Parente de Oliveira in Brazil, Mauricio Sanchez Monge and Rudolfo Vargas Mora at CODEFORSA, and Rudolfo Peralta Lobo at Tecnoforest. The work in all cases has been part of ongoing ODA projects, and I would like to thank Ian Thompson and Gordon Armstrong in Brazil, Stewart Maginnis in Costa Rica, and Desmond Chaffey in Mexico City for their positive encouragement for this work.

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Dynamique de la foret dense humide de Yapo en Côte d'Ivoire - neuf ans apres intervention sylvicole

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IDEFOR/DFO

Résumé

En Côte d'Ivoire, les premiers dispositifs d'étude de la dynamique de croissance de la forêt dense humide ont été mis en place à partir de 1976. Le massif forestier de Yapo ayant subi plusiers passages d'exploitation commerciale de bois d'oeuvre est conduit en périmètre expérimental (en 1986) transitoire entre les premiers dispositifs (Irobo - Mopri - Téné) et le reste des domaines permanents de l'Etat.

Des études de la dynamique de croissance des essences principales sont également menées depuis l'installation du dispositif en 1986. La diamètre de précomptage est de 10 cm et la périodicité de mesure des arbres est de deux ans. Des éclaircies des espèces secondaires de diamètre supérieur à 30 cm ont été réalisées dans 12 parcelles sur 16, prélevant 17 à 25% de la surface terrière globale initiale.

Aujourd'hui, les résultats disponibles couvrent en réalité une période de 9 ans. L'évolution dans le temps du recrutement, de la mortalité, de la densité, de la surface terrière, du volume sur pied, est quantifiée. On se rend compte que la vitesse de reconstitution de la forêt de Yapo est quasiment très faible et pertubèe par une forte mortalité qui est accentuée par l'éclaircie. Les effets de l'intervention sylvicole sur le recrutement des jeunes tiges ne sont pas très perceptibles. Cela est également vrai en ce qui concerne la productivité de la forêt de Yapo.

Rien n'est encore très précis, ce dispositif promet de riches enseignements au-delà de 9 ans, car on semble assister à une dynamique presque favorable à l'éclaircie à la limite de cette période. Cette tendance doit être vérifier lors des prochaines campagnes de mesures.

Contribution of big trees to total forest production: a case study in Taï National Park, Côte d'Ivoire

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Abstract

Forest productivity figures form the basis of forest management planning, in the tropics as well as in temperate zone countries. Ideally, annual country-wide harvest and damage should equal annual increment of standing volume, with constant forested area. In reality, harvest often exceeds increment, and both standing volume and forest area decrease. In the end, annual harvest drops drastically, timber industries close down and import of timber becomes necessary.

Reliable forest volume increment figures are scarce in the tropics. Undisturbed natural forests have a zero net increment and full stocking (e.g. Taï National Park). In exploited forest stocking has been reduced, but the forest ecosystem produces biomass to re-attain pre-disturbance stocking levels. Much of this increment is of non-commercial species, so value increment is still limited.

Using a straightforward exponential size distribution model and a gaussian volume increment function, it is demonstrated that more than 4/5 of value increment occurs on trees larger than 50 cm diameter. The standard one ha permanent sample plots with all trees monitored above 10 cm diameter generally produce low-precision estimates of the increment of these large trees. Special monitoring techniques (permanent dendrometers, growth ring analysis) are presented to improve the precision of these increment estimates. Volume increment of 200 large trees (6 species) in Taï National Park has been estimated with these techniques. For Heretiera utilis, Terminalia superba, Entandrophragma utile and Entandrophragma angolense, a slow down of diameter increment was found towards their maximum diameter. For Petersianthus macrocarpus and Piptadeniastrum africanum, no trend was found. For all 6 species, volume increment kept increasing with size, attaining 0.4 m^3 per annum per individual tree. Terminalia superba, the most widely planted native species in West Africa, showed slow growth above 50 cm diameter. This contrasts with its fast growth during the youth, but is a clear disadvantage when value increment is aimed at.

It is concluded that the measurement effort in permanent sample plots should be more focused on the trees that contribute the most to value increment, e.g. by precisely measuring increment of 300 large trees per site instead of measuring all those small ones.

Growth, regeneration and mortality in managed natural forest

R. Bibani Mbarga

1. Summary of the research problem

The purpose of the present research is to develop a silvicultural system for natural forest management directed at sustainable production of timber and other products and services. Silvicultural methods and techniques adapted to the local conditions of the rain forest in southern Cameroon will be formulated and tested. The impact of logging and silvicultural interventions on growth, regeneration and mortality of tree species will be recorded and analyzed using standard statistical procedures. The study will also provide data to develop a growth and yield model to predict long-term stand development.

The research is part of the multi-disciplinary Tropenbos-Cameroon research programme. Within the forestry component, this project is concerned with the impact of logging and silvicultural treatments on growth, regeneration and mortality and on key ecological functions of the ecosystem and its biodiversity. The project is a long-term one. Results obtained in the first four years will be published by the present author as Ph.D. thesis.

2.0 Background and justification

2.1 Forestry sector in the national economy

Cameroon has approximately 165,000 km^2 of tropical moist forest, and about 40% of this area can be classified as undisturbed (Foaham and Jonkers 1992). The tropical moist forest constitutes the natural vegetation in the south-west and the humid south of the country.

Since 1986, the contribution of the forest sector to the national economy increased. This contribution is important. The forestry sector provided 20,000 permanent jobs (TFAP 1988). In the fiscal year 1990/1991, timber production has increased to 2,290 million m^3, of which about 30% was processed locally (Direction des Forêts 1992). Forest fees constitute revenues to the Government and the contribution of the forest sector to the national economy is far greater because a large part of the production of forest products other than timber. In southern Cameroon, the life of local populations depends on the forest products of which collecting and harvesting are done every day; fuelwood, wood for house construction, hunting, fishing, etc.

The principal activity of the local population in southern Cameroon is agriculture. Shifting cultivation which is the main cause of deforestation is increasing.

Without forest management, the deforestation and forest degradation by shifting cultivation, logging and hunting pressure may ultimately result in destruction of the forest.. Therefore, there is a need for sustainable forest management and land use.

2.2 Forestry and forest policy in Cameroon

The policy of Cameroon to manage its humid tropical forest is very important and certain actions have been set up like the International Tropical Forestry Action Plan (TFAP) which documents have been published in 1988 by the FAO/UNEP. The National Programme for the Environment (PNGE) has the same objectives as the TFAP. This has consequently led many projects to be set up in the country: API (Aménagement Pilote Intégré) at Dimako, Programme de Conservation et d'Utilisation Rationnelle des Ecosystèmes Forestiers en Afrique Centrale, So'o la la Project at Akonolinga, the Korup Project at Mundemba, the Mount Cameroon Project at Limbe, the Tropenbos research programme in Cameroon, etc. All these projects have as an ultimate goal, the sustainable management and conservation of the tropical humid forest of Cameroon. Since Cameroon's moist forests are being logged and used for shifting cultivation and extraction of non-wood forest products without proper management, lack of management combined with an intensification of forest use, leads to forest degradation and ultimately deforestation. The deforestation rate of the Cameroonian forest is about 0.9% per annum (Foaham & Jonkers 1992).

An important aspect of a forest management system aiming at sustainability is a sustainable production of timber. The research project will look for opportunities to reach increased productivity of the stand by applying silvicultural treatments to favour desired species. This kind of forest management has been carried out in research projects in Suriname, Peru, Papua New Guinea and elsewhere during the 1970s and 1980s.

In Suriname, improvement of production for commercial timber species have been obtained by the Celos Silvicultural System (CSS, see de Graaf 1986; Jonkers 1987). The natural regeneration trials were also initiated in African countries (Ivory Coast, Central African Republic, Gabon and Congo), in Amazonia (Brazil, French Guyana) and in the Pacific region (New Caledonia) by French research workers. The results of these experiments were presented by Mielot and Bertault (1980), Maître (1986a, 1986b, 1991) and Aïdara (1992). These experiments share coherent designs and setting up of trials and treatments, and they all aim at studying the reaction of the forest as a result of two operations: logging for timber and thinning for stand improvement.

2.3 Literature overview of the first results of experiments carried out in the moist forest.

Silvicultural (refinement) treatment experiments carried out by Schulz (1967) and Boerboom (1965) showed that the growth response of commercial timber species proved favorable for all size classes. Boerboom recorded a diameter increment of approximately 1 cm/yr, with larger trees growing slightly slower than small individuals. However, treatment costs were unacceptable: 30 man-days and 1000 litres of 2, 4, 5-T solution per hectare (Vink, 1970 in Jonkers, 1987).

The results indicated that a polycyclic system was preferable, and this led ultimately to the Celos Silvicultural System (CSS, de Graaf 1986). The total expenditure was appraised at 12 man-days and 60 litres of 2,4,5-T solution per hectare during the entire cutting cycle. The growth response of commercial species presented an increment in diameter of 1 cm/yr (de Graaf & Geerts 1976; de Graaf 1982, 1986, Jonkers & Schmidt 1984).

Jonkers (1987) indicated that the growth in pristine forest is low. The mean diameter increment for commercial trees larger than 15 cm dbh in the virgin forest was only 0.36 cm/yr. Increment during the first year after logging and refinement was slightly faster, with average rates of 0.43, 0.46 and 0.51 cm/yr after yields of 15, 23 and 46 m^3/ha respectively. Therefore, these results indicate a positive correlation between growth and logging intensity. The results of Jonkers (1987) also illustrate that most growth rates found in virgin forest were lower than rates found in logged-over stands. These observations indicate that virtually all commercial trees respond favorably to the improvement in light conditions and nutrient availability induced by logging. With ICSS, the average growth rates for commercial trees larger than 15 cm dbh increased by about 0.5 cm/yr in treated stands, which is slightly higher than growth rates found in untreated stands (Jonkers 1987). Differences in growth rates was statistically significant between different intensity of refinement. The total treatment input per hectare for a 20 cm diameter limit refinement was three (3) man-days plus 0.4 litres of 2, 4, 5-T and 16.6 litres of diesel oil, plus overhead costs and some minor expenses.

The first results in the Ivory Coast experiments published by Mielot and Bertault (1980), Maître and Hermine (1985), Berthault (1986), Maître (1986a, 1986b) and Aïdara (1992), indicate a positive effect of logging combined with silvicultural treatments on tree growth. The growth rates of trees from 10 to 20 cm dbh is higher than trees between 25 to 40 cm dbh, approximately 75% and 50% respectively. The reaction of dominant trees which are in the upper canopy stratum seems not significant. The effect of treatments on trees is individual and complex, influenced by many other factors like genetic factors and pedologic factors. The growth of desired species is correlated with silvicultural treatment intensity. After thinning, the initial basal area of 25 m^2/ha can be restored within 20 to 30 years. The results of Ivory Coast also show that natural mortality in the natural forest is very important. It can be considered as natural regeneration tool of the dynamic. This natural mortality is difficult to quantify, and study must be emphasized on it. In Mopri stand the results of ten years of observations indicate that one to two trees per hectare which is the equivalent lost of 0.2 m^2/ha/yr of the basal area. However, the loss is lower in Irobo forest, 0.1 m^2/ha/yr of the basal area. No correlation has been established between the intensity of thinning.

The regeneration of commercial trees has also been observes. The ingrowth in the 10-15 cm dbh is accelerated by the opening in the canopy due to logging and silvicultural treatments. This recruitment of new trees in upper diameter classes is variable between different commercial species. Although there is still a lack of knowledge in natural regeneration of most commercial species, a study must be carried out on this aspect.

2.4 Theoretical considerations in formulation of silvicultural treatments

Considering earlier results of the experiments carried out in the tropical moist forest, and some general principles of forestry and other disciplines, we can underline key elements to formulate silvicultural treatments which are mainly concerned with: logging damage; the remaining stand; the impact of treatment on micro-climate; the conservation of biodiversity; the nutrient status of the stand; the interests of the local population; the composition and the structure of the forest; costs and the easy implementation of the silvicultural method formulated.

Logging damage in the stand is important, open sites created by logging operations are often altered drastically, very large gaps create favorable conditions for infestation of faster growing pioneer species, lianas and weeds which grow vigorously and hamper the regeneration and the growth of commercial trees (Hawthorne 1993). The micro-climate in the stand changes after too severe logging damage and the applying of high intensity of thinning; the forest micro-climate could change irreversibly. These phenomena are described by several forest researchers in the African tropical moist forest and play an essential role in the succession forest process (Bertault 1986; Osafo 1970; Dawkins 1960; Foggie 1960).

The remaining stand after logging is also essential in the formulation of treatments; the remaining potential crop trees (PCTs) will form the yields in the next felling cycle, they play an important role in the silvicultural system adopted. That is why inventories of the stand must be taken before and after felling and silvicultural treatment applying in order to know the species composition, the number of PCTs in the stand and their sizes, and their spatial distribution. The remaining stand must contain well formed seed bearers since polycyclic logging will otherwise progressively remove the best seed trees, while poorly formed and slow growing individuals remain in the stand, thus creating an inferior next generation (dysegenic effect, Jonkers 1987).

Considering the forest structure of the evergreen forest in southern Cameroon, with its three vertical strata, harvestable trees are mainly recruited in the upper canopy stratum while potential crop trees are concentrated to the medium canopy stratum; it is in that medium level we have to concentrate the actions to implement for the silvicultural system formulated.

The composition of the stand is also important. To guarantee sustainable timber production, a wide range of potential timber species is needed. In Cameroon a limited number of species are harvested (30 species out of 59 species considered to be commercial at present by ONADEF). This list of species must be completed with tree species which will possibly be of economic value within 20-30 years for timber or other products, and which should be promoted through silvicultural treatment.

This project in the evergreen rain forest of southern Cameroon will develop a silvicultural system and the silvicultural techniques tested will be inspired by methods applied in Côte d'Ivoire and in Suriname which will be adapted to local conditions. This study will develop a sustainable polycyclic management system for timber production in the evergreen rain forest of Cameroon. It is part of the interdisciplinary Tropenbos-Cameroon Programme, and the silvicultural treatments to be designed will partly depend on the results of other studies (e.g. studies on logging by van Leersum and Parren, research on non-timber forest products by van Dijk, sociological studies by van den Berg, Biesbrouk, Nkoumbélé and Tiayon, a study on timber tree regeneration by Nsangou and van Waterloo, and a forest management study by Eba'a Atyi). The logging studies are partially conducted in the same experiment as the present Ph.D. project, and so do the pre-felling treatments, aimed at reducing felling damage, which are part of these logging studies. The project is a long-term one, and the Ph.D. research will only cover the first four years of the project.

2.5 Specific objectives

1. To formulate silvicultural treatments to:
    - ⇒ stimulate the growth of timber species, which are likely to be on the timber market at the end of the first cutting cycle, to stimulate natural regeneration of these tree species and to keep their mortality at a low level;
    - ⇒ preserve and/or stimulate the production potential of non-timber forest products and other tree species important for the local population. Such treatments should also preserve the biodiversity and stability of the forest ecosystem, and should be inexpensive and easy to carry out.
2. To assess the impact of these silvicultural treatments on:
    - ⇒ tree growth, regeneration and mortality;
    - ⇒ the composition and development of the tree stand as a whole.
3. To provide data for adjusting the yield prediction model to be developed by the Econ1 study to growth conditions in south Cameroon, and other scientific information required for the development of a sustainable forest management system.

The Ph.D. study will deal with the first objective, and will provide a preliminary assessment of the second objective. The third objective will not be part of the Ph.D. study.

2.6 Research questions and other questions related to the execution of the project

In order to meet the general and specific objectives formulated above, the following questions related to the research have to be addressed:

<u>In formulating treatments:</u>

a) Questions related to the selection of species to be promoted.

a1) which timber species will possibly be of commercial value after 20-30 years, and which of those should be promoted through silvicultural treatment?

a2) which tree species are being used by the local population, and should be preserved for this purpose?

b) Questions related to the stimulation of tree growth.

b1) what is the species composition of the forest?

b2) what is the size class distribution per category of species (e.g. presently commercial species?

b3) what are the spatial distribution patterns per category of species?

b4) assuming that large trees grow optimally if exposed to full light, and medium-sized and small trees grow best with full overhead light and shade from the sides, light conditions of commercial trees can be improved through killing other trees and lianas. A subsidiary effect of such an intervention is that additional nutrients become available from decaying killed trees and climbers. How can the growth conditions for timber species be optimized, considering the costs of treatment?

c) Questions related to conditions for regeneration of species to be promoted.

c1) is the total area of felling gaps and natural chablis in logged forest sufficiently large to support adequate regeneration of timber species, and are the sizes of these openings such that they provide good conditions for growth of such regeneration?

c2) is it desirable to create additional gaps for the regeneration of timber species?

d) Questions related to ecological stability of the forest and the requirements of the local population.

d1) how do treatments relate to the objectives of preserving species value for the local population, biodiversity and the stability of the ecosystem, and what adjustments should be made to the treatments to reach these objectives:

d2) which areas should be excluded from treatment because of:
- unsuitable physical environment for species to be promoted;
- environmental hazards (e.g. pollution of water courses);
- safety (e.g. near roads)?

e) Questions related to operational aspects and costs.

e1) what equipment and materials (quantities) will be needed
- for the treatments;
- for the enumerations?

e2) what personnel will be needed (number, qualifications, duration)
- for the treatments;
- for the enumerations?

e3) how should the fieldwork be organized:
- for the treatments;
- for the enumerations?

e4) what will be the costs involved
- for the treatments;
- for the enumerations?

In testing the treatments formulated:

e) Questions related to operational aspects and costs (cont'd)

e5) what equipment and materials (quantities) have actually been used for the treatments?

e6) what personnel have been involved (number qualifications, duration) in the treatments?

e7) what is the most efficient way to organize treatments (working procedures)?

e8) which were the actual costs of the treatment (in man-days, quantities and in financial terms)?

f) Questions related to the impact of the treatments on vegetation components to be eliminated.

f1) which trees have actually been poison-girdled (and which lianas have been cut) and how does this compare to the theoretical treatment results?

f2) what is the rate of mortality of poison-girdled trees, and which species do frequently recover from poison-girdling?

g) Questions related to growth conditions.

g1) to what extent has the canopy been opened by logging and silvicultural treatment?

g2) at what rate do these openings close?

g3) how many nutrients become available for the vegetation from logging debris and vegetation components dying as a result of silvicultural treatment or natural causes?

g4) to what extent has competition between trees been reduced by silvicultural treatment?

g5) at what rate does the competition increase in the years thereafter?

h) Questions related to the growth and response to treatment of promoted species and to mortality.

h1) what are the growth and mortality in the timber stand after treatment, and how does this compare to the increment in untreated forest in terms of:

- diameter growth in relation to species and tree size;
- volume and basal area increment;
- increase in number of trees of harvestable size;
- timber volume in the harvestable size classes;
- production of new leaves and twigs (flushing) and the growth of tree crowns?

h2) how do growth and mortality change when competition in the stand increases?

i) Questions related to natural regeneration.

i1) how does the natural regeneration of tree species develop in natural and artificial openings of different sizes and under a closed canopy, in relation to silvicultural treatment?

i2) what are the ecological requirements for a successful regeneration in openings of the most important commercial species?

i3) at what size do timber species reach sexual maturity?

i4) what is the seasonal variation in reproduction phenology of timber trees, and what is their relation to seasonal variation in flushing (production of new twigs and leaves)?

i5) to what extent is successful germination of timber species impeded by the leaf litter layer?

j) Questions related to the needs of the local population.

j1) how do tree species which produce non-timber forest products develop (growth, regeneration, mortality) in relation to silvicultural treatment, and how does this affect the availability of these products?

j2) how much employment can silvicultural treatment generate, and to what extent can the local population benefit from these jobs?

k) Questions related to biodiversity and ecosystem stability.

k1) what is the actual impact of the treatments on the tree species composition of the forest?

k2) what is the impact of the treatments on key ecological functions of the ecosystem (nutrient conservation mechanisms, plant-animal relations)?

In adopting the yield production model to local conditions:

l) Questions related to growth, mortality and regeneration. (see under h and i).

m) Questions related to timber volume

m1) what is the relation between stem diameter at breast height and stem volume of timber species?

2.7 Experimental lay-out

2.7.1 Main experiment

The experiment will consist of factorial randomized blocks with two pre-felling and three post-felling silvicultural treatments in three replications. Hence it is a 2x3x3 factorial randomized experiment. In addition, four plots will be established in the forest which will remain untouched.

Plot design

The experimental plots will consist of a 100x100 m assessment plot, subdivided in 10x10 m quadrats and surrounded by a 8 ha buffer zone (zone tampon). Two boundaries of the assessment plot parallel to the expected direction of fall of the tree to be felled, at 50 m distance from the trunk. The third and fourth boundary perpendicular to the expected direction of fall, at 15 m (-20 m) and 85 m (-80 m) from the foot of the tree, in such a way that the entire tree falls within the assessment plot. The 1 ha central permanent sample plot can be located eccentrically, but the main experimental plot including the buffer zone remains 9 ha. In case of eccentricity of the 1 ha plot, the buffer zone extends to at least 50 m from the boundary of the 1 ha plot. The buffer zone is also used to collect data, particularly growth data. In each 1 ha plot, 17 sub-plots of 1x5 m have been established, in which tree regeneration is assessed.

2.7.2 The transect

A 500 m permanent transect has been established inside the experimental block. This transect was established in representative virgin forest, avoiding steep slope, valley and swamp zones. The buffer will also receive one of the silvicultural treatments.

2.8 Treatment schedule

The experiment will have two treatment levels:

a) Pre-felling treatments
   D_o - Control (without climber cutting)
   D_9 - Climber cutting 9 months prior to felling

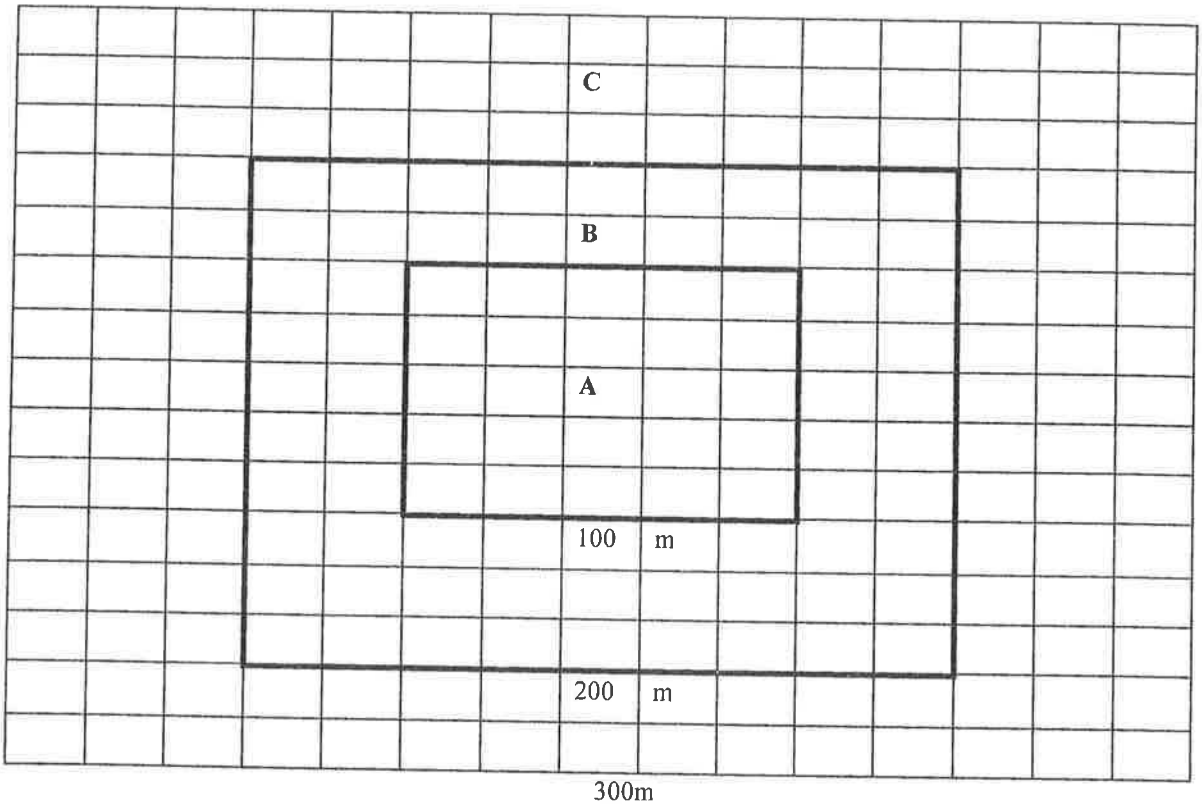
b) Post-felling treatments
   A. Control (no post-felling treatment)
   B. Low intensity liberation
   C. High intensity liberation.

Between pre- and post-felling treatments, 1 tree per hectare will be felled in all plots (i.e. 9 trees per plot). Trees to be felled will be selected by the researcher.

Treatments B and C consist of liberating commercial timber trees and future crop trees (species which are likely to be commercial after 20-30 years). The objective of treatments B and C is to improve growth of timber trees by reducing competition in the stand and to ameliorate light conditions for natural regeneration. Therefore, non-desirable trees around the commercial stem will be eliminated. The prescriptions of treatments B and C will be formulated on the basis of an analysis.

Demarcation of buffer zones in the permanent sample plots (psps)

PSP Azobe 18 / 9 ha



Bipindi/Lolodorf moist evergreen tropical forest
Plot enumeration Nov. 1995/Feb. 1996

Total number of trees = 4045
Total number of dead trees = 75
Density = 451.45 tree/ha
Mean basal area = 33.41 m^2/ha

Legend:	
	A: Central plot 100 x 100 m^2
	B: Buffer zone 200 x 200 m^2
	C: Buffer zone 300 x 300 m^2

Table 1: Experimental design of treatments

Post-felling treatment	Replication Block 1	Pre-felling treatment Block 2	
		D_0	D_9
A	1	13	21
	2	14	25
	3	18	29
B	1	11	23
	2	16	26
	3	19	28
C	1	12	22
	2	15	24
	3	17	27

2.9 Enumerations and observations

2.9.1 Main experiment

Data collection is done through repeated enumerations of trees, seedlings and saplings, and mapping of trees and terrain characteristics. The following data will be recorded during each enumeration:

- Plot number, sub-plot number and sub-plot type;
- Type of enumeration;
- Date of assessment;
- Names of crew leader and tree spotter

2.9.1.1 Enumeration in the central 1-ha plot

Each human intervention (including the logging operation) will be preceded and followed by a tree enumeration. Thereafter, enumerations will be continued on a biennial basis for several decades.

In the central 1-ha plot, all trees greater than 10 cm dbh will be enumerated per 10x10 m sub-plot. The following data will be assessed for each living stem:

- Vernacular (and scientific) name;
- Location of the stem in the quadrat;
- Diameter at breast height or 30 cm above buttresses;
- Trunk quality (stem class);
- Crown form and crown position;
- Physical damage to the crown;
- Physical damage to the trunk;
- Treatment received (e.g. felled, girdled completely, girdled partially).

Characteristics which are not supposed to change (name, geographic position) are assessed once for each tree (or twice if checking is needed), other data will be recorded during each enumeration.

In addition, the following parameters will be assessed every four or five years:

- Stem length;
- Stem diameter at crown point:
- Total tree height;

- Crown dimensions.

For trees which died since the previous enumeration or which were not found, one of the following stem classes will be recorded:

- Uprooted tree;
- Broken trunk or felled tree;
- Complete tree (standing, with crown);
- Tree not found.

Living trees which are broken below the point of measurement are treated as dead trees, even if they coppice (coppice shoots reaching 10 cm dbh are recorded as ingrowth). The same applied to living felled trees. In addition, the treatment (none, felled, girdled completely or partially) will be recorded for each dead tree.

2.9.1.2 Enumeration in the buffer zone

The enumeration of the trees in the buffer zone will be the same as in the central 1-ha plot, except that only species to be liberated in treatment C > 10 cm dbh will be measured during each enumeration, and that the geographic position of the tree will be mapped instead of precise recording of the coordinates. The skid trails will also be mapped.

2.9.1.3 Enumeration in the permanent transect

In the enumeration of the transect, , the same data will be recorded as in the 1-ha central plot. However, all trees of less than 5 m height will be recorded in a 5 m wide strip, all trees 5-10 cm diameter in a 10 m wide strip and all larger trees in a 20 m wide strip, and all tree dimensions will be recorded during each assessment. The assessment will include a complete drawing of the transect, following the method of Oldeman (1974; 1978).

The data will be recorded after each human intervention. Thereafter the transect will be drawn every five years for several decades.

2.9.1.4 Liana enumeration

Liana enumeration will be done in the 1-ha central plot. All lianas greater than 5 cm dbh will be tallied per diameter class in each 10x10 m sub-plot before the pre-felling treatment. This enumeration will be repeated very five years after the post-felling treatment. An effort will be made to assess the botanical identity of lianas found. At least two categories of lianas will be tallied separately: rattan and other climbers.

2.9.1.5 Seedling and sapling enumeration

Tree seedlings and saplings will be enumerated per taxon and size class in each 1x5 m sub-plot. Botanical identification will be as precise as possible, e.g. if individuals cannot be identified to the species level, the genus or family will be indicated. One meter height classes are use for individuals up to 5 m total height, larger trees will be grouped in one size class.

2.9.1.6 Mapping of permanent sample plot

Detailed maps of all central 1-ha permanent sample plots will be made before the pre-felling treatments and after logging, showing the exact position of all sub-plots, trees measured, gaps, skid trails and terrain characteristics. In the buffer zone the same features will be mapped, but with slightly less precision.

2.9.1.7 Assessment of treatment costs

Costs of treatments B and C will be measured in terms of labour input, materials used, equipment needed and other cost items. Costs will be estimated in quantities applied (e.g. man-hours, litres of paint), as well as in financial terms.

2.9.2 Phenological observations

Flushing, flowering and fruiting of all trees larger than 10 cm dbh will be recorded in 0.25 ha plots in an untouched forest, in a logged forest and in the forest to be treated silviculturally. The logged and treated plots will be part of 1-ha plots of the main experiment. In addition, the phenology of some common commercial species will be recorded on selected trees in the rest of the 1-ha plot and the surrounding buffer zone.

2.9.2.1 Specific objectives

The objectives of our phenological study can be located down stream of natural forest management activities and genetic resources conservation for the rain forest of southern Cameroon. These objectives are:

1. To gather scientific information on the phenology of tree species encountered at the TCT research site.
2. To determine the dimension (diameter) at which the species of interest reach sexual maturity and thus produce viable seeds.
3. To determine the periods when flowering and fructification occur and thus the best time for seed collection in the rain forest of southern Cameroon.
4. To check the effects of silvicultural treatments on the tree species encountered at the TCP research site.
5. To check and determine the best ecological conditions for growth and the occurring of phenological activities not only at the site level, but also at the specific conditions of each tree.
6. To determine for each species of interest the time interval between flowering and the maturity of fruits and seeds. This time may vary considerably from one species to the other, taking only a few weeks for some and up to 18 months for others.
7. To estimate productive potentials of different species and the dimensions (age) at which the seed trees may produce good quality seeds in a sufficient amount.
8. To determine species which have problems of sexual breeding as well as the nature and causes of such problems.

The study will concern the timber species actually commercialized in the market and also timber species with commercial value which will possibly be marketed 20-30 years later. The experimental lay out will consist of two designs, one composed with individual trees in four diameter classes (15-30 cm, 30-45 cm, 45-60 cm, > 60 cm): 6 trees per class, chosen whenever possible in three ecological site conditions (e.g. plateau, slope, valley). The second design with ¼ ha plot, chosen in the 1-ha center plots.

2.9.2.2 Enumeration and observations

In each design, trees will be chosen and diameters will be measured. Each chosen tree will have a number.

Twice a month, trees will be visited and phenology data will be scored. This phenology data will include flowering, fruiting, tree wintering and new leaves regeneration (species flushing). In this experiment, the size at which timber species reach sexual maturity will be determined.

We will also determine the seasonal variation in reproduction of timber trees and if there is a relation to seasonal variation in flushing (production of new twigs and leaves). We will also determine timber species which have biological reproduction problems.

2.9.2.3 Flushing, flowering and fruiting of all trees larger than 5 cm dbh

Phenological observations will be recorded in four (4) plots measuring 50 x 50 m. Each plot will be established in one of the central 1-ha plots, and each will receive a different silvicultural treatment (treatments A, B, C and virgin forest control, see section 2.8). The objectives of the observations will be to study the impact of treatments on flushing, flowering and fruiting of trees.

3.0 Data analysis

3.1 Defining silvicultural treatments

The main experiment will deal with three treatments:

- Treatment A (control), which does not require further analysis to define the treatment;
- Treatments B and C are respectively, relatively light and heavy liberations of commercial timber trees and future crop trees (species which are likely to be commercial after 20-30 years). Non-desirable trees (trees of non-commercial species and trees of commercial species with very serious defects) around the commercial stem will be eliminated. The optimum area in which liberation will be implemented around the commercial stem will be estimated, among others by using the critical basal area in the climax forest of the experimental plots and the relation between crown diameter and stem diameter. Liberation will be restricted to areas within a specified distance from the nearest tree to be liberated. The theoretical distance obtained will allow to formulate light and heavy liberation treatments.

The intensity of treatments will be (partially) determined by the area around the commercial timber stem where liberation is to be applied. The intensity of liberation may also be determined by the list of species to be liberated, which may be longer in treatment C than in treatment B. Within the liberation operations, the diameter of trees to be killed should be approximately the same or larger than the stem to be liberated. Different liberation intensities will be simulated in the permanent transect (see below), and based on this simulation, the treatments to be implemented in the field will be defined. The simulation will be made either by hand or by computer.

3.1.1 Trees to be liberated

Four categories of species can be distinguished:

1. Timber species actually on the market, i.e. all timber species exploited within Cameroon and/or in other African countries;
2. Timber species of high future potential (species which are likely to be commercial after 20-30 years), i.e. other species with known good technological qualities and very promising lesser-known timber species studied in project F3;
3. Other potential timber species, i.e. other timbers with a known commercial potential;
4. Species of value to the local population; species of this category may be liberated or only preserved.

The list of species which will be liberated in treatment B will include all tree species of categories 1 and 2 (short list). The list of species to be liberated in treatment C may include in addition to all species of categories 1 and 2, a number of species of categories 3 and 4. In addition, trees to be liberated should be at least 20 cm dbh and of good stem quality.

3.1.2 Trees to be killed

Trees to be killed will be selected among trees which are:

- not to be liberated or preserved, and
- which compete for light with trees to be liberated, or
- which are supposed to become competitors before the next silvicultural treatment.

As the rate of future competition depends on the crown expansion of trees, which cannot be predicted accurately, it seems useful to base the initial selection of trees to be killed on two different scenarios, that is, one assuming that trees grow about 1 cm/yr in stem diameter, and that the relation between crown dimensions and stem diameter will not alter, and one assuming that trees to be liberated need about 50% more space than in the first scenario. Another approach which may be considered is one based on the critical basal area, that is to reduce the basal area in the immediate vicinity of the tree to be liberated to 25 or 50% of this critical basal area.

3.1.3 Simulation of treatments

Based on the considerations mentioned above, at least two treatments will be defined initially. These treatments will be subject to a reiterative simulation process to detect possibilities for improvement. The first step will be to select one or more tracts of the forest (transect, 1-ha plots), which are representative for the experiment as a whole in terms of species composition, size class and spatial distributions of tree species groups, occurrence of gaps, etc.

For the simulation, a three-dimensional model of the forest in the transect and/or 1-ha plots will be made, either by hand or by computer. The treatments will be simulated in this model. This will allow the researcher to detect possibilities to improve light conditions for regeneration and growth of timber species further and to eliminate less desirable ecological effects. After modification, the improved treatment will be simulated, and the procedure is repeated until the treatment cannot be improved any further. Finally, two distinctly different treatments will be selected among those resulting from the simulation process, taking in consideration treatment costs, easy implementation and other aspects not covered by the simulation procedure.

3.2 Analysis of vegetation

Vegetation analysis will consist of:

- variation in species composition;
- diameter class distribution;
- spatial arrangement of trees;
- (spatial distribution of seedlings and saplings);
- (spatial distribution of lianas).

Species composition of trees in permanent sample plots will be analyzed. The post-felling treatments will be based, among others, on this detailed analysis. An ordination technique will be used to investigate vegetational variation in itself, and the spatial patterns of categories of trees (e.g. species, size classes) and diameter class distributions will be analyzed as well. Spatial distributions of seedlings, saplings and lianas, carried out as part of other projects within the Tropenbos-Cameroon Programme, will also be used in the simulation.

3.3 Analysis of phenological data

The phenological data will be analyzed using simple statistical methods. They will be compared with results from the Tropenbos weather stations.

3.4 Results of silvicultural treatments

After treatments B and C have been applied in the field, the actual treatments will be compared with the results of the simulation. Furthermore, initial growth response will be analyzed using standard statistical methods (ANOVA, t-test, regression analysis), and the impact on biodiversity will be assessed. In a later phase of the project (i.e. after the Ph.D. study has been completed), more growth, mortality and regeneration data will become available to be used for the prediction of long-term stand development.

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Session IV

Chair: Dr. R.G. Lowe

Crown dimensions and stem sectional area growth of some mixed tropical forest tree species in Ghana

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Abstract

The use of tree crown dimensions as indices of tree growth potential has been well documented for many tree species in temperate regions. Crown dimensions are useful in determining growing space and optimum stand density, and for improving the accuracy of tree growth models. However, for mixed tropical forest tree species such information is lacking, not least because the complex structure of such forests makes it difficult and expensive to collect data on tree crowns. Where such data can be collected, however, its usefulness in improving the efficacy of models for forest management cannot be over-emphasised.

This paper examines the relationship of the crown dimensions of five mixed tropical forest tree species in Ghana to their growth rates. Data on crown diameter and stem diameter were collected from a total of 408 trees in Bobiri Forest Reserve. From these data crown area, crown volume, diameter increment and sectional area increment (over a period of ten years) were calculated. Regressions of stem sectional area increment on projected crown diameter, crown area and crown volume were all highly significant statistically, but crown area was found to be a better predictive variable than the other attributes of crown size. The regressions on crown area explained 18%, 49.6%, 56.1%, 58% and 62% of the total variation in increment for Guarea cedrata, Mansonia altissima, Entandrophragma angolense, Triplochiton scleroxylon and Khaya ivorensis respectively. In the regression combining all five species 72.8% of the total variation was explained by the regression. From these regressions general linear models were developed for the individual species, from which stem sectional area increment can be predicted, given the crown area of the species. But the strengths of these models in predicting growth are limited to the range of data used in the study, as extrapolation beyond the extremes of this range may reduce their reliability. The study confirms the widely held belief that increment in tree stem diameter or sectional area is related to crown size, or the amount of foliage in the crown.

***Keywords**: crown dimensions; sectional area increment; diameter increment; growth models.*

Introduction

Tree growth may be defined as the accretion of woody material over time, as is evident in the increase in girth, sectional area, diameter, height or volume (Wan Razali 1988; Alder & Synnott 1992; Philip 1994). It is generally believed that organic production in trees is related to the amount of foliage (Assmann 1970; Waring *et al.* 1980; Waring *et al.* 1981; Snowdon 1987). This suggests that growth in diameter is related to crown size. Crown size and its relation to tree diameter and growth has been considered in many mensurational studies in temperate regions (e.g. Smith *et al.* 1992; Sprinz and Burkhart 1987; Waring 1983). It has also been shown to improve the accuracy of individual tree taper and volume equations (Hahn *et al.* 1987). But few studies have been reported for mixed tropical forest tree species, notable among them being Dawkins' (1963) treatise on crown diameter and its relationship to stem diameter. In general, however, tree crown dimensions constitute an important component in modelling forest growth, as the crown is made up of that part of the tree responsible for photosynthesis.

In normal mensurational practice, data on crown size are difficult, expensive and time consuming to gather (Alder 1995). However, where such data are available the accuracy of growth models and other estimates of stand characteristics such as optimum crop density and growing space can be enhanced. It is in this direction that this paper seeks to examine the relationship between crown dimensions and diameter or sectional area growth for some mixed tropical forest tree species in Ghana.

Source of data and methods

The data for this study were collected from the Bobiri Forest Reserve in Ghana where permanent plots (Girth Increment Sample Plots or GISPs) had been set up since 1946. Since 1962 a number of silvicultural experiments had been carried out by FORIG, aimed at producing conditions for natural regeneration and obtaining information on the growth rates of the more valuable species. From these GISPs nine 1-ha plots were randomly selected, and measurements were carried out on a total of 408 individual trees. The parameters measured were crown radius, crown depth or crown length, tree total height and stem diameter.

Crown measurements were based on the assumption that the vertical projection of the crown is roughly circular (Krajicek, *et al.* 1961; Nance *et al.* 1988; Smith, *et al.* 1992). On each tree, four radii were measured, in directions forming equal angles, by projecting them vertically to the ground by ocular estimation, as described by Alder and Synnott (1992). Crown diameter was calculated by summing up the four radii measurements and dividing by 2. Crown length, or crown depth, was also estimated by measuring tree total height and tree height up to the base of the crown and subtracting the latter from the former. Projected crown area was calculated from $\frac{1}{4}\pi.C_d^2$, and crown volume, assuming a paraboloid shape, from $C_v = \frac{1}{8}\pi C_d^2 \cdot C_l$. The symbols C_v, C_l and C_d represent crown volume, crown length or depth and crown diameter respectively.

Stem diameter was measured at 4 m above ground level, following the earlier measurement protocol for these plots. This was to offset inconsistencies which were likely to result from measuring diameter at different reference points, especially in buttressed trees whose diameters could not be measured at breast height. These diameter measurements were then used to calculate diameter and sectional area increment based on earlier measurements taken on the same subject trees ten years earlier.

Stem diameter increment and sectional area increment were regressed on crown diameter, crown area and crown volume to determine which of them had the better relationship with the various measures of crown size. All negative increment values were excluded from the regressions or assumed to be zero.

Preliminary examination of the data showed no significant curvature of the regressions for individual species from the different plots. Hence several simple linear models were compared, using diameter and sectional area increment as the dependent variate in each case. The models compared were:

$$I_d = \alpha + ß.C_d + \xi_i \qquad \{\text{eqn. } 1\}$$

$$I_d = \alpha + \beta.C_a + \xi_i \qquad \{\text{eqn. } 2\}$$

$$I_d = \alpha + \beta.C_v + \xi_i \qquad \{\text{eqn. } 3\}$$

$$I_s = \alpha + \beta.C_d + \xi_i \qquad \{\text{eqn. } 4\}$$

$$I_s = \alpha + \beta.C_a + \xi_i \qquad \{\text{eqn. } 5\}$$

$$I_s = \alpha + \beta.C_v + \xi_i \qquad \{\text{eqn. } 6\}$$

where I_s and I_d denote sectional area increment and stem diameter increment respectively. C_d, C_a and C_v are crown diameter, crown area and crown volume respectively. A summary of the statistics on the data obtained is presented in Table 1.

Table 1: Summary statistics of data for the main parameters in the diameter increment-crown size regressions. CV is the coefficient of variation and Std. Error is standard error of estimate of the dependent variable.

			Species			
Parameter	**TRI**	**EA**	**KI**	**GC**	**MAN**	**All species**
No. of cases	119	105	47	91	46	408
Stem diameter, D (cm)						
Minimum	20.50	6.50	6.50	6.00	10.20	6.00
Maximum	89.90	49.60	73.40	50.50	39.10	89.90
Mean	56.13	18.21	33.52	18.79	19.44	31.41
Std. Error	1.366	0.867	2.415	0.890	0.718	0.908
CV	0.264	0.478	0.494	0.442	0.248	0.640
Crown diameter, Cd (m)						
Minimum	3.30	0.70	1.20	0.80	1.90	0.70
Maximum	21.70	11.80	16.60	10.60	11.60	27.80
Mean	10.18	3.10	6.65	4.25	5.17	6.27
Std. Error	0.329	0.195	0.481	0.197	0.260	0.196
CV	0.351	0.632	0.496	0.432	0.337	0.691
Crown area, Ca (m^2)						
Minimum	8.600	0.400	1.100	0.500	2.800	0.400
Maximum	369.800	109.400	216.400	88.200	105.700	369.800
Mean	91.320	10.455	43.023	16.772	23.358	41.071
Std. Error	5.889	1.585	6.134	1.585	2.480	2.602
CV	0.700	1.516	0.977	0.891	0.712	1.266
Crown volume, Ca (m^3)						
Minimum	20.60	0.100	0.400	0.300	6.400	0.100
Maximum	2375.300	235.200	1341.700	344.000	406.900	2375.300
Mean	385.611	22.691	154.946	34.647	53.641	152.981
Std. Error	37.380	4.272	34.583	5.314	9.896	14.388
CV	1.053	1.854	1.514	1.447	1.224	1.867
Sectional area increment, Is ($cm^2 yr^{-1}$)						
Minimum	8.600	0.400	1.100	0.500	2.800	0.400
Maximum	369.800	109.400	216.400	88.200	105.700	369.800
Mean	91.320	10.455	43.023	16.772	23.358	41.071
Std. Error	5.889	1.585	6.134	1.585	2.480	2.602
CV	0.700	1.516	0.977	0.891	0.712	1.266
Diameter increment, I_d ($cm yr^{-1}$)						
Minimum	0.230	0.040	0.440	0.180	0.150	0.040
Maximum	86.030	13.300	76.510	17.960	5.900	89.030
Mean	10.800	2.480	7.126	4.351	2.185	6.025
Std. Error	0.883	0.289	1.750	0.439	0.239	0.411
CV	0.876	1.093	1.610	0.876	0.702	1.299

Results and discussion

The results of the regressions in models {eqn. 1}, {eqn. 2} and {eqn. 3} showed a weak relationship between diameter increment and the predictor variables - crown diameter, crown area and crown volume, with the regression explaining from as low as 1.4% to about 31.9% of the total variation in diameter increment. Nevertheless, except for *Guarea cedrata* - in {eqn. 1} to {eqn. 3} and *Mansonia altissima* - in {eqn. 3} the regressions were very significant ($0.01 < P \leq 0.001$). Sectional area increment, on the other hand, was found to be consistently better predicted by crown diameter, crown area and crown volume. Here, also, the regressions were mostly highly significant for the five species. But a stronger relationship was found between sectional area increment and crown area than for the other predictor variables ({eqn. 5} in Table 2), explaining between 18% and 62% of the total variation in sectional area increment. The regression lines showing these relationships are shown in figures 1, 2 and 3.

The regression constants, *a*, were not significantly different from zero for *Guarea cedrata* and *Mansonia altissima* in {eqn. 4} and *E. angolense, K. ivorensis* and *Mansonia* in {eqn. 5}, but in the latter the *a* term was not significantly different from zero in the combined regression. This seems to suggest that trees with very small crowns may not be as efficient in producing increment as those with larger crowns in terms of projected area.

Greater consistency in the significance of the regression coefficients was obtained in {eqn. 6}, in which most of the coefficients were highly significant ($P \leq 0.001$). The exceptions were *Entandrophragma angolense* and *Khaya ivorensis* for which the α terms were significant at 5% and 1% respectively.

Further analysis of the distribution of residuals in {eqn. 4}, {eqn. 5} and {eqn. 6} revealed that {eqn. 5} and {eqn. 6} satisfied the basic assumptions of constant variance and homogeneous distribution. However the residual standard deviations were smaller in magnitude in {eqn. 5}. This model also gave higher determination coefficients, (r^2) than {eqn. 6}, both in the regressions for the individual species and in the regressions combining data for all the species, the only exception being *Khaya ivorensis* which had a lower r^2 value in {eqn. 5}. On the strength of these observations therefore crown area was chosen as the most suitable predictor variable {eqn. 5} for predicting sectional area increment from crown size.

The reason for crown volume not predicting increment as satisfactorily as crown area may be explained in the light of the argument advanced by Jack and Long (1992) that stem wood production per unit crown area or leaf area decreases with increasing crown volume. This is attributed to the presence of a bare, non-foliated core within tree crowns, and the fact that as crown volume increases so does the proportion of total crown volume occupied by the bare core. This implies that a certain maximum size of crown is required to produce optimum growth, beyond which growth is likely to decline.

From {eqn. 5} therefore, the following general predictive equations were obtained for the five species:

T. scleroxylon: $I_S = 20.293 + 0.739\ C_a$
E. angolense: $I_S = 1.433 + 0.600\ C_a$
K. ivorensis: $I_S = 4.565 + 0.628\ C_a$
G. cedrata: $I_S = 6.473 + 0.334\ C_a$
M. altissima: $I_S = 1.261 + 0.239\ C_a$

It is interesting to note that the inclusion of tree total height as an additional predictor variable in the regression combining all species was highly significant, but did not contribute much to the reduction of the amount of unexplained variation in sectional area increment ($R^2 = 0.665$) nor the error in the estimate ($\sigma_{(y)} = 30.829$). The coefficients of multiple determination were 0.516, 0.446, 0.358, 0.294 and 0.281 for *Triplochiton scleroxylon, E. angolense, Khaya ivorensis, Guarea cedrata and Mansonia altissima* respectively; all these values being lower in magnitude than those in {eqn. 5} (Table 2). This seems to suggest that tree total height is important but does not contribute as much to increment as does projected crown area.

Table 2: Parameter estimates and coefficients for the regression of diameter increment/sectional area increment on crown diameter, crown area and crown volume.

Parameter estimates and coefficients	Model					
	{eqn. 1}	{eqn. 2}	{eqn. 3}	{eqn. 4}	{eqn. 5}	{eqn. 6}
Triplochiton						
r^2	0.217***	0.204***	0.134***	0.580***	0.580***	0.485***
a	-1.625$^{n.s}$	4.782***	7.623***	-47.118***	20.293**	46.633***
β	1.225***	0.066***	0.008***	13.282***	0.739***	0.107***
$\sigma_{(y)}$	8.401	8.480	8.838	41.001	41.164	45.565
E. angolense						
r^2	0.319***	0.316***	0.359***	0.498***	0.561***	0.599***
a	0.040$^{n.s}$	1.466***	1.626***	-7.002**	1.433$^{n.s}$	2.478*
β	0.768***	0.092***	0.038***	4.697***	0.600***	0.238***
$\sigma_{(y)}$	2.271	2.257	2.203	9.699	8.987	8.584
K. ivorensis						
r^2	0.166**	0.168**	0.148**	0.568***	0.620***	0.559***
a	-2.074$^{n.s}$	2.381$^{n.s}$	4.213**	-19.487*	4.565$^{n.s}$	15.144**
β	1.375**	0.108**	0.018**	7.707***	0.628***	0.107***
$\sigma_{(y)}$	10.605	2.257	10.722	22.885	21.466	23.106
G. cedrata						
r^2	0.014$^{n.s}$	0.018$^{n.s}$	0.002$^{n.s}$	0.158***	0.180***	0.108**
a	3.392**	3.794***	4.327***	0.962$^{n.s}$	6.473***	9.472***
β	0.240$^{n.s}$	0.032$^{n.s}$	0.003$^{n.s}$	2.646***	0.334***	0.077**
$\sigma_{(y)}$	3.830	3.817	3.854	11.500	11.317	11.804
M. altissima						
r^2	0.168**	0.213**	0.060$^{n.s}$	0.341***	0.496***	0.486***
a	0.356$^{n.s}$	1.226**	1.969**	-3.017$^{n.s}$	1.261$^{n.s}$	3.499***
β	0.358**	0.041**	0.005$^{n.s}$	1.915***	0.239***	0.061***
$\sigma_{(y)}$	1.405	1.377	1.493	4.888	4.275	4.318
All species						
r^2	0.271***	0.324***	0.247***	0.682***	0.728***	0.628***
a	-2.188***	2.438***	3.971***	-32.110***	1.077$^{n.s}$	14.345***
β	1.162***	0.083***	0.013***	10.965***	0.831***	0.141***
$\sigma_{(y)}$	7.427	6.441	6.832	29.509	27.179	31.771

*** highly significant: $P \leq 0.001$; ** very significant: $0.01 < P \leq 0.001$; * significant: $0.01 < P < 0.05$;
n.s.: not significant

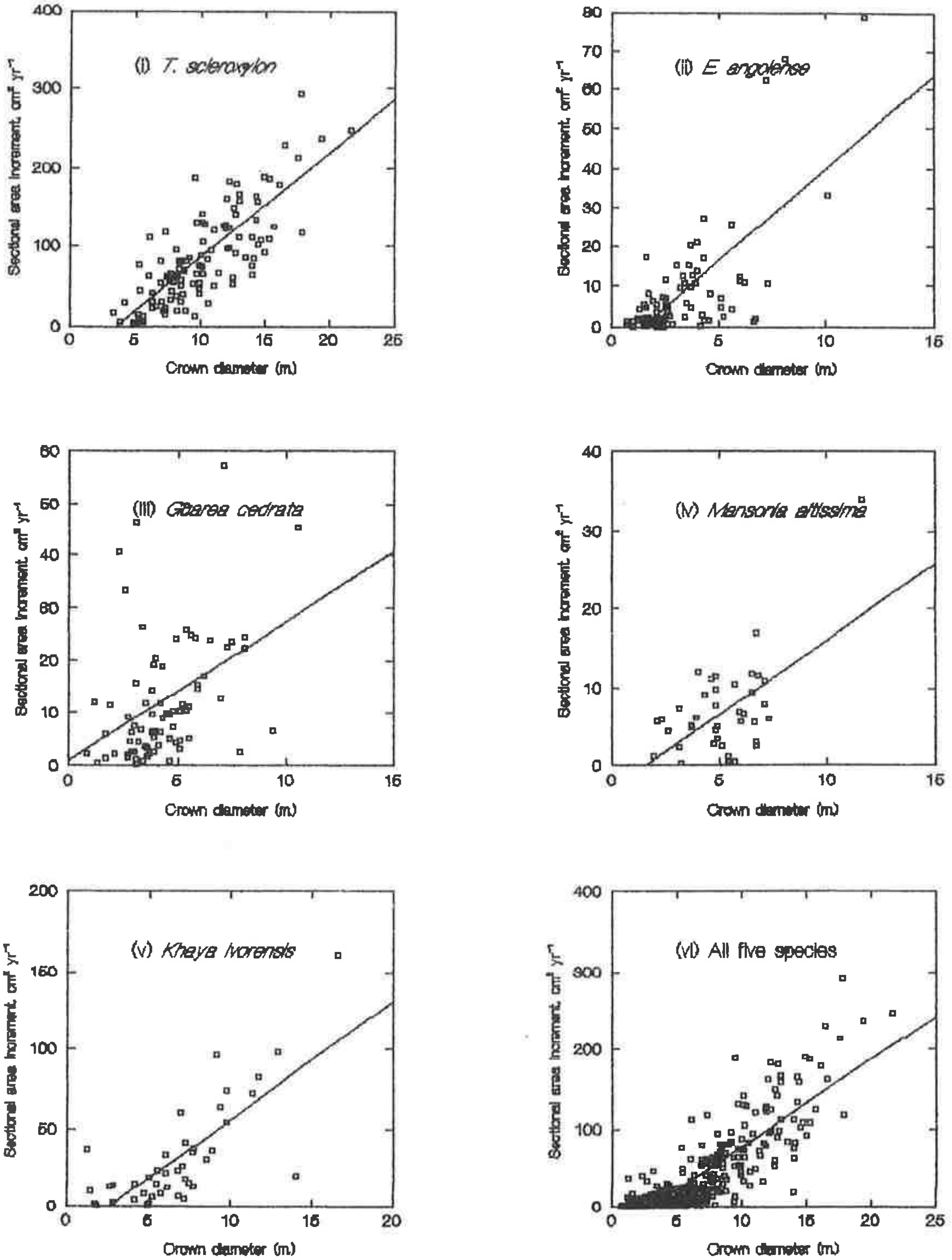

Figure 1: Relationship between stem sectional area increment and projected crown diameter

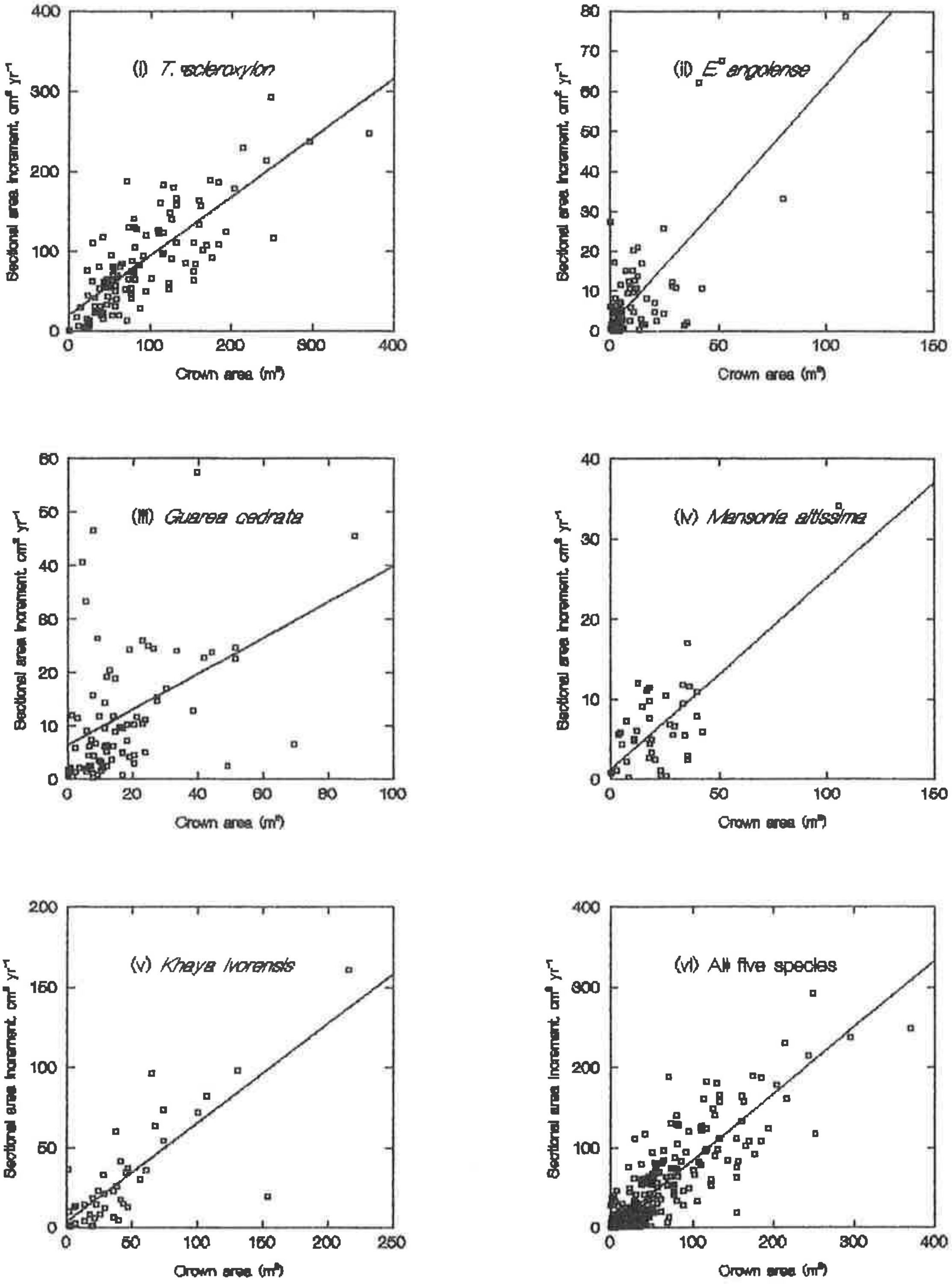

Figure2: Relationship between stem sectional area increment and crown area.

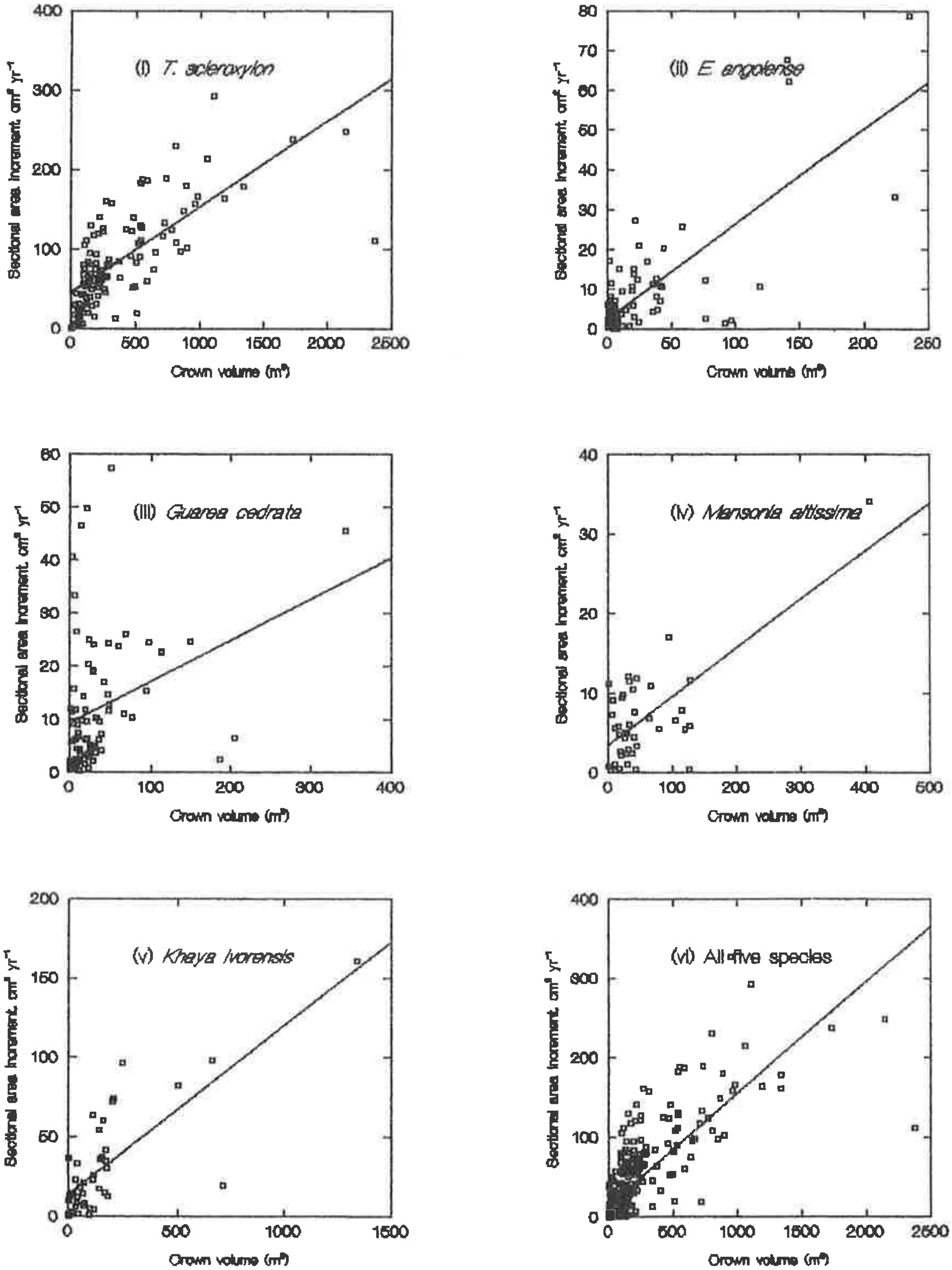

Figure 3: Relationship between stem sectional area increment and crown volume.

Conclusion

The results from this study confirm the observation that crown size influences stem increment, and that crown area is a more useful predictor variable for models relating increment in sectional area (or basal area) to crown size than crown diameter or crown volume. It is concluded that projected crown area is important as a predictor variable, and that a certain maximum crown area is required for optimum growth of trees. A knowledge of this maximum can be beneficial as a guide for determining the growth rates in a stand, as well as the optimum spacing required for establishing particular species in plantations. With the range of data available for this study it was not possible to determine this maximum. It would, however, be interesting in future studies to observe the trend of the increment curve to determine the size of crown at which the species tend to put on maximum increment, and whether increment declines or remains constant over the range of girth classes. It may also be interesting to study the contribution of other predictor variables, such as crown projection ratio (which expresses the amount by which crown diameter is larger than stem diameter; and is an index of growing space) and the degree of spread (the ratio of crown width to total height) in reducing the amount of unexplained variation in sectional area increment.

The models developed for the five species studied fit the data quite satisfactorily as the results of the regressions show, but their reliability may be limited by the range of data used in this study. Therefore there is need for caution in using them for data which fall outside this range.

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Some data on diameter and height of Okoumé (*Aucoumea klaineana)* forests of Chaillu region (Congo).

Quelques données sur le diamètre et la hauteur des forêts d'Okoumés (*Aucoumea klaineana)* dans la région du Chaillu (Congo).

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Abstract

Okoumé (Aucoumea klaineana) is one of the main forest species of south-Congo. The structure study of forest stands where Okoumé is growing is carried out in the Chaillu area. Diameter (DBH) and height are the main parameters taken into account to study the variability of size, growth, and colonizing ability. The presence of understory species or secondary species in man-made or natural Okoumé forest is also investigated. Several forest plots and one Okoumé plantation are analysed. Mean values of DBH and height of these stands are respectively 29,8-72,1 cm and 30,1-43,8 m in forest, and 23.2 cm and 21.3 m in 14-year-old plantation.

Keys words: *Okoumé, diameter, height, plantation, forest.*

Résumé

L'Okoumé (Aucoumea klaineana) est l'une des principales essences forestières du Sud-Congo. L'étude de la structure des formations forestières qu'elle occupe dans la zone du Chaillu est entreprise. Le diamètre (DBH) et la hauteur sont les principaux paramètres retenus pour étudier la variation de sa taille, sa croissance, son caractère colonisateur et la présence des espèces du sous-bois ou des espèces accompagnatrices en plantation ou en forêt naturelle. Des placettes de forêt naturelle et une plantation d'okoumé sont essentiellement analysées. Les valeurs moyennes de diamètre (DBH) et de hauteur de l'okoumé dans ces formations sont respectivement: 29,8-72,1 cm et 30,1-43,8 m en forêt, et 23,2 cm et 21,3 m pour la plantation de 14 ans.

Mots-clés: *Okoumé, diamètre, hauteur, plantation, forêt naturelle.*

1 Introduction

Congolese forests cover more than 60% of the national territory (65.6% according to estimations made in 1980/1981) corresponding to 9.9% of the closed forests of the African continent, and 12.3% of those of Central Africa. The forests of southern Congo, which occupy at least 5 millions ha,are the natural expansion area of Limba (*Terminalia superba*) and Okoumé (*Aucoumea klaineana*). These species have a high economic value. Okoumé is one of the most important timber resources of the Congo; Okoumé wood stock is estimated to be about 5 millions m^3 (Vergnet 1986 in Hecketsweiler 1990). It is an important resource for plywood (Wood 1963, Scheiber, 1970 in Brunck et al. 1990). Therefore, a particular attention must be paid to forest stands where this species is growing, in order to manage a sustainable productivity.

Deforestation in southern Congo is estimated to be 0.5 ha/year (Sibona 1985 in Hecketsweiler 1990). Afforestation programmes are necessary to maintain and to save the forest and to ensure its regeneration. In order to contribute to the suitable management of Chaillu forest, analysis of its structure and growth is carried out. This work completes forestry studies led by C.P.A.L[15]. at Ngoua 2 (Chaillu area) since 1989.

Preliminary results are presented here on DBH and height of forest plots and plantations. A 12-13-year-old Okoumé plantation is the main studied stand. Acacia and eucalypt plantations with similar age are also studied.

2 Material and methods

2.1 Site characteristics

The study site is Ngoua 2, located in the Chaillu forest area in the southern Congo. Its geographical characteristics are: 2°58"S latitude, 12°25"E longitude and 250m altitude. The climate is sub-equatorial with two seasons: a rainy season (october-may) and a dry season (june-september). Mean anual rainfall (1987-1994) is 1658 mm and mean annual temperature is near 25°C. Relative humidity is always high (generally more than 75%).

Soils are ferrallitic (according to the french classification), acids, desaturated in cations with a low exchange capacity (Champs & Denis 1974). Some chemical characteristics of top soils are in Table 1. Native vegetation is mainly a semi-evergreen rain forest. There are also open forests with Maranthaceae invading the undergrowth, where Okoumé forms natural patches. Grassy savannas also occur: the herb strata is dominated by *Hyparrhenia cf diplandra* and the shrub strata by *Hymenocardia acida*, *Annona senegalensis*, *Nauclea latifolia* or *Bridelia ferruginea* (Teillier 1994).

Table1: Characteristics of top soils of savanna and Okoume natural forest at Ngoua 2 area (Congo).

Composition chimique élementaire des sols de surface de la savane et d'une forêt naturelle d'Okoumé de la zone de Ngoua 2 (Congo).

Stand	Depht	pH	C(%)	N(%)	C/N
Savanna	0-6 cm	4.81	1.01	0.16	6.31
Okoume forest	0-10 cm	3.29	3.28	0.31	10.58

2.2 Studied stands

- The study was carried out in forest and in tree plantations.
- In natural forest, two kinds of plots were studied:
  - ⇒ two permanent plots in closed forest. They were set up in 1987 by FAO PRC 80/005 Project to observe the Okoumé growth;
  - ⇒ one plot in an Okoumé patch where the experimental study was set up by C.P.A.L. to investigate the dynamic of Okoumé rich natural forest stands

A forest fallow was manually cleared in the savanna area. An Okoumé plantation was made in Ngoua 2 Arboretum, in November 1982, with tree spacing 4 x 4m. Two other plantations, with a similar age, are studied in the same area: *Acacia mangium* and *Eucalyptus deglupta.*

2.3 Methods

Stand structure and growth were assessed by measurements of DBH (Diameter at Breast Height) and height. Measurements were made on 15 or 20 trees (depending on plot) in closed forest, in order to follow the growth of main species, and on 3-10 stems of main species in the Okoumé patch. DBH

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[15] Centre Pilote d'Afforestation en Limba (Congolese research center for Limba afforestation, former section of french research center C.T.F.T.)

measurements were made on all planted trees, in one from two plantation lines in Okoumé plantation, and height was measured on some of these trees. Diameter of all erected woody plants of the understory vegetation was measured in a quarter of the stand. Naturally regenerated stems of Okoumé were also measured in Okoumé plantations and in others plantations (acacia and eucalypt) where 5 to 15 stems were selected.

Chemical analysis of soils was made by ORSTOM laboratory at Pointe-Noire (Congo).

3 Results

3.1 Forest

Mean value of DBH and height of Okoumé in natural forest are in Table 2. Sizes change with stands: 29.8 to 72.1 cm DBH and 27.8 to 43.8 m total height.A strong correlation is observed between these parameters (r = 0.71).

Table 2: DBH, bole height and total height of Okoume in natural forest plots of Chaillu area (A=FAO plot, B=CCAF plot, CPAL data; C=OCF 81bis plot)

DBH, hauteur du fût et hauteur total de l'Okoumé des placettes de forêt naturelle dans la zone du Chaillu (A=placette FAO, B= placette CCAF, données du CPAL; C=placette OCF 81 bis)

Plots	A	B	C
Diameter (cm)	38,9 ± 2,11	72,1 ± 4,0	29,8 ± 5,49
Bole height (m)	16,2 ± 1,33	19,8 ± 1,68	20,1 ± 2,74
Total height (m)	27,8 ± 0,73	43,8 ± 1,68	30,4 ± 2,60

Table 3: Diameter (DBH), bole height and total height of Okoume and *Musanga cecropioides* in a 12-year-old Okoume plantation at Ngoua 2 (Chaillu area, Congo).

Diamètre (DBH) et hauteurs des pieds d'okoumé (*Aucoumea klaineana*) et de parasolier (*Musanga cecropioides*) d'une plantation d'okoumé de 12 ans de Ngoua 2 (Massif du Chaillu, Congo).

	Okoume	Musanga cecropioides
DBH (cm)	17,4 ± 0,403	16,2 ± 2,217
Bole height (m)	7,6 ± 0,396	13,5 ± 1,143
Total height (m)	16,1 ± 0,911	17,9 ± 0,779

The girth growth of Okoumé is indicated on Figure 1. Measurements made during 7 years (1987-1994) show a low mean annual increment, 0.30-0.45 cm. Figure 2 shows the size data of some trees from a stand which was studied by Mellinger (1993). *Aucoumea klaineana* (Okoumé), *Xylopia aethiopica* and *Strombosia grandifolia* form approximately 60 % of total stem number, 30.8 % of which are Okoumé).

Figure 1 : Girth growth of Okoume in two forest plots (A=FAO plot, B=CCAF plot ; CPAL data): Croissance en circonférence de l'okoumé à l'état naturel dans deux placettes (A= FAO, B=CCAF, données du C.P.A.L.)

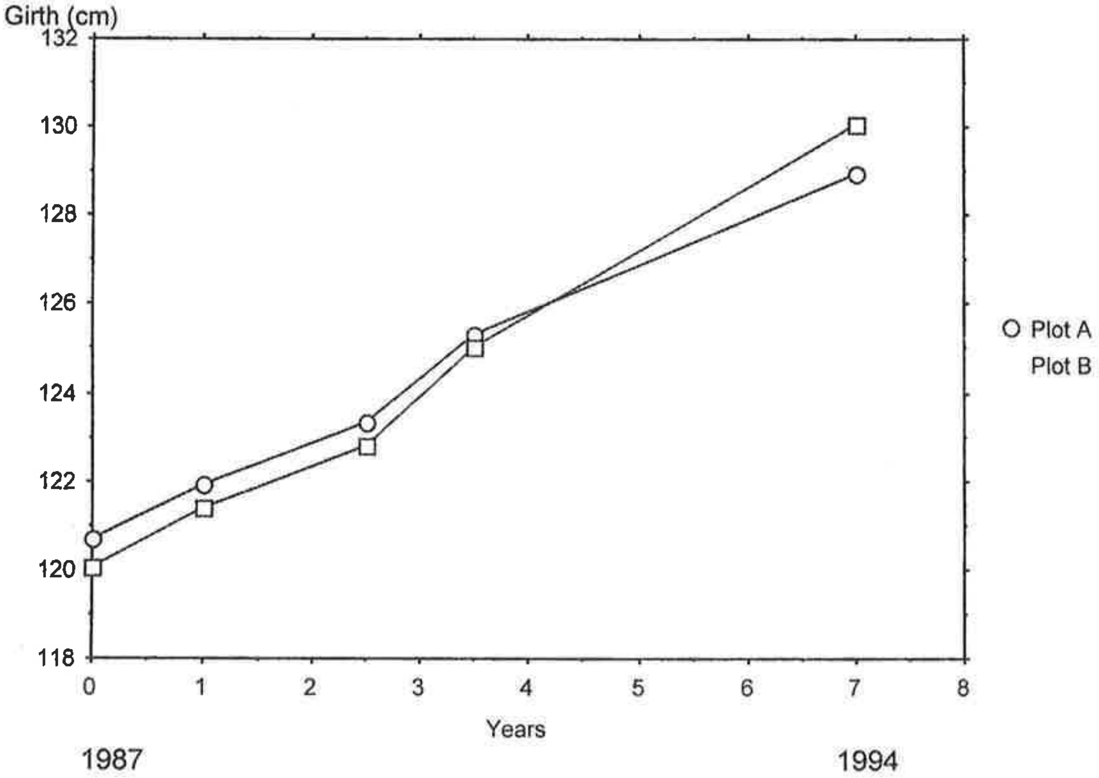


Figure 2: DBH, Bole height and total height of some species of Okoume natural patches in Chaillu area (Congo)
DBH, hauteur de fût et hauteur totale de quelques espèces dans une tache naturelle d'okoumé du massif du Chaillu (Congo).

Ak= *Aucoumea klaineana* ; Xa= *Xylopia aethiopica* ; Sg= *Strombosia grandifolia* Py= *Pausinystalia yoyimbe* ; Pe= *Pentachletra eetveldeana* ; Pa= *Piptadeniastrum africanum* ; Kg= *Klainedoxa gabonensis* ; Us= *Uapaca sp* Fd= *Filaeopsis discophora* ; Ns= *Newtonia sp* .

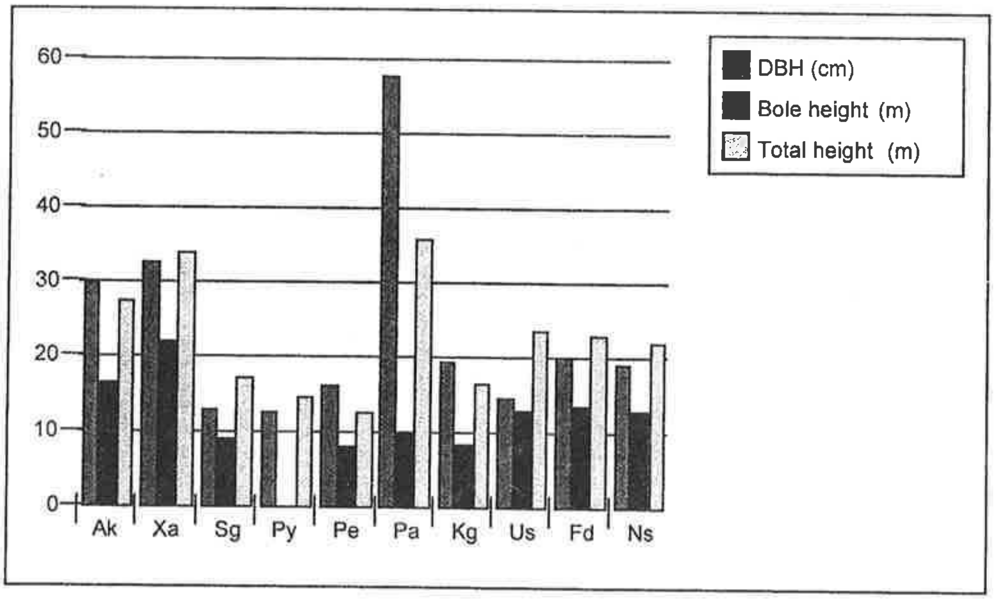
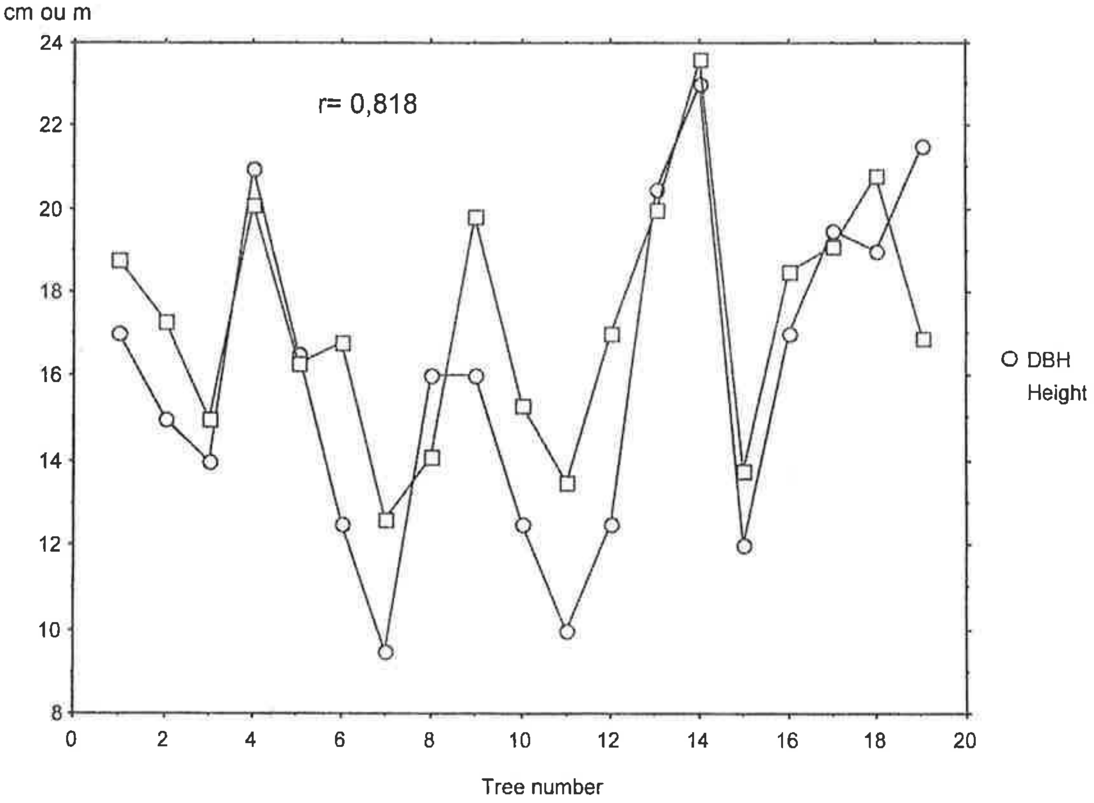


Figure 3: Diameter and height variation of Okoume in a 12-year-old plantation of Ngoua 2 Arboretum (Chaillu areaCongo)
Variation du diamètre et de la hauteur de l'okoumé dans une plantation de 12 ans de l'arboretum de Ngoua 2 (Massif du Chaillu, Congo)



3.2 Plantations

3.2.1 Okoumé plantation

Mean value of DBH and height of the Okoumé plantation are in Table 3 and annual increment in Table 4. Figure 3 shows the strong relation between these two parameters (r=0.818). Height growth is on Figure 4.

The main shrubs species of understory, sorted out into diameter class, are in Table 5. *Euphorbiaceae* is the most important family. *Hymenocardia ulmoides* and *Chaetocarpus africanus* are the most important species. Besides shrubs, understory is mainly made up with ferns (*Nephrolepis undulata* and *Selaginella cf myosorus*) and lianas (*Manotes pruinosa, Smilax kraussiana* and *Gnetum africanum*), the ground cover coefficient of which is 3 according to Braun-Blanquet (1964) scale.

Figure 4 : Height growth of Okoume in plantation at Ngoua 2 (Chaillu area, Congo) (First three points from Fabbri 1990)

Croissance en hauteur de l'Okoumé en plantation à Ngoua 2 (Zone du Chaillu) (Les trois premiers points sont tirés de Fabbri, 1990)

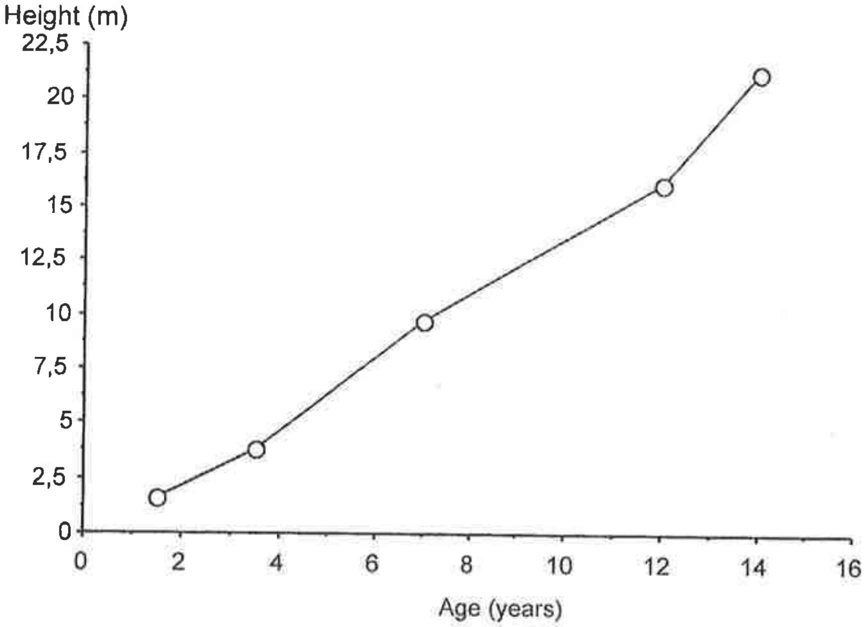


Table 5: Distribution in diameter classes of understorey main species of the 12-year-old Okoume plantation at Ngoua 2 (Congo).

Nombre d'individus des principales espèces du sous-bois de la plantation d'okoumé de 12 ans de Ngoua 2 répartis en classes de diamètre.

		Diameter class(cm)					
Species	Family	1-5	5-10	10-15	15-20	20-25	>25
Hymenocardia ulmoides	*Euphorbiaceae*	122	96	25	11	4	
Chaetocarpus africanus	*Euphorbiaceae*	111	74	6			
Macaranga spinosa	*Euphorbiaceae*	6	8	6	2	4	
Maprounea membranacea	*Euphorbiaceae*	0	3	4	2	3	3
Bridelia ferruginea	*Euphorbiaceae*	2	4	5	2	0	1
Alchornea cordifolia	*Euphorbiaceae*	2	9				
Total	-	243	194	46	17	11	4

3.2.2 Okoumé regeneration in plantations

Diameter and height of regenerated Okoumé in 12-13-year-old plantations of *Acacia mangium, Aucoumea klaineana* and *Eucalyptus deglupta* are in Table 6. Regenerated Okoumé is slightly bigger and taller in eucalypt plantation where shade canopy is lighter, than in acacia and eucalypt plantations. Mean annual increment of regenerated stems is only slightly lower than that of planted stems in all studied plantations, but regenerated stems are smaller and shorter compared to planted stems.

Table 6: Diameter (DBH) and height of regenerated Okoume and planted species in plantations of *Acacia mangium* (12 years), *Eucalyptus deglupta* (13 years) and *Aucoumea klaineana* (Okoume, 12 years) at Ngoua (Congo).

Diamètre (DBH) et hauteur et de l'okoumé naturel et des espèces plantées dans les plantations d'*Acacia mangium* (12 ans), *Eucalyptus deglupta* (13 ans) et *Aucoumea klaineana* (Okoumé, 12 ans) de Ngoua 2.

Stand	size of Regenerated Okoume		size of planted species	
planted species	DBH (cm)	height (cm)	DBH (cm)	height (cm)
Acacia	10,9	10,7	12,7 ± 0,819	15
Eucalyptus	13,7	12,3 ± 0,865	20,6 ± 0,877	21,3 ± 0,845
Okoume	9,8	11,2	17,4 ± 0,403	17,0 ± 0,699

Regenerated Okoumé stems are more numerous in acacia plantation than in eucalypt plantation, mostly in the border (these plantations are separated by approximately 10m). Regenerated stems represent 8.4 % of a hundred Okoumé listed in Okoumé plantation.

Only few planted species survived in others plantations inside the arboretum, where Okoumé is well established and becomes the dominated species in some cases, such as in plantations of *Terminalia mantali, Entandophragma angolense, Samanea saman* and *Cedrela augustifolia.*

4 Discussion

The study of diameter and height, which are important parameters of stand structure and growth, leads to emphasize the following facts.

1. In natural patches, or nearly monospecific stands of Okoumé, where trees diameter (or girth) has been studied by some authors, values of diameter are 20-33 cm in Chaillu area (Croisé & Fabbri 1991, Mellinger 1993) and 41-85 cm in littoral zone of Conkouati (Doumengue 1992) where this species is also abundant. Trees are bigger in closed forest which may be older. Natural patches of Okoumé in Chaillu area are around 40-year-old (Schwartz et al. 1996). The mean annual increment is low (0.30-0.45 cm).

   Differences observed between sites (Mariaux 1973, Croisé & Fabbri, Doumengue 1992, Mellinger 1993) can also be ascribed to intrinsic and/or local factors which may be more limiting than the surrounding ones suh as regional rainfall, as noted by Belingard et al. (1996) who studied the radial growth chronologies of Okoumé.

2. The annual increment of Okoumé in plantation is 1.45-2.3 cm for diameter and 1.3-1.7 m for height. These values seem to change according to age. Okoumé reacts in an anarchic way to rainfall when it is young (Belingard et al. 1996).

The authorized minimum standard for Okoumé logging is 70 cm diameter (Biraud 1959); therefore these plantations must be approximately 48-year-old to be logged; Okoumé requires a rotation of 50 years (Grainger 1988). The managers of the natural forest have to address this long period of tree growth and the low growth rate of regenerated trees (mean girth increment is 0.30-0.45 for the forest). Projections of future production of high-grade tropical hardwoods, as Okoumé, from tree plantations are important (Grainger 1988).

3. The establishment of Okoumé in eucalypt and acacia plantations with similar age has an increment slightly lower (diameter 0.91-1.05 cm and height 0.89-1.05 m). However, the pioneer character of Okoumé is obvious. Its aptitude to colonize cleared lands is well known. As already reported (Brunck et al. 1990, Doumengue 1992) Okoumé grows the best in moist well drained lands; its regeneration and first step of growth are better at the edge of the shading area than inside, as noted in studied plantations.

   Musanga cecropioides grows as quickly as Okoumé (Biraud 1959, Doumengue 1992) which is therefore hindered; both are heliophilous species and usually in competition. Consequently, the elimination of this invading species is often advised for silvicultural practices. *M. cecropiodes* falls down about six months after belting. Its highest height is 24 m at 15-20-year-old (White 1986).

5 Conclusion

Forest management is a long term work, and it si very important to do the good choices (Houllier et al. 1991). Therefore guideline data must be established. The present data on diameter and height may contribute to better knowledge of the growth and development of Okoumé stands, and may improve the silviculture of Okoumé in the Congo. The development of Okoumé forest is also involved in vegetation dynamics investigations. For instance, it indicates the settlement of forest in savanna area, which was studied in southern Congo (Doumengue 1992, Schwartz 1991,Schwartz et al. 1996).

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Résumé explicatif

L'okoumé est une des plus importantes ressources en bois d'oeuvre du Congo. Son aire naturelle correspond aux forêts du sud du pays. Pour contribuer à leur bonne gestion, l'analyse de la structure et de la croissance de ces formations forestières est entreprise en complément des études de foresterie menées par le Centre Pilote d'Afforestation en Limba (C.P.A.L.) à Ngoua 2 (zone du massif forestier du Chaillu), portant sur l'étude de la dynamique des forêts naturelles riches en okoumé depuis 1989.

Les premières données de cette étude sont présentées ici, à partir des mesures de diamètre (DBH) et de hauteur faites dans les placettes de forêt naturelle d'une part, et dans une plantation d'okoumé, complétées par celles d'acacia et d'eucalyptus du même âge de l'autre.

Les dimensions des arbres d'okoumé en forêt naturelle diffèrent selon les placettes : 29,8 - 72,1 cm de DBH et 27,8 - 43,8 m de hauteur totale. La croissance en circonférence de l'okoumé mesurée pendant 7 ans (1987-1994) révèle un faible accroissement moyen annuel, de l'ordre de 0,30 - 0,45 cm.

Les valeurs moyennes de DBH et de hauteur de l'okoumé sont respectivement 23,2 cm et 23,1 m dans la plantation de 14 ans. Le parasolier (*Musanga cecropioides*) croissant dans la même plantationa une taille voisine de celle de l'okoumé (mesurée à 12 ans).

Le diamètre et la hauteur de l' okoumé issu de la régénération naturelle dans les plantations d'*Aucoumea klaineana* (Okoumé), *Acacia mangium* et *Eucalyptus deglupta* ont été aussi mesurés. Ces pieds d'okoumé naturel ont des dimensions plus importantes sous Eucalyptus, dont le feuillage est moins dense que sous les deux autres plantations; leur taille est plus faible que celle des espèces plantées.

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Un modèle matriciel pour simuler la dynamique d'un peuplement forestier tropical semi-decidu (dispositif de M'baiki, République Centrafricaine).

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Résumé

Une des questions techniques centrale pour l'aménagement durable de la fôret tropicale concerne la durée de rotation ou plutôt le temps de retour d'un peuplement à son état initial après une intervention sylvicole. En effet, une règle de prudence consiste à ajuster prévalèment et la production.

La station de recherche de M'baiki, dans le sud de la République Centrafricaine, est un exemple de dispositif permanent permettant d'étudier en vraie grandeur cette question. Ce dispositif est rapidement présenté et les principaux résultats obtenus, entre 1982 et 1995, c'est à dire 13 ans après sa mise en place, sont donnés.

Toutefois, le temps d'observation est encore trop courte au regarde de la vitesse de réaction de la fôret. On prupose donc d'utiliser un modèle déterministe simple, basé sur le matrices de passage avec régulation par la densité, pour synthétiser les données disponibles et simuler dans ;e temps la réaction d'un peuplement après exploitation.

A matrix model to simulate the stand dynamics in a semi-deciduous tropical forest (M'baiki, Central African Republic).

Abstract

One of the central points regarding the sustainable management of the tropical forest is the length of the rotation or the time required by the forest to return to its initial state after a silvicultural disturbance. It is indeed a basic precaution to adjust the timber extraction and the production of the system.

The forest research station at M'baiki, in the south of the Central African Republic, is an example of permanent plots that enable to study this question on the long term. This station is shortly presented and some main results, obtained between 1982 and 1995 are given. However, the time of observation is too short yet, compared to the stand response. We propose therefore to use a determinist matrix model, based on growth probability matrix with density-dependence, to synthesize the data available and to simulate the stand behaviour after an artificial disturbance.

Introduction

La République Centrafricaine s'étend entre 2°30' et 11° de latitude Nord et 14°30' et 27°30' de longitude Est. Elle est couverte du Nord au Sud par une succession de formations végétales très variées, liée-au gradient climatique, allant de la savane arborée à Combrétacées jusqu'à la forêt dense ombrophile. Cette forêt dense subit de longue date un prélèvement de bois d'oeuvre, souvent modéré mais répété, qui fournit un revenu non négligeable à l'etat. Les essences les plus nobles, grandes

Meliacées essentillement puisque 85% des essences esploitées appartiennent au genre Entandrophragma, sont récoltées puis exportées via les ports des pays voisins. Si le gouvernement souhaite une production durable de cette ressource de qualité, il s'avère nécessaire de mieux contrôler et organiser les prélèvements de façon à respecter les capacités de régénération et de production de l'écosystème forestier. C'est la rôle de l'aménagement forestier que d'intégrer ces actions dans le contexte socio-économique local.

Sur le plan technique, il est donc important pour le Service Forestier de mieux connaître la dynamique de cette forêt et de suivre sa réaction après une intervention sylvicole (exploitation ou éclaircie). C'est pourquoi le Ministère des Eaux et Forêts a décidé de mettre en place, en collaboration avec le Gouvernement français, des parcelles permanentes de suivi de la dynamique forestière au sein du massif de la Lobaye près de la ville de M'baiki.

Nous présentons dans un premier temps l'objectif de ce dispositif, son implantation et son organisation ainsi que les mesures effectuées. Ensuite, quelques résultats importants sont soulignés. Dans un troisième temps, on expose une méthode simple qui permet de synthétiser une partie des données récoltées et de fournir des estimations quant à la possibilité de reconstitution du peuplement adulte à moyen terme en vue d'une prochaine exploitation.

1.0 Le Dispositif de M'baiki

1.1 Objectifs et conception

Pour rédiger les aménagement forestiers, il est nécessaire de pouvoir quantifier la réaction des peuplements soumis à une exploitation traditionnelle de bois d'oeuvre et définir ainsi une "possibilité volume" (ou quotité annuelle des coupes) et une "durée de rotation" (temps séparant deux passages en exploitation de la même parcelle). En particulier, il s'agit d'estimer la production annuelle de la forêt et de voir quel est l'impact de l'exploitation sur le peuplement résidue;. Dans un souci d'augmentation de la production, il est également intéressant de voir si, à travers des techniques simples telle que l'éclaircie systématique, on peut favoriser la croisannce des arbes d'avenir et réduire ainsi le temps de retour sur une parcelle. L'implantation et la mesure à long terme de parcelles permanentes de recherche en forêt naturelle a été le chemin suivi depuis 1981 pour répondre à cet objectif (Maître 1981, Tandeau de Marsac *et al.* 1995).

Deux forêts non exploitées, situées dans le Massif de La Lobaye, ont été retenues pour implanter ce dispositif. Les forêts de Boukoko et de La Lolé sont situées à 15 kilomètres de la ville de M'baiki au sud-ouest de Bangui. Le climat est de tyoe guinéen forestier, appelé encore Oubanguien, avec des températures moyennes de 19.8°C (minima) et 29.1°C (maxima). La pluviométrie annuelle est de 1700 mm avec 8 mois à plus de 100 mm (indice 8-3-1 d'Aubréville). Les sols sont faiblement ferralitiques sur grès-quartzites, formés d'une argile compacte à forte rétention d'eau (Freytet et Tandeau de Marsac 1992). La couverues végétale dite "climatique" de la zone est une forêt dense tropophile, comportant des essences secondaires (Ayous - *Triplochiton scleroxylon,* Limba - *Terminalia superba*) et des essences héliophiles à feuilles caduques.

Le dispositif, délimité en 1981-1982 après un préinventaire de la zone, comprend 10 parcelles carrées disjointes. Chaque parcelle a une surface de 9 hectares, dont les 4 hectares centraux sont mesurés, la bordue servant de zone tampon. Le protocole expérimental en bloc complet permet de tester l'effet de 2 traitements par rapport à un témoin non pertubé (TO) avec 3 répétitions (4 répétitions dans le cas de T2). Ces deux traitements sont les suivants:

- ✓ traitement 1 (T1): exploitation commerciale des essences de bois d'oeuvre à partir d'un diamètre minimum de 80 cm.
- ✓ traitement 2 (T2): exploitation commerciale des essences de bois d'oeuvre à partir d'un diamètre minimum de 80 cm suivie d'une éclaircie par dévitalisation des espèces

secondaires, c'est à dire des essences non commercialisables, de plus de 50 cm de diamètre.

Les traitements sont appliqués après la troisième campagne d'inventaire ce qui permet à chaque parcelle d'être son propre témoin.

1.2. Mesures

Sur chaque parcelle, de 4 hectares chacune, tous les arbres de plus de 10 cm de diamètre à 1.30 m (dbh) sont numérotés et positionnées en coordonnées (x, y). Leur diamètre de référence est mesuré chaque année, à la même période, au ruban métellique souple au niveau d'un anneau matérialisé à la peinture sur le tronc, ce qui présente l'avantage de la fiabilité du point de masure mais pourrait occassioner une perturbation de la croissance (Sheil, 1995). Ces mesures ont débutées en 1982 par Schmitt (1982) et sont encore réalisées aujourd'hui soit maintenant 14 ans après la mise en place des parcelles. La chaîne d'apurement informatisées et les vérifications immédiates sur le terrain de toutes les mesures "anormales" donne une très bonne fiabilité au travail réalisé. Des codes spéciaux sont attribués dans les fichiers aux arbres dont le niveau de mesure est remonté ou dont la conformation s'écarte fortement du cylindre. Ces arbres ne sont pas pris en compte dans les calculs de criossance moyenne. En outre, l'identification botanique des 36 essences commerciales ou potentiellement utilisables a été réalisé dès 1982. Entre 1991 et 1993, c'est l'ensemble des tiges qui a fait l'objet d'une détermination botanique précise et il ne subsiste aujourd'hui plus que quelques individus non déterminés fautes de materiel fertile ou de connaissance systémeatique (Petrucci et Tandeau de Marsac 1994). On notera dans la suite le groupe des essences commerciales nobles par la lettre A (15 essences), le groupe des essences commerciales complémentaires par la lettre B (21 essences) et l'ensemble des autres essences, dites secondaires, par la lettre C. Les arbres morts entre 2 campagne sont notés avec un code correspondant à la cause de la mort (naturelle, dégât d'exploitation). Ceux apparus entre deux campagnes (arbres recrutés) sont pris en compte au fur et à mesure comme les arbres déjà présents au départ.

L'ensemble des parcelles a fait l'objet d'un relevé topographique et d'une étude pédologique débouchant sur une cartographie au 1/2000. Une station météorologie simplifiée est relevée quotidiennement à Boukoko, à quelques kilomètres de la forêt. Ces travaux devraient permettre d'éventuelles analyses de l'impact des facteurs du milieu sur la dynamique forestière et rendre ainsi plus aisée un transfert des connaisances vers d'autres massifs forestiers (Freytet et Tandeau de Marsac, 1992).

Un suivi de la phénologie des essences principales a été engagé en 1991 et progressivement étendu. Le dispositif compte aujourd'hui 287 arbres choisis parmi 19 essences et répartis dans toutes les catégories de diamètres. La floraison et la fructification de ces arbres sont observées une fois par semaine. Cette étude a pour principal objectif de trouver une corrélation entre la maturité sexuelle des arbres et leur diamètre et donc de guider l'aménagiste dans le choix des semenciers à préserver (Freytet et Tandeau de Marsac, 1992).

Par ailleurs, un dispositif complémentaire pour l'étude de la régénération a été proposé en1987, et modifié en 1991. Il vise à apporter une quantification moyenne de la régénération selon le traitment, pour estimer l'impact à long terme des interventions sylvicoles et signaler rapidement un éventuel dysfonctionnement du renouvellement de la forêt. Ce dispositif procède par inventaire régulier de la régénération acquise sur des placettes de 5 m x 20 m (100 m^2) réparties de façon systématique selon 4 axes nord-sud par parcelle. Le taux de sondage est donc de 6%. Sur chaque placette, tous les ligneux entre 0.5 et 10 cm de diamètre sont mesurés (par classe de 1 cm) et identifiés. sur 1/4 de la surface de la placette, les plantules de moins de 0.5 cm de diamètre sont comptées. Enfin. l'environnement de chaque placette est noté selon un code d'éclairement estimé visuellement (Tran-Hoang *et al*, 1991).

Citons pour terminer deux autres études en cours. La première concerne le contexte social de la zone et en particulier l'utilisation des produits forestiers non-ligneux par les riverains (ethno-botanique). La seconde s'attache à décrire la qualité des arbres de 17 espèces commerciales. Un indice, combinant des critères de forme et des critères de vigeur, permet de caractériser chaque individu. Ce travail, débuté en 1994, est un complément essentiel aux études de croissance des arbres car il permet de savoir quels seront les arbres réellement exploitables lors de la prochaine rotation (Morel et Tandeau de Marsac, 1995).

Les données recueillies sur ce dispositif sont donc à plus d'un titre exemplaires. La surface observée est vaste et la durée d'observation longue. En outre les mesures ont toujours été faites avec beaucoup de soins par une équipe nationale motivée, appuyée pars chercheurs expatriés. Les travaux sont supervisés étroitement par le Ministère des Forêts avec l'appui scientifique du CIRAD-Forêt. La volonté du personnel sur place a permis également d'enrichir les connaissances par des observations complémentaires nombreuses (régénération, phénologie, pédologie, etc.). Ce dispositif ouvre donc la porte à de très nombreusses analyses. Cette présentation sera centrée sur quelques résultats concernant la dynamique du peuplement après intervention sylvicole, en s'appuyant sur les parcelles de Boukoko entre 1982 et 1994. Elle montrera ensuite en quoi ces résultats peuvent être utilisés pour construire un modèle de croissance, outil d'aide à la décision d'aménagement.

2.0 Quelques resultats

La structure et la dynamique d'un peuplement témoin puis l'intensité des traitements seront tout d'abord caractérisés rapidement. Puis l'évolution des paramètres de recrutement, mortalité, croissance et régénération après intervention sera décrite, en comparison avec les parcelles témoins.

2.1 Dynamique en forêt intouchée

A Boukoko, la densité moyenne est de 594 tiges/ha et les espèces des catégories A - commerciales de valeur, B - commerciales et C - non commerciales représentent respectivement 5%, 15% et 80% de cet effectif total. La surface terrière est de 32.65 m^2/ha et le volume total de 308 m^3/ha. Le nombre total d'espèces dépasse 250 sur le 40 hectares du dispositif. Entre 1982 et 1995 et toutes espèces confondues, la croissance moyenne en diamètre est de 0.21 cm/an, le nombre d'arbres recrutés d'environ 10 /ha/an et le nombre de morts de 9 /ha/an. Si l'on effectue un bilan rapide sur cette période, on s'aperçoit que le peuplement, bien que n'ayant pas subi d'intervention, est en phase d'accumulation nette. L'effectif, la surface terrière et le volume gagnent respectivement, sur 13 ans, 1 tiges/ha/an, 0.2 m^2/ha/an et 3.2 m^3/ha/an.

2.2 Caractérisation des traitements

L'exploitation moyenne T1 sur l'ensemble du dispositif a été de 3.6 arbres de plus de 80 cm diamètre par hectare. Cette exploitation a provoqué des trouées dans la voûte d'une surface moyenne de 350 m^2/arbre abattu. Le débardage a occasionné également des ouvertures d'environ 200 m^2/arbre exploité. Pour un arbre exploité, on a recensé en moyenne 22.5 arbres détruits par l'abattage ou le débardage. En volume, le potentiel total sur pied passe ainsi de 312 m^3/ha à 217 m^3 soit une réduction de 30%.

L'éclaircie pratiquée est systématique, en principe à partir de 50 cm de diamètre soit en moyenne sur des arbres de 70 cm, pour toutes les essènces secondaires. Cela représente un prélèvement effectif de 15 tiges à l'hectare. Practiquée à l'aide d'entailles circulaires continues avec injection d'un arboricide (GARLON 4E), ce traitement a une efficacité très bonne, proche de 100%, et ne provoque pas de dégâts induits au peuplement. Le traitment T2 entraîne donc une diminution du volume qui passe de 296 à 237 m^3/ha lors de l'exploitation,puis de 237 à 177 m^3/ha après l'éclaircie. La réduction totale en volume pour le traitment T2 est donc de 40% (Chatelperron et Commerçon, 1986).

2.3 Evolution des paramètres de dynamique du peuplement après traitment

Entre 1993 et 1994, le recrutement annuel en effectif, rapporté à l'effectif total, est de 2.1% en parcelles témoins, 5.3% en T1 et 4.5% en T2. Il est donc globaement favorisé par l'ouverture de couvert. Ce gain de recrutement induit par les interventions est observé après un laps de temps de 4 ans environ, période pendant laquelle les jeunes régénérations d'espèces héliophiles n'atteignent pas encore le diamètre de précomptage (Figure 1). D'autre part, la répartition de ce recru par grandes catégories d'espéces semble indiquer que les espèces du groupe C, et un particulier les espèces héliophiles ou pionnières, sont proportionnellement plus favorisées que les espèces commerciales des groupes A et B (Petrucci et Tandeau de Marsac, 1994).

Pendant la même période, la mortalité naturelle en effectif, relative à l'effectif initial, est de 1.3% en T0, 1.5% en T1 et 1.6% en T2. Son évolution présente un pic dans les deux années qui suivent l'inyervention puis elle redescend progressivement à un niveau voisin mais toujours très légèrement supérieur à celui des parcelles témoins (Figure 2).

La croissance annuelle enfin, exprimée par la variation du diamètre, montre l'impact immédiat des traitments sylvicoles, d'autant plus important que l'ouverture du couvert est forte (Figure 3). Cette croissance, toutes espèces confondues, est approximativement doublée en T1 et triplée en T2. L'effet des traitments semble encore se maintenir aujourd'hui, soit 10 ans après la date des interventions. Toutefois, cette réaction touche différemment les espèces et les classes de diamètre. Les espèces héliophiles réagissent bien sûr plus fortement et les diamètres petits à moyens (diamètre < 50 cm) sont également plus sensibles que les gros.

2.4 La régénération acquise et les semis

L'analyse de ces données délicate et souffre encore d'un manque de recul dans le temps. Toutefois on peut indiquer quelques tendances. Toute d'abord, en ce qui concerne la régénération acquise, on observe un phénomène de "sur-régénération" des espèces de catégorie C, non commerciales, au détriment des espèces commerciales (catégories A et B). En second lieu, l'ouverture importante du couverte par exploitation entraîne une apparition abondante de lianes, significantivement plus fréquentes qu'en parcelles témoins. Il semble d'autre part que la régénération des espèces de catégorie A soit favorisée dans le cas du traitment 2 (exploitation modérée et éclaircie). Une analyse par espèce distingue celles qui réagissent positivement à l'ouverture et celles qui sont pénalisées. On observe en particulier que le Sapelli *(Entandrophragma cylidricum)*, le Dibétou (*Lovoa trichilioides*) et le Dabéma (*Piptadeniastrum africanum*) sont significativement sur-régénérés en parcelles traitées (Morel et Tandeau de Marsac, 1995).

Les données sur la dynamique du peuplement adulte seront maintenant utilisées pour simuler l'évolution à moyen terme. Les résultats des simulations seront ensuite discutés à la lumière d'autres données disponibles.

3.0 Un essai de modelisation

3.1 Principe du modèle utilisé

A la suite des travaux de Usher (1996), repris par Buongiorno et Michie (1980), nous avons construit un modèle déterministe à compartiments pour simuler la dynamique d'un peuplement. Le principe de ce modèle est simple. Au temps t, les arbres sont répartis en k classes de diamètre, d'effectifs n_{1t} n_{2t} … n_{it} n_{kt}. La dynamique du peuplement est représentée par le suivi de la croissance et de la mort des individus. Un arbre vivant dans la classe de diamètre I au temps t, peut, au temps t+1:

- ✓ soit rester dans cette classe avec la probabilité $p_{ii,t}$
- ✓ soit passer dans la classe i+1 avec la probabilité $p_{ii+1,t}$
- ✓ soit mourir avec la probabilité $m_{i,t}$

On ne considère ici que les arbres de plus de 10 cm de diamètre. Le peuplement est donc tronqué et l'on doit introduire également le recrutement, $r_{i,t}$ c'est-à-dire le nombre d'arbres qui attegnent le diamètre de prètre de précomptage entre les temps t et t+1.

Ce modèle peut être formalisé par une équation de récurrence:

$$N_{t+1} = P(t)\,(N_t - H_t) + R(t)$$

où

N_t (N_{t+1}) est le vecteur d'état au temps t (t+1)

P(t) est la matrice des probabilités de passage, $p_{ij,t}$ entre les temps t et t+1

H(t) est le vecteur de prélèment, par exploitation ou éclaircie au temps t

R(t) est le vecteur des effectifs recrutés, $r_{i,t}$ entre les temps t et t+1

Pour calculer le vecteur N_{t+1}, on procède donc de la façon suivante: à partir du vecteur (N_t-H_t) on applique la matrice P(t) qui inclue la survie et les probabilités de passage. On ajoute ensuite le recrutement R(t). On peut noter que la matrice P et le vecteur R dépendent du temps. Plus précisément, on traduira cette absence de stationnarité du système par la dépendance entre les paramètres du modèle et des variables liées à l'état du peuplement au temps t. Cette dépendence permet de faire le lien entre les observations disponibles sur le système (construction des équations de régulation) et les prédictions (simulation du comportement futur). Dans notre cas, ce sont les probabilités de passage $p_{ii+1,\,t}$ et de survie $m_{i,t}$ qui sont estimées; les probabilités $p_{ii,t}$ en sont alors déduites par la relation:

$$p_{i\,i+1,\,t} + m_{i,t} + p_{ii,t} = 1 \qquad \text{pour } i = 1\ldots n-1$$

$$m_{i,t} + p_{ii,t} = 1 \qquad \text{pour } i = n$$

3.2 Calibration du modèle sur les données de Boukoko

On a construit un modèle pour chacun des groupes d'espèces (j = 1, 2, 3) distingués depuis le début des mesures à savoir les deux catégories d'espèces commerciales A et B et les espèces secondaires C. Les individus de chaque groupe sont répartis en 9 classes de diamètre: [10-20, 20-30, 30-40, 40-50, 50-60, 60-70, 70-80, 80-90, 90 et +]. Les estimations et simultations sont réalisées sur une surface de référence de 1 hectare avec un pas de temps de 2 ans.

Les fonctions de regulation suivantes ont été retenues.

Le recrutement

Il est ajusté par une fonction de la surface terrière totale du peuplement. L'hypothèse sous-jacente est que plus le peuplement est dense, moins il y a de lumière au sol et donc plus faible doit être le recrutement. La surface terrière totale G_t à l'hectare, toutes espèces confondues, représente donc un indice moyen de compétition.

Catégorie A:
$r_1 = 2.5688 - 0.05369G_t$ ($r^2 = 0.06$, $p = 0.003$, 127 ddl)

Catégorie B:
$r_1 = 13.872 - 0.3176G_t$ ($r^2 = 0.24$, $p = 0.0001$, 127 ddl)

Catégorie C:
$r_1 = 225.e^{(-0.0801Gt)}$ ($r^2 = 0.34$, $p = 0.0001$, 127 ddl)

et

$r^{(j)}_i = 0$, pour $i > 1$ et $j = 1,2,3$

Les coefficients de corrélation sont faibles. Les relations ont été conservées car elles sont significatives et permettent la régulation du modèle, contrairement à d'autres méthodes proposées, comme celle de Osho (1991).

Les probabilités de passage

Elles sont ajustées en fonction de deux variables: le diamètre et la surface terrière totale. La première variable traduit l'effet de compétition moyenne; la seconde permet de lisser d'éventuels irrégularités entre classes de diamètre voisines (Solomon *et al.* 1986; Favrichon 1995).

Catégorie A:
$p_{i\,i+1} = 0.3066 - 0.01154D_i + 0.000324D^2_i - 0.0000023D^3_i - 0.004786G_t$,
($r^2 = 0.57$, $p = 0.0001$; 212 ddl)

Catégorie B:
$p_{i\,i+1} = 0.1333 - 0.00033D_i + 0.0000709D^2_i - 0.00000064D^3_i - 0.004034G_t$
($r^2 = 0.70$, $p = 0.0001$; 212 ddl)

Catégorie C:
$p_{i\,i+1} = 0.05648 + 0.00604D_i - 0.0000839D^2_i + 0.00000034D^3_i - 0.004072G_t$
($r^2 = 0.84$, $p = 0.0001$; 212 ddl)

où D_i est la borne supérieure de la classe de diamètre i.

Les probabilités de mort

Ces probabilités n'apparaissent pas corrélées à l'état du peuplement et semblent constantes par classes de diamètre i et par groupe d'espèces (j):

$$m^{(j)}_{i,t} = c^{(j)}_i$$

Compte tenu des dificultés d'estimation de la mortalité sur une période de temps courte, ces constantes c_i sont calculées de façon à ce que l'effectif soit constant par classes de diamètre et groupes d'espèces en parcelles témoin au cours du temps (Favrichon et Kim, 1996), sous l'hypothèse que les parcelles témoins soient dans un état stable. En appliquant cette hypothèse, on obtient par simulation, en l'absence d'intervention, un effectif constant par classes de diamètre et donc un volume constant dans le temps. Ceci n'est pas en conformité avec ce qui est observé à Boukoko pendant la période d'observation (§II-1), mais cela permet de tester l'effet réel d'une intervention par rapport à un état témoin stable.

Quand une exploitation est simulée par le modèle, il faut également calculer le taux de dégâts provoqués au peuplement résiduel. Ces dégâts s'élèvent comme on l'a vu à 22.5 arbres par arbre exploité; on considère qu'ils se répartissent uniformément par classes de diamètre sauf pour la dernière classe où les dégâts sont quasiment nuls. On considèr enfin que l'éclaircie ne provoque pas de dégâts directs.

Remarque:

On présentera quelques résultants en volume. L'estimation du volume est faite en utililisant une approximation des tarifs de cubage détaillés établis pour le dispositif à savoir:

pour les Catégories A et B, $V = 10.433D^2 - 0.2667D$

pour la Catégorie C, $V = 7.87D^2 - 0.3D$

où V est le volume fût individuel, en m^3, et D le diamètre à 1, 30 m, exprimé en m.

3.0 Résultats

Les équations retenues pour modéliser les paramètres de dynamique forestière ne permettent pas d'étudier directement le comportement du modèle dans le cas où le recrutement et les probabilités de passage sont régulés. Pour observer et analyser ce comportement il est nécessaire d'appliquer le modèle à un peuplement réel (projection dans le temps) et de calculer lévolution des principales caractéristiques de celui-ci. Ce qui intéresse le gestionnaire est surtout l'évolution des parcelles après exploitation et éclaircie. Nous avons dons simulé des traitements à partir d'un peuplement moyen de Boukoko.

Nous avons plus précisément comparé trois scénarios sylvicoles.

S1: exploitation forte seule
S2: exploitation forte et éclaircie
S3: exploitation forte et éclaircies successives

Pour ces trois scénarios, l'intensité des prélèvements et des dégâts cumulés en volume est la suivante (en % du volume initial):

S1: 26% du volume est prélevé par exploitation et dégâts,
S2: 40% du volume est prélevé par explotation, dégâts et éclaircie,
S3: 40% du volume est prélevé par exploitation, dégâts et éclaircie à t = 1 puis de nouveau 5% du volume résiduel est prélevé par éclaircie à t = 10 et à t = 20.

La figure 4 montre l'évolution de la surface terrière totale en fonction du temps pour les trois scénarios. On peut y noter l'impact plus imortant des scénarios 2 et 3 mais le temps de retour assez similaire vers l'état initial. Sur la figure 5, est représentée l'évolution du volume commercialisable à l'hectare, c'est à dire le volume total des arbres de plus de 80 cm de diamètre appartenant aux espèces des catégories A et B. Au départ ce volume était d'environ 60 m^3/ha. L'exploitation en prélève 44,1 m^3 auxquels il faut ajouter quelques 2 m^3 de dégâts. Ce volume exploité est forte, en comparaison des pratiques traditionnelles en RCA (4 arbres exploités par hectare contre en général 1 arbre seulement). Juste après exploitation, le potentiel sur pied ne répresente plus que 24% du stock initial. Après trente années, ce potential s'est reconstitué à 44% en l'absence d'intervention complémentaire, et respectivement à 46 et 47,5% dans le cas d'une ou de plusieurs éclaircies successives. Le volume total, tous diamètres confondus, atteint dans tous les cas environ 95% du volume initial. Dans le cas d'une simple exploitation, le gain net total en volume est donc d'environ 2,3 m^3/ha/an, à comparer aux 0 m^3/ha/an théoriques en parcelles témoins. Avec une éclaircie complémentaire, la productivité passe à 3,8 m^3/ha/an. Toutefois, l'effet l'ouverture forte du couvert, par exploitation intense par exemple, entraîne surtout un développement rapide des espèces de catégorie C qui prennent une place plus importante dans le peuplement (figure 6). La productivité des arbres de taille exploitable dans les catégories A et B passe donc de 0 m^3/ha/an. valeur théorique en parcelles témoins, à 0,40 m^3/ha/an après exploitation et 0,44 m^3/ha/an après exloitation et éclaircie.

Scénario	Intervention	50-60	60-70	70-80	80-90	90+
S1	expl. cat. A	-	-	-	0.5	0.75
	expl. cat. B				0.75	0.75
	ecl. cat. C	-	-	-	-	-
S2	expl. A	-	-	-	0.5	0.75 0.75
	expl. B				0.75	
	ecl. C à t = 1	0.75	0.75	0.75	0.75	0.75
S3	expl. A	-	-	-	0.5	0.75
	expl. B				0.75	0.75
	ecl. c à t = 1, 10, 20	0.75	0.75	0.75	0.75	0.75

Conclusion

Il semble donc que la reconstitution progressive du potentiel exploitable aprés exploitation modérée soit peu améliorée par l'éclaircie, qui favorise surtout les individus taille inférieur. En outre, une ouverture plus forte du couvert, par exploitation intense ou par éclaircie complémentaire, entraîne un gain de croissance au profit essentiellement des essences secondaires et parmi elles aux essences héliophiles. Les données sur la régénération confirme ce risque. Une amélioration du modèle permettrait de mieux préciser cette évolution à long terme. Il s'agiraitdans un premier temps de séparer le peuplement en un plus grand nombre de groupes d'espèces, comme ceux proposés par Morel at Tandeau de Marsac (1995); la construction de modèles matriciels avec des groupes d'espèces à tempéraments différenciés a en effet déjà utilisée avec succés dans d'autres sites (Favrichon 1995; Ojo 1991). Il s'agirait ensuite de prendre en compte dans la mesure du possible les données sur la régénération.

Pour espérer obtenir une production durable dans un temps assez court, il est tentant de proposer une exploitation de type assez extensif à courte rotation. Elle pourrait prendre par exemple la forme d'un prélèvement partiel des tiges exploitables à partir d'un diamètre inférieur à 80 cm. de façon à limiter le prélèvement et surtout pour permettre le maintien d'une structure forestière proche de celle d'une forêt naturelle (Maître, comm. pers.). C'est à ce niveau plus une décision politique des autorités décidant de la nature des plans de gestion qui gouvernera l'action sur la forêt. Faber-Langendoen (1992) propose ainsi deux scénarios possibles: (i) rotation courte, de l'ordre de 15-20 ans, avec récolte d'espèces plutôt héliophiles pour maximiser la biomasse produite; ou (ii) rotation longue, supérieure à 60 ans, pour récolter de petites quantités de bois d'oeuvre de grande qualité technologique et maintenir la biodiversité à un niveau plus élevé. Des éclaircies sytématiques de faible intensité à intervalles réguliers ne semblent pas entraîner un gain substantiel de croissance des individus potentiellement exploitables et leur coût de mise en oeuvre risque également d'être dissuasif pour le gestionnaire. Des travaux d'optimisation des différents scénarios, tels ceux de Osho (1991) ou de Buongiorno *et al* (1994, 1995) permettent de guider les décideurs dans ces choix de compromis écologique et économique.

Remerciements

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Tree growth, mortality and recruitment on abandoned farms of 0 - 30+years at Likombe, Mount Cameroon

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Abstract

This paper presents results of the first two years of a proposed four year Darwin Initiative research project which started in 1994. Changes in structure, species composition, growth, mortality and recruitment of woody plants have been studied in abandoned farms of various ages on Mount Cameroon. This was to understand the impact of shifting cultivation on forest regeneration and recommend ecologically sustainable uses of rain forest lands for farmers. For this, a total of 30 plots of 20 × 20 m, containing 90 sub-plots of 4 × 5 m were established between 800 m and 1150 m altitude. They were grouped into 5 age classes: 0-2 years, 3-5 years, 6-10 years, 11-30 years, and over 30 years. In each plot, woody plants ≥ 2 m tall were tagged, their height and diameter recorded, and specimens collected when necessary. A similar operation was conducted in each sub-plot for woody seedlings of 30 -199.9 cm tall. The density varied from 479 - 2,891 and 1,138-10,556 stems / ha for woody plants ≥ 2 m tall and seedlings of 30 -199.9 cm tall respectively. Mortality per annum varied from 48 - 66% in the plots and was higher, 85 - 97% in the sub-plots of 0-2 and 3-5 years age classes. It decreased to about 40 % in the sub-plots of 11-30 and over 30 years age classes probably because weeds were then suppressed. Recruitment (seedlings reaching sampling size) was higher (150-300%) in plots below 5 years old after which it decreased drastically to about 45%. In sub-plots, recruitment was low (12-20%) in the 0-2 and 3-5 years age classes when mortality was high and recruitment then increased 11-30 years, and over 30 years as mortality decreased to reach about 100%. It was concluded after the first two year study that regeneration of forest species was poor in abandoned farms. Secondary species were the main early colonisers and were progressively replaced by the primary species from 11 years following farms' abandonment.

Introduction

Plants are very important to mankind and understanding them has always been a subject of great interest to humanity. They regenerate and form a mixed population which is exposed to changes in structure, composition and number. The changes are often encouraged either by natural or human disturbance (Healey 1990). On Mount Cameroon, there are many types of disturbance such as selective logging, natural treefall, volcanic eruption, burning and shifting cultivation. In this paper the relative impact of the traditional farming system on tree growth, mortality and recruitment on Mount Cameroon is discussed. This work was funded by the Darwin Initiative scheme of the British Department of the Environment.

Study site

Mount Cameroon, located in the coastal belt of the Gulf of Guinea, is the highest (4,095 m) peak in West and Central Africa. Its main massif is about 50 km long and 35 km wide running SW to NE. Likombe is a located at its eastern slope, 4°07'N, 9°13E. The mean rainfall varies between 3,000 mm and 12,000 mm per annum and occurs mostly between April and November peaking between July and September.

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The mean monthly temperature at sea level, varies from 24° C to 35° C with the maximum in March-April. The soil temperature, measured at 10 cm depth, varies from 25° C at 200 m through 20° C at 1,100 m to 15° C at 2,200 m altitude (Payton & Edwards 1993). The air humidity remains at 75 to 80 % through out the year on the south-western site of the mountain due to the influence of both the sea and the mountain. The persistent cloud cover and mist make Mount Cameroon one of the areas which receive amongst the lowest Figures of annual sunshine hours in West Africa. This starts with 900-1,200 hours per annum at sea level and decreases with altitude (Payton 1993).

The soils on the Mountain are mainly built of basaltic lava of many different ages (Fitton et al., 1983). Some consist of lava flows and bear pyroclastic craters in various stages of erosion and others, mainly the upper part, are made of ash and almost stoneless airfall deposits of cindery pyroclastics (Richards 1963b; Payton & Edwards 1993). In some areas of the lowland, ferralitic soils are found in addition to the volcanic type (Hawkins & Brunt 1965). The maximum rooting depth for trees varies between 80 cm and 120 cm (Payton 1993). This relatively shallow rooting may contribute to be the cause of natural tree-fall during heavy rains or severe winds.

Mount Cameroon is one of the few places (if not unique) in Africa where there is a remaining unbroken altitudinal profile of rainforest from sea-level to its upper tree limit and beyond into grassland (Thomas 1985). It is one of the richest areas for plant species in Africa (Myers 1988; Gartlan 1989 and Kirsch-Jung 1992). Evidence for this richness is that nearly half of the 7-8, 000 species of "Flora of West Tropical Africa" (Keay & Hepper 1954-72) region are found in this part of Cameroon (Hepper 1972). It is also one of the two main Pleistocene refugia postulated for Africa (Hamilton 1976; Maley 1987; Gartlan 1989; Maley 1991; Cheek 1992b; Cheek and Hepper 1993 and Cheek *et al.* 1996). Mount Cameroon has probably Africa's greatest concentration of saprophytic flowering plants (Cheek & Ndam 1996). It is characterised by a high level of plant and animal endemism. Out of 156 plant species unique to Cameroon, 45 are recorded on Mount Cameroon (Gartlan 1989). The surrounding lowland forests are also rich. A recent floristic survey of the lowland forest, south-east of the mountain and lying between Mabeta and Moliwe showed that about 24 plant species are strictly endemic to that forest (Cheek 1992a).

Forests of many parts of the lowlands around Mount Cameroon foothills have been replaced by large commercial plantations of bananas, oil-palm, rubber, tea and coffee. The commercial plantations and the locally based oil refinery have attracted a corresponding large human population of people and this has put pressure on the use of available natural resources. The method of farming widely practised is that which follows a pattern of clearing, burning, cultivation, shifting, and fallow cycles (Jeanrenaud 1991). Farmers look at the forests as bank of fertile soils and consider tree recovery in abandoned farms as a means to restore soil fertility during the fallow periods (Thomas *et al.* 1989). This concept has caused clearance of the forest upwards to the mountain forest belt.

Past studies

Some detailed ecological studies were carried out in places relatively close to Mount Cameroon such as Korup (Gartlan *et al.* 1986) and Douala-Edea (Newbery *et al* 1986) where 135 x 0.64 ha plots and 104 x 0.64 ha plots were established respectively and trees ≥ 10 cm dbh measured. In the Mount Cameroon area, work has consisted partly of plant collection in specific habitats such as lava flow (Keay, 1959). Plot-based forest inventories were carried out in selective areas including Mann's Spring in upper montane forest near the savannah (Richards 1963b), at Mundek (Jentsch 1911); at Likumba (Mildbraed 1930); and Southern Bakundu (Richards 1963a; and Songwe *et al.* 1988). With the beginning in 1988 of a conservation project in Limbe now called the Mount Cameroon Project, the need for other intensive forest inventories was realised and selected rich areas such as Mabeta-Moliwe, Etinde, Onge, Mokoko and forest at different altitudinal zones were sampled respectively (LBGRGCP 1992; Cheek 1992a; Cheek & Thomas; Thomas 1992, 1994a & 1994b; and Payton & Edwards 1993). For these inventories, a total of 174 x 0.25 ha plots have been established and about species density varied between 18 - 94 species / ha. Very few (10%) of the plots were permanent sample plots, also, neither disturbed areas nor trees ≤ 10 cm dbh were sampled during the operation. This study is therefore contributing to fill one of the existing research gaps (Healey 1992 and Hall 1995).

Objectives

1. To investigate changes in population structure, species composition, and species dominance in abandoned farms of various ages.
2. To gather information on growth, mortality and recruitment of tree species.
3. To understand the impact of shifting cultivation on the maintenance of biodiversity.
4. 4-To recommend ecologically sustainable uses of rain forest lands for farmers' benefit.

Methods

The study was carried out in two stages. Firstly villagers were contacted to obtain their permission and support and secondly, plots were then established to begin the study.

Social contact

Much botanical field work offers little interaction between the field workers and local dwellers. Study of agricultural fallow requires a particular participatory approach by it very nature. Contacts which permitted the field study were made at three main levels in the following order: the chief of the village, the village council, and the farmers. This phase of the study, although difficult and time consuming, is nevertheless necessary to ensure gathering valid information on the history of selected fallows chosen for study and to maintain the security of plots once they are established therein. At each level of contact, the study was fully explained and assurances were given that there would be no perceived negative consequences such as review of landownership or creation of "government conservation projects". The work programme consisted of repeated farm surveys, farmer interviews following a triangulation method (McCracken 1988), selection of study sites, and negotiation with owners of the selected sites. Some money was paid to the village development fund and to owners of selected farms as a "thank you" for permitting the proposed 4 year study in their farms. Only farms of well-known farming history and not planned to be used during the forthcoming 4 years study were selected.

Plot establishment

The following plan was adopted.

a) The farmland area was divided into two zones:(i) the upper zone (960 - 1150 m altitude), generally called *waily* in the local Bakweri language, where trees are still dominant and the forest stands are more developed and the soil is reported to be more fertile; and (ii) the lower zone closer to the village (800 - 940 m altitude) where shrubs, tall herbs and grass are dominant and the forest cover is more patchy with scattered weedy tree species of about 15 m high (Thomas and Cheek 1992). This division was carried out using both ecological and socio-economic information which seemed to be well correlated.

b) In each of these two zones, agricultural fallows were grouped into five age-classes of the time since last farming: 0-2 years, 3-5 years, 5-10 years, 11-30 years, and over 30 years. The division of the fallows into age-classes was based on farmers' knowledge and information gathered (Jeanrenaud S. 1991; MCP 1996).

c) Three 20 x 20 m plots were replicated in each age-class fallow and in each zone, i.e. three replicates x two zones x five age-classes making a total of 30 plots for a total area of 1.2 ha (Map1).

d) Woody plants of at least 2 m tall were tagged, height and diameter (at 1.3 m) were measured and voucher specimens collected for identification where necessary.

e) In each plot, three sub-plots of 4 x 5 m were located in a randomly stratified arrangement (Figure 1). Seedling density in each plot was surveyed and the area classified subjectively divided into seedling dense, fairly dense and sparse parts and a sub-plot was located in each of these parts.

f) In each of those sub-plots, woody seedlings ≥ 30 cm and < 2 m tall were tagged, height and diameter (at ground level) measured, and voucher specimens collected for identification where necessary in the 90 established sub-plots (Figure 1).

g) Plots and sub-plots were demarcated using nylon rope, cairns, wooden pegs, and 50 cm long iron bars with their tops painted red to demarcate the boundary.

h) Initial measurements were taken in 1995 when the plots were established and in 1996 and will continue for two more years.

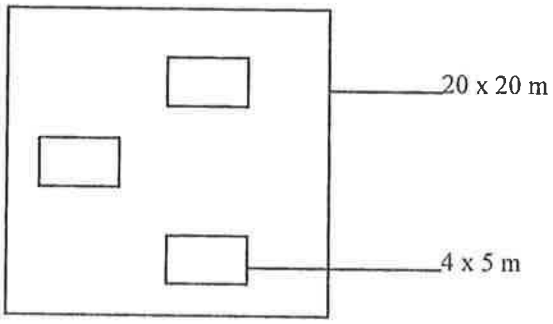

Figure 1: Plots and sub-plots layout

Results and discussion

Our observations on the rapport between farmers and forests and measurement of plant density, structure, composition and changes occurring in abandoned farms are presented and discussed.

Farmers' knowledge of forest farm land

Farmers selectively choose their farm sites. These have to be easy to work, less stony, free of forest stands with big trees, and away from gullies (locally called "water holes"). They recognise two types of undisturbed vegetation: (a) open areas of herbs (locally called "Gnuawa") dominated naturally by ferns, Zingiberaceae, Commeliniaceae (Thomas & Cheek 1992) but when farmed and later abandoned are recovered with forest trees, suggesting that shifting cultivation may stimulate forest regeneration under certain circumstances, and (b) primary forest, locally called "Black bush", which is clear-felled for farming when Gnuawa is not available.

Some timber species are deliberately protected on farms by farmers. Examples are *Entandrophragma angolense* (Meliaceae) or "Mbowu" in Bakweri is used in carpentry and *Turraeanthus africanus* (Meliaceae) or "Mukumu" in Bakweri is used in building and is reported to be resistant to termites and to last half a century. Pioneer species such as Polyscias fulva (Araliaceae) and *Trema orientalis* (Ulmaceae) are known and used but not protected because farmers are aware that they grw quickly and appear everywhere.

Tree density

Out of 30 plots sampled the density of woody plants ≥ 2 m tall from 479 varied stems/ha in the 0-2 years plot age class to 2,891/ha in the 30+ years age class (see Figure 2). The small reduction of stems per hectare in fallows above 10 years old is possibly due to the death of shading from the developing canopy of climax tree species.

Considering the 90 regeneration sub-plots, the same pattern emerges with the average seedling density varying from 1,138 -10,555 seedlings /ha. The peaks occured in the early years of abandonment (the 0-2 years age class) and in the 11-30 years age class (Figure 3). The first peak is due to the establishment of pioneer species while the second one is due to the overlap of an influx of seedlings climax coinciding with persistent, soon-to-die pioneer seedling species.

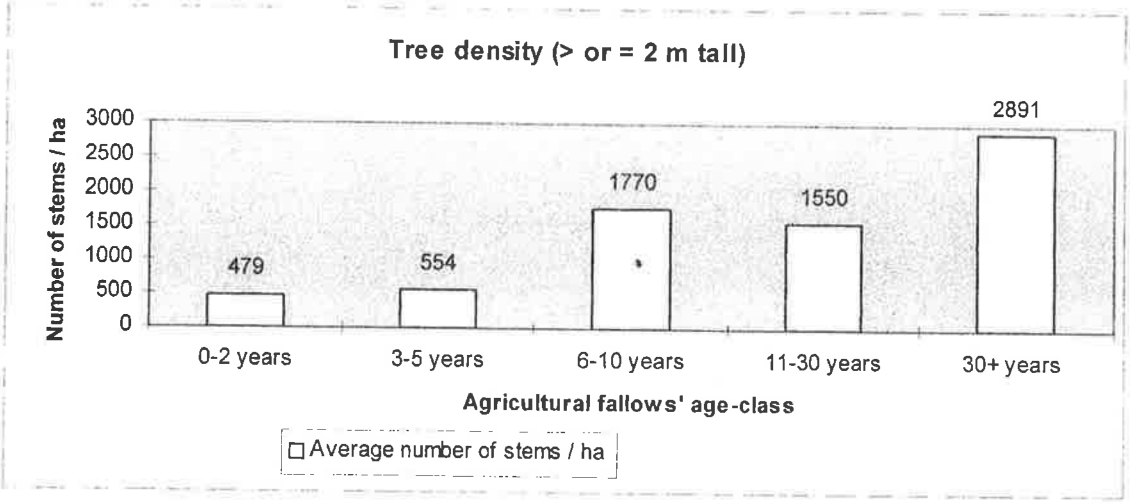

Figure 2. Distribution of number of stems per hectare between age classes

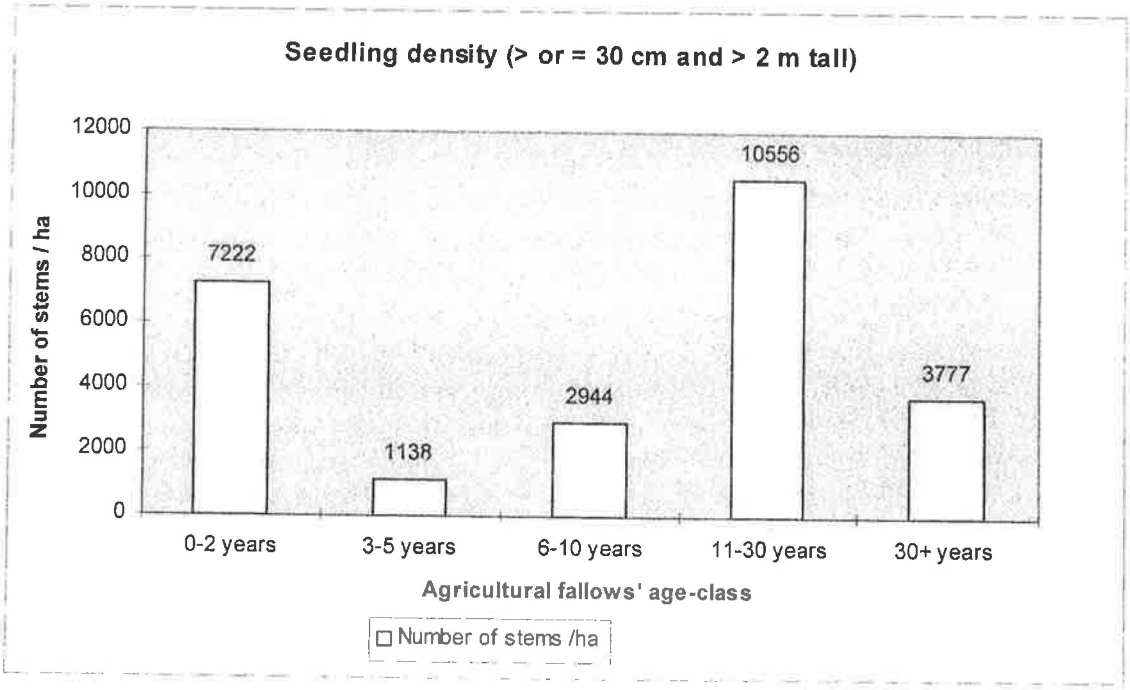

Figure 3. Distribution of number of seedlings per hectare between age classes

Forest structure

It was observed that more thant 50% of woody plants more than 1 cm dbh growing in fallows are of smaller size classes i.e. < 5 cm dbh. There was no tree > 20 cm dbh in fallows of below 10 years old and in fallows of above 10 years old only 5% of trees were > 30 cm dbh (Figure 4).

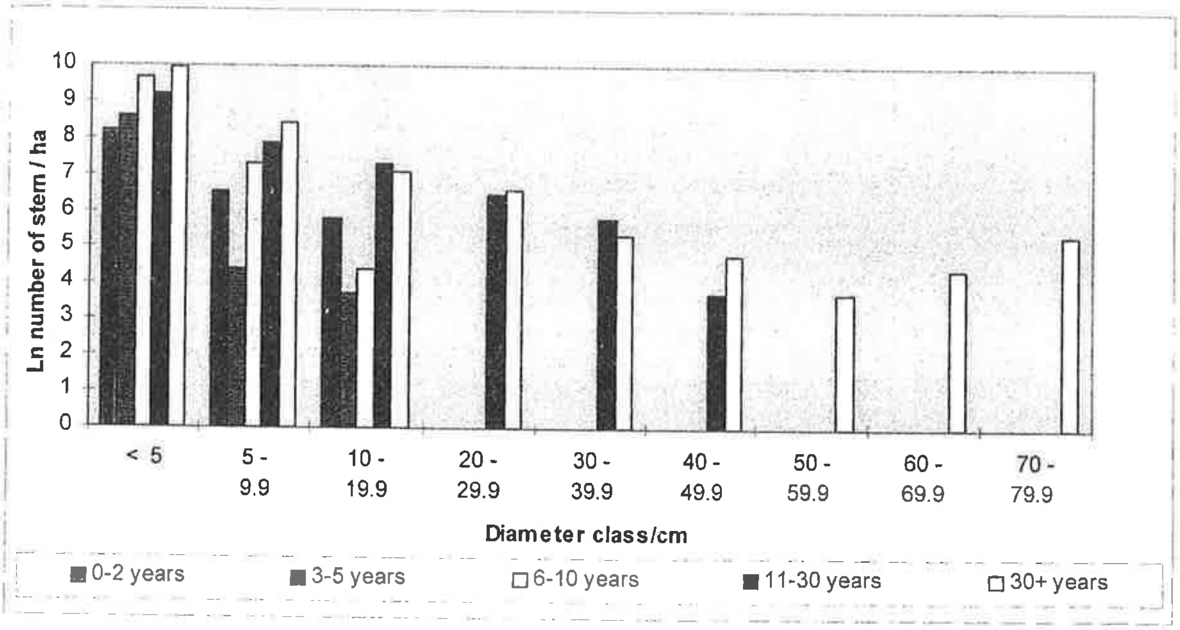

Figure 4 Distribution of Log numbers of stems per hectare by diameter classes

The distribution of numbers of stems per hectare the 30+yeass fallow is similar to that of pantropical means from Philip (1983). Althought there are many large trees (60-79.9 cm dbh) in abandoned farms of 30+ years, there is no tree above 80 cm dbh (Figure 5)

Species relative dominance

A total of 40 familes, 74 genera, and 95 species were recorded. The dynamics of only the six commonest tree species have been presented in this paper. *Cecropia peltata* (Cp); *Musanga cecropioides* (Mc), *Polyscias fulva* (Pf); *Macaranga occidentalis (Mo) Etandrophragma angolense* (Ea) and*Turraeanthus africanus (Ta).*

It was observed that numbers of Cp and Mc started to reduce in fallows of more than five years old and Cp later almost disappeared while Mc showed better survivorship in old regrowths (Figure 6). Pf population became almost stable from the 3-5 years fallow age class to the 30+ yearss age class near mature forests (Figure 6). Pf was the most frequent pioneer in young fallows and seems relatively adaptable to most stages of vegetation succession at this site. Timber species monitored were *Entandropragma angolense* (Ea) and *Turraeanthus africanus* (Ta). For both species, numbers of seedlings were relatively higher in just abandoned farms and then gradually reduced to almost nil. This can be attributed to competition, probably due to colonisation of herbs such as *Andropgon* spp, and *pennisetum purpureum.* Regeneration of Ea and Ta improved and their numbers increased again when the pioneer speciesseedlings populations declined (11-30 years age class) in the stands. This stage was observed to be favourable to Ea where are Ea performed better in much older forest stands

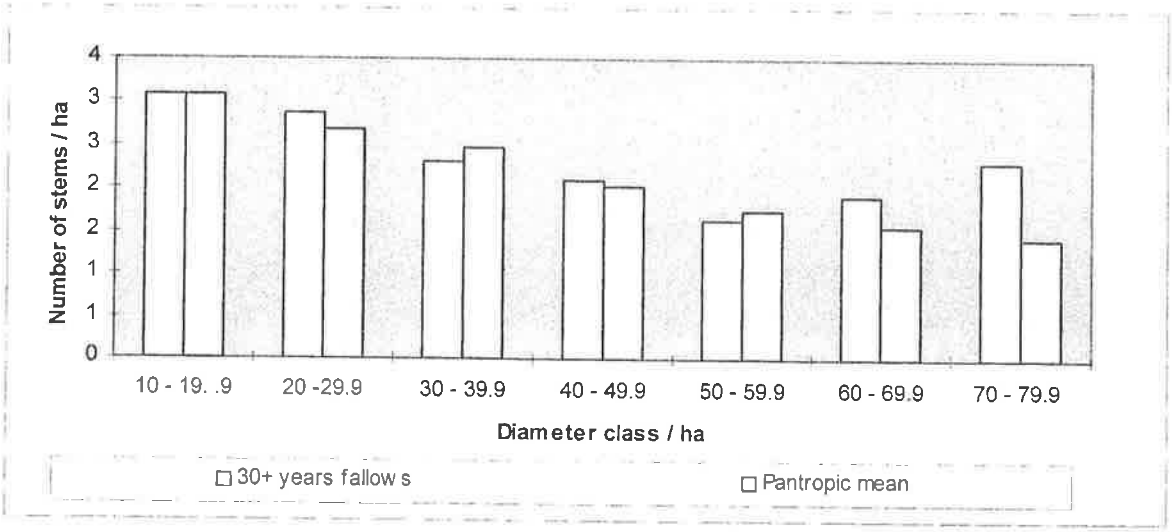

Figure 5. Distribution of Log number of stems per hectare of 30+ fallow between diameter classes compared with pan-tropical means from Philip (1983)

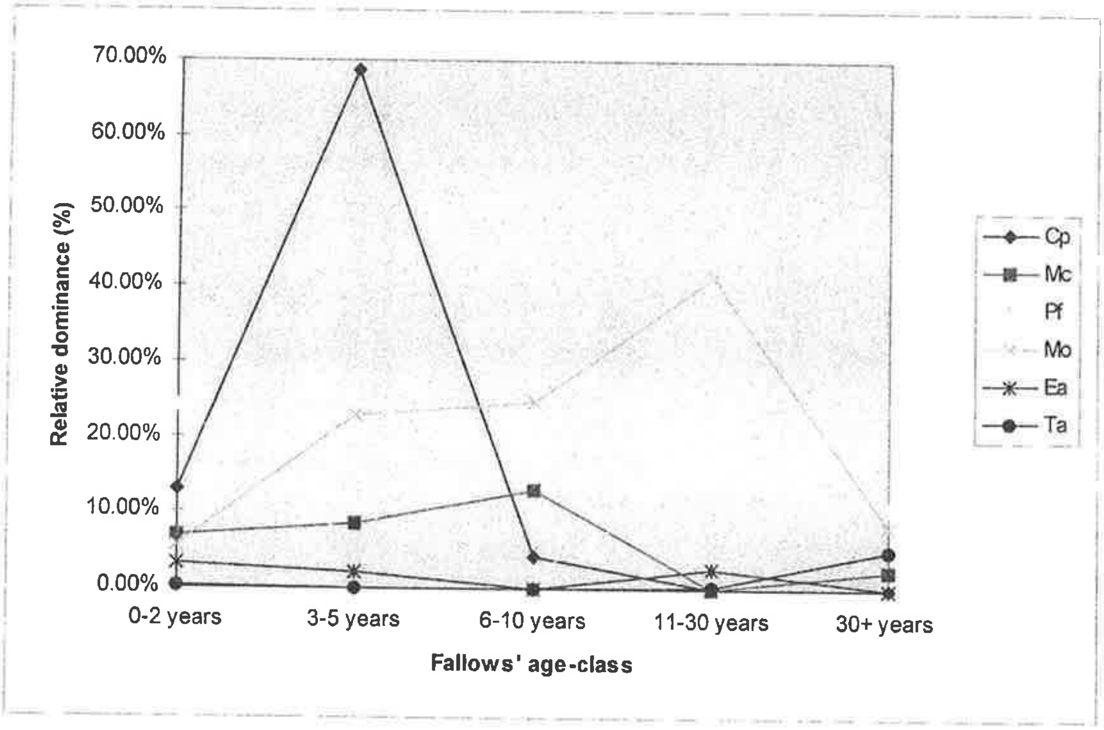

Figure 6. Species relative dominance by age-class of fallows

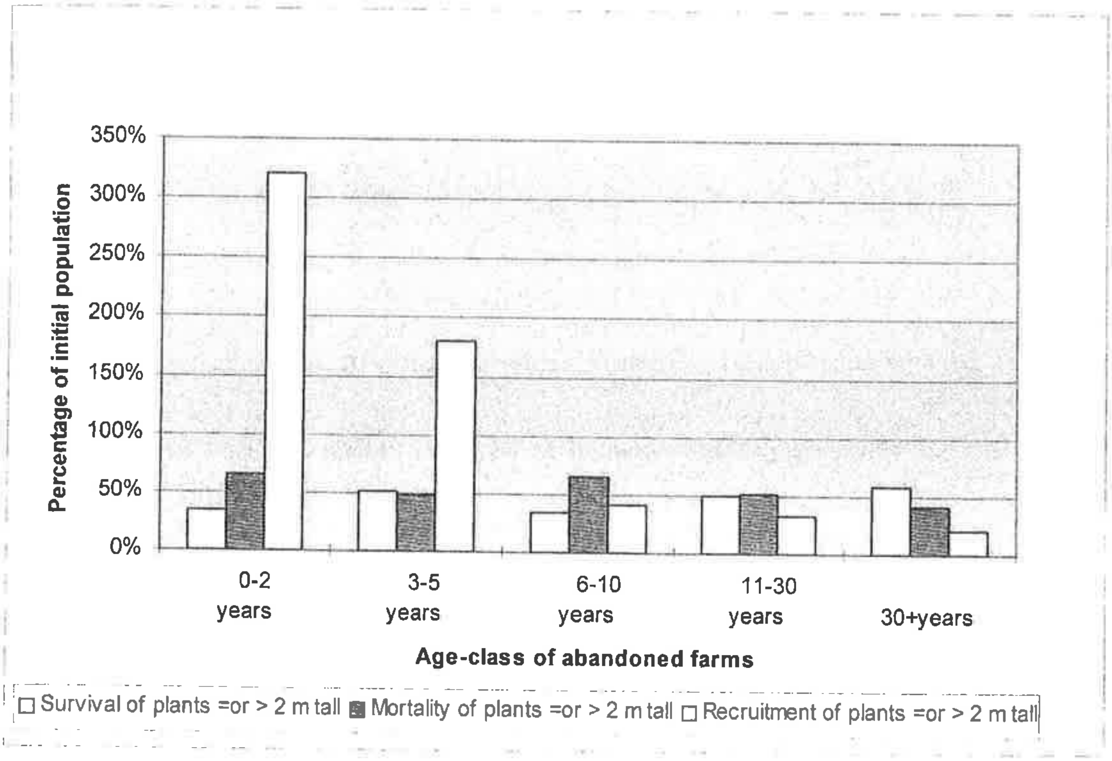

Figure 7. Dynamics of plants ≥ 2 m tall following 1995 and 1996 censuses

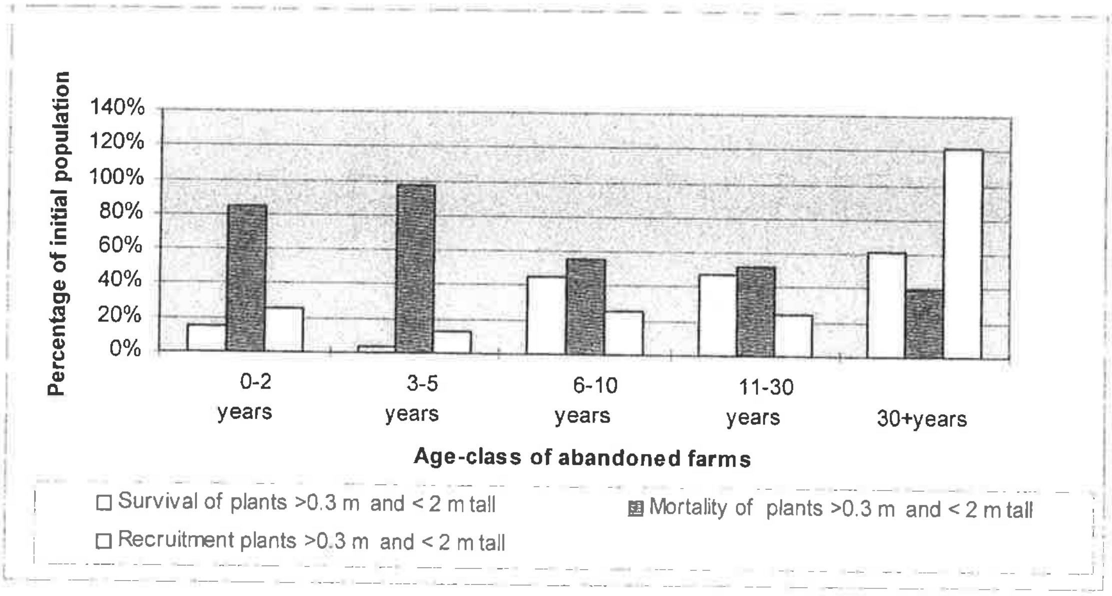

Figure 8. Dynamics of plants ≥ 30 cm and < 2 m tall following 1995 and 1996 censuses

Population dynamics of woody plants

It was observed that about half to two thirds of plants died yearly in abandoned farms and that seedling mortality is higher (97%) in 0-2 and 3-5 years age classes (Figures 7 & 8). Here the recruitment was more than 100% for plants ≥ 2 m tall and very low (20%) for seedlings in 0-2 and 3-5 years age classes. The situation is reverse in 11-30 and 30+ years age classes.

Conclusion

Secondary species which are the main colonisers of abandoned farms tend to give way to forest species in fallows between 11-30 years old at this study site. Musanga cecropiodes and Cecropia peltata seem to be the most invasive poineer species in early ages of open areas but will to disappear after 10 years. Musanga cecropiodes seems to have a longer life time than the latter which hardly survives into older regrowth. Among the main pioneer species, Macaranga occidentalis and Polyscias fulva appear to be the most persistent invaders and account for up to 10 % of stems in some mature stands (30+ years plots).

Regeneration of forest species was generally poor in farms of all age classes land and was patchy depending of the availability of the parent trees. When these species do occur, they hardy survive the early weed invasion period.

It was observed that from what grows in abandoned farms during one year, a large proportion (41-97%) died the following year. This mortality reduces with time when climax species are established.

Recruitment seems to follow the same pattern except that it reduces sharply for seedlings when herbs are dense and only begins to increase when increasing tree canopy shade has suppressed the weeds.

Recommendations

To encourage the establishment of more forest tree species, farmers when clearing farms should consider cutting woody plants at a workable of height e.g. 1. 5 m so as to permit more rapid canopy closure by stump sprouting after farms are abandoned. These shrubs could be regularly pruned to allow sufficient light to reach crops the during the farming period. This approach would have the secondary benefits of increasing soil litter, suppressing weeds and in some cases providing additional firewood.

Some recognised and protected (not cut) timber species could still suffer the weed invasion of the early period after farm abandonment if this approach was taken. One way of encouraging their survival would be to weed their surroundings during the time that takes for shrubs and treelets to form a closed canopy (in 2-3 years age class). Because regeneration of desirable timber species depends on the presence nearby of seed producing parents which set seeds, selective forest clearance leaving well distributed parent trees would facilitate recovery of farmland.

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Appendices

Appendix 1: Forest composition

List of woody species * 2m tall in 30 fallows (1.2 ha) on Mount Cameroon: case study at Likombe (800 - 1150 m asl) (1995and 1996 censuses)

Keys: 1= 0-2 years; 2 = 3-5 years; 3 = 6-10 years; 4 = 11-30 years and 5 = 30+ years

* denotes species found in unexpected vegetation stands (young i.e. < 10 years or old i.e. > 10 years)

spp code	Genus	species	Family	Location in age class
1	*Alangium*	*chinense* *	Alangiaceae	**1, 5***
2	*Albizia*	*zygia*	Leguminosae	**1*, 4**
3	*Alchornea*	*floribunda*	Euphorbiaceae	**2, 3, 5***
4	*Allophyllus*	*africanus*	Sapindaceae	**5**
5	*Angylocalyx*	*oligophyllus*	Leguminosae	**fs5**
6	Anthonotha	cladanta	*Leguminosae*	***5***
7	Blighia	sapida	*Sapindaceae*	***5***
8	Boehmeria	platyphylla	*Urticaceae*	***4***
9	Bridelia	micrantha	*Euphorbiaceae*	***1, 2, 3, 4****
10	Bridelia	grandis	*Euphorbiaceae*	***3, 5***
11	Bridelia	sp1	*Euphorbiaceae*	***3***
12	Caloncoba	cf lophorcarpa	*Flacourtiaceae*	***5***
13	Carapa	procera *	***Meliaceae***	***1, 2, 3***
14	Cecropia	peltata	***Cecropiaceae***	***1, 2, 3, 5****
15	Celtis	integrifolia	***Ulmaceae***	***4***
16	cf Ancistrocarpus	densispinosus	***Tiliaceae***	***4, 5***
17	Chazaliella	sciadephora	***Rubiaceae***	***4***
18	Cissus	cf barteri	***Vitaceae***	***4***
19	Claoxylon	hexandrum	***Euphorbiaceae***	***3***
20	Cordia	aurantiaca	***Boraginaceae***	***5***
21	Cordia	platythyrsa	***Boraginaceae***	***5***
22	Cuviera	acutifolia	***Rubiaceae***	***4***
23	Cyathea	manniana	***Cyatheaceae***	***4, 5***
24	Dichapetalum	sp1	***Dichapetalaceae***	***5***
25	Dicranolepis	cf vestita	***Thymeleaceae***	***4, 5***
26	Draceana	sp1	***Agavaceae***	***5***
27	Drypetes	sp1	***Euphorbiaceae***	***4, 5***
28	Drypetes	staudtii	***Euphorbiaceae***	***3***
29	Ekebergia	staudtii	***Meliaceae***	***4***
30	Entandrophragma	angolense	***Meliaceae***	***1*, 2*, 3*, 4, 5***
31	Eriocoelum	africanus	***Sapindaceae?***	***5***
32	Ficus	asperifolia	***Moraceae***	***4***
33	Ficus	exasperata	***Moraceae***	***2, 3, 4, 5***
34	Ficus	mucuso	***Moraceae***	***3, 4, 5***
35	Ficus	sur	***Moraceae***	***1, 2, 3, 4, 5***
36	Ficus	vogeliana	***Moraceae***	***5***
37	Gambeya	africana	***Sapotaceae***	***5***
38	Garcinia	mannii	***Guttiferae***	***4***
39	Harungana	madagascariensis	***Guttiferae***	***1, 2, 3***
40	Hibiscus	sp1	***Malvaceae***	***3***
41	Homalium	letestui	***Flacourtiaceae***	***5***
42	Hypselodelphis	scandens	***Marantaceae***	***5***
43	Ixora	cf foliosa	***Rubiaceae***	***4***

44	Ixora	cf hiernii	Rubiaceae	4
45	Jollydora	duparquetiana	Connaraceae	5
46	Leea	guineensis	Vitaceae	3
47	Lindackeria	dentata	Flacourtiaceae	4
48	Macaranga	dentata	Euphorbiaceae	3
49	Macaranga	occidentalis	Euphorbiaceae	1, 2, 3
50	Macaranga	schweinhuttii	Euphorbiaceae	4, 5
51	Macaranga	sp1	Euphorbiaceae	5
52	Macaranga	spinosa	Euphorbiaceae	1
53	Macaranga	zenkeri	Euphorbiaceae	5
54	Maesa	latifolia	Myrsinaceae	1, 2, 4, 5
55	Manilkara	sp1	Sapotaceae	5
56	Margaritaria	discoidea	Euphorbiaceae	4
57	Markhamia	sp1	Bignoniaceae	5
58	Milicia	excelsa	Moraceae	1
59	Mimulopsis ?	solmsii?	Acanthaceae	4, 5
60	Monodora	sp1	Annonaceae	5
61	Neoboutonia	mannii	Euphorbiaceae	3, 4
62	Pavetta	sp1	Rubiaceae	4
63	Persea	americana	Lauraceae	2
64	Polyscias	fulva	Araliaceae	1, 2, 3, 4, 5
65	Polysphaeria	macrophylla	Rubiaceae	4, 5
66	Pseudospondias	microcarpa	Anacardiaceae	5
67	Psychotria	gabonica	Rubiaceae	5
68	Raphia	sp1	Palmae	2
69	Rauvolfia	vomitoria	Apocynaceae	1, 2, 4*, 5*
70	Ritchiea	sp1	Capparaceae	5
71	Rothmania	cf longiflora	Rubiaceae	4
72	Solanum	cf torvum	Solanaceae	1, 2, 3
73	Sterculia	tragacantha	Sterculiaceae	5
74	Strombosia	grandifolia	Olacaceae	2*, 3*, 4, 5
75	Strombosia	pustulata	Olacaceae	5
76	Strombosia	sp1	Olacaceae	4
77	Strophanthus	sp1	Apocynaceae	5
78	Strychnos	cf staudtii	Loganiaceae	4, 5
79	Strychnos	elaeocarpa	Loganiaceae	5
80	Tabernaemontana	sp1	Apocynaceae	3
81	Tabernaemontana	sp2	Apocynaceae	3, 4, 5
82	Trema	orientalis	Ulmaceae	1, 2, 3
83	Trichilia	rubescens	Meliaceae	3, 4, 5
84	Trichoscypha	sp1	Anacardiaceae	5
85	Turraeanthus	africanus	Meliaceae	3, 4, 5
86	Uapaca	staudtii	Euphorbiaceae	4, 5
87	Uvariodendron	fuscum	Annonaceae	
88	Uvariodendron	grandifolia	Annonaceae	4, 5
89	Uvariopsis	sp1	Annonaceae	5
90	Vernonia	amygdalena	Compositae	3
91	Vernonia	conferta	Compositae	1, 2, 3
92	Vernonia	sp1	Compositae	4, 5
93	Voacanga	sp1	Apocynaceae	5
94	Xylopia	africana	Annonaceae	4
95	Zanthoxylum	gillettii	Rutaceae	3
Total	74	95	40	

Potentials of cluster analysis for the aggregation of tree species from African tropical forests

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Abstract

Some of the most common problems encountered by tropical forest management specialists relate to the large number of species met in tropical forests. Thus, it is often wished to aggregate species in a few groups based on objective criteria. Cluster analysis was used here to aggregate 26 tree species encountered in west and central Africa. The data were collected from Permanent Sample Plots installed in logged over forests of Liberia. The data set analysed consisted of 878 trees, each of which was subject to two measurements made six years apart. The clustering procedure was based on two variables: the average diameter increment per species and the average diameter recorded during the first campaign of measurements. The analysis allowed to form five groups were formed, and cluster analysis has shown interesting potentials for species aggregation for tropical forest management.

Résumé

Certains des problèmes les plus courants que rencontrent les specialistes en aménagement des forêts tropicales sont liés au grand nombre d'essences rencontrées dans ces écosystèmes. Ainsi, on souhaite souvent regrouper ces espèces sur la base de critères objectifs. L'analyse des aggregats a été utilisé ici pour regrouper 26 essences rencontrées en Afrique de L'ouest et du Centre. Les données ont été collectées dans des parcelles échantillons permanentes installées dans des forêts exploitées du Libéria. L' ensemble des données analysées est constitué de 878 arbres ayant fait l'objet de deux mesures séparées de six ans. La procédure d'aggregation

Introduction

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

These attributes give tropical forests a special priority in all attempts to preserve biological diversity at the global level, but also make the development of management strategies for tropical forests rather 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 (all species tend to be equally represented). As a consequence, the number of individuals for any species is often small (National Research Council 1982). This further complicated 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 1991).

These facts have encouraged forest management specialists and forest Biometrician to group species based on more or less objective criteria. For example, Vanclay (1991) working on data from tropical forest of North Queensland used regression analysis to form 41 species groups out of the 237 tree species identified in that country 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 having the same commercial status do not necessarily have the same growth habits. Therefore, it would be desirable to have only a few groups based on an objective criterion, allowing growth and yield prediction as well as prediction of future stand structure and composition.

The objective 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. Such groups might be used later for modelling in forest management.

Materials and Methods

The data set

The data analysed here were collected in Liberia, West Africa. Starting from 1978, several pilot projects were installed in the country with the co-operation of German institutions, the general objective being to determine the silvicultural potentials of logged-over forests (Parren & de Graaf 1995). Within the framework of these projects, about 39 one-hectare Permanent Sample Plots (PSP) were established in four different 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. In the three other stations studies aimed at testing the effects of different silvicultural treatments after logging.

Within each PSP, all 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 illumination. Each tree was also located on the map using rectangular co-ordinates. A total of about 20,000 trees of 245 species were so monitored.

Because of variations among silvicultural treatments which were tried from one station to the other, and due to the inconsistency in re-measurement dates, only eight plots were used for the following analysis. Five of these plots are from Grebo where no silvicultural treatment were applied after logging and three are control plots from Cavalla (only logging without treatment). All together, these plots constitute a raw data set of 3475 trees re-measured six years apart.

From this raw data set, only commercial tree species found both in West Africa and Central Africa were retained because the results are intended to be used also in Central Africa. In addition, data on trees that died between the two measurement were eliminated as were species which were represented by less than 10 trees. The final data set was thus made up of 878 trees belonging to 26 species.

Method of analysis

The aggregation of species was done using Cluster Analysis in the Sestet procedure (Systat Inc, 1991). Cluster analysis is a method of detecting the natural groupings in data. The analysis was mainly based on two variables: the average diameter increment(DI) and the average dbh recorded at the beginning of the growth period (d_1).

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 forests. 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 analysed in terms of individual tree increment", he went on to identify diameter increment as "a basis for species grouping". In fact, Vanclay (1991), 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 & Johnson 1987), diameter increment, a change in tree diameter over a specified period of time, should necessarily be one of the best variable 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 characterise 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 like Rollet (1974) or 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.

Each tree species j could thus form a single statistical case characterised by d_{1j} the average diameter of the species at the beginning of the growth period and DI_j the average diameter increment for that species (Table 1). Given that the aim of the analysis is to group species, by using a method which aggregates these statistical cases, species are 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:

$$DI_{ij} = d_{2ij} - d_{1ij}$$

d_{1j} and DI_j were found as:

$$D_j = \Sigma D_{ij} / n_j$$

$$DI_j = Di_{ij} / n_j$$

Where n_j is the number of trees of species j.

The two values d_{1j} and DI_j are used as co-ordinates to locate each tree species on a two-dimensional plan. The principle of the clustering procedure consists of calculating the Euclidean distance from the location of a randomly chosen species to the location of its nearest neighbour (Newnham 1992; Kent & Coker 1992). If the starting species is j and its neighbour species j+1, $E_{j,j+1}$ the Euclidean distance between the two is :

$$E_{ij+1} = \sqrt{}(d_j - d_{j+1})^2 + (DI_j - DI_{j+1})^2$$

Similarly the distance from j+1 to its nearest neighbour can be calculated. If the nearest neighbour of j+1 is j, then a potential cluster has been formed. Otherwise, the aggregation continues by choosing another species which 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 centre 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 co-ordinates d_{1j} and DI_j, the centroïd of the cluster c can also be located by co-ordinates d_{1c} and DI_c defined as:

$$D_c = 1/m \Sigma d_j$$

$$DI_c = 1/m \Sigma DI_j$$

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 (SPSS

Inc. 1988), but within each level the clusters are disjoint (fig 2). Depending on the objective of the analysis, an appropriate level is chosen as the final solution.

Table 1: Average dbh and diameter increment (both in cm)

Species	Mean dbh first mensuration	Diameter increment
Hannoa klaineana	14.66	2.29
Gilbertodendron preusii	30.03	1.64
Dalium guineensis	20.37	1.96
Coula edulis	23.22	0.82
Lophira alata	35.42	0.82
Strephonema pseudocola	18.95	0.79
Uapaca guineensis	24.78	0.19
Xylopia staudtii	29.00	1.60
Parkia bicolor	19.90	7.80
Dacryodes klaineana	20.87	0.88
Newtonia dupatquetiana	36.71	2.99
Anthonotha fragrams	41.86	1.95
Erythrophleum ivorensis	39.20	1.75
Lovoa trichiloïdes	13.84	3.13
Pentaclethra macrophylla	11.60	2.80
Pygnanthus angolensis	13.73	1.20
Penda oleosa	15.27	1.52
Parinari exelsa	40.97	1.67
Schrebera arborea	18.50	5.30
Nauclea diderichii	18.90	10.10
Funtumia elastica	11.80	3.20
Entandrophragma utile	20.10	2.40
Alstonia boonei	11.60	1.00
Canarium schweinfirthii	19.90	9.50
Entandrophragma angolense	13.00	3.80
Khaya anthotheca	11.20	0.40

Results

The hierarchical cluster diagram has yielded 20 levels of groupings (fig 2). There are two extremes solutions, one consisting of a single group formed with all the 26 species, the other showing as many groups as species (26 groups). In between there, are many solutions ranging from a level of two groups to a level of 24 groups. Given the above stated objective the level comprising five clusters was chosen as the final solution. Table 2 gives the distribution of species between different groups the first group consist of nine species, the second four species, the third six species, the fourth two species and the fifth five species.

Table 2: Distribution of species among group (clusters)

Group number	Species
I	Acajou blanc (*Khaya anthotheca*) Ekouk (*Alstonia boonei*) Mubala (*Pentaclethra macrophylla*) Muntondo (*Funtumia elastica*) Tiama (*Entandrophragma angolense*) Bibolo (*Lovoa trichiloïdes*) Nom osek (*Hannoa klaineana*) Afane (*Penda oleosa*) Ilomba (*Pygnanthus angolensis*)
II	Bilinga (*Nauclea diderichii*) Aiele (*Canarium schwinfurti*) Parkia (*Parkia bicolor*) Obang (*Schrebera SP*)
III	Eyen gwe (*Strephonema pseudocola)* Adjouapha *(Dacryodes klaineanaapha)* Eyous foncé *(Dalium guineense)* Sipo *(Entandrophragma utile)* Coula *(Coula edulis)* Rikio *(Uapaca guineensis)*
IV	Objobi *(Xylopia staudtii)* Ekobem *(Gilbertodendron preusii)*
V	Kibekoko argent (*Anthonotha fragrams)* Azobe *(Lophira alata)* Nom atui *(Newtonia duparquetiana)* Tali *(Erythrophleum ivorense)* Parinari *(Parinari excelsa)*

Table 3: Average diameter increment per species group

Species group	Average DBH / cluster (cm)	Average Increment/ cluster (cm)
I	13.0	2.15
II	19.0	8
III	21.4	1.17
IV	29.5	1.62
V	38.8	1.84

Table 3 gives average for dbh at the first mensuration and for diameter increments. It suggests that, among all the species analysed, group II clearly contains the fastest growing followed by group I.

Conclusion

This analysis has allowed to form five groups species out of the 26 species analysed. This is an attractive number because it can be easily handled for forest management purposes and such a number has already been considered in some tropical countries such as North Queensland (Vanclay 1988, Vanclay 1989). In addition, given that the basis of the analysis was tree growth, such a grouping has potentials of being utilised in growth and yield studies. Thus, cluster analysis has interesting potentials of being used for species grouping. Moreover, some species known to have similar uses and comparable technological properties are in the same groups this is particularly the case of Acajou Blanc, Tiama and Bibolo in group I, Azobe and Tali in group V. It can be foreseen that a better data set (which is difficult to obtain in tropical Africa), with more trees per species and with a wider range of diameter values may yield improved results.

Although the variables on which the analysis was based were quantifiable attributes which should allow an objective grouping, it should be remarked that a subjective element is introduced about the decision on the "cut-off" point and the final number of groups. However, this should not be seen as drawback for the method because it permits the analyst to be flexible and use professional experience.

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C. Case Studies in Miombo, Secondary and Plantation Forests

C. Case Studies in Miombo,Secondary and Plantation Forests

Session V

Chair: Mr. J.G.K. Owusu
Mr. Jean Loumeto

Fifty years of experience with permanent sample plot data in the Baikiaea Woodland of Zimbabwe

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Abstract

The permanent sample plot programme in the Baikiaea forests of Zimbabwe started during the early 1930s. These plots were established inside Zimbabwe's "demarcated" state forests found in the northwest part of the country. This type of woodland is dominated by B. plurijuga, interspaced by G. coleosperma, P. angolensis, T. sericea, B. speciformis and Combretum species. Forty-one plots were established with a main objective to monitor growth and species composition. Since then, a lot of data has been collected representing over 50 years of experience.

Several local and international scientists have in recent years, attempted to analyze and develop growth models for these Baikiaea forests. Analysis results at hand from these endeavours have established mean annual increment growth rates of 1.5, 2.3, 1.9 and 2.9 mm/yr. for B. plurijuga, P. angolensis, G. coleosperma and B. speciformis respectively. This paper provides a profile of over 50 years experience in terms of establishment, management and maintenance, data assemblage, analysis, successes and problems; and the way forward.

Introduction

For thirty-two years from 1935 to 1967, the Zimbabwe Forestry Commission established 41 plots in what is known as the "demarcated" Kalahari Sand Baikiaea forests of northwestern Zimbabwe. Once established, the same ones were regularly re-visited for assessment at five-year intervals unless otherwise stated. The first plot was set up in 1935 and more were established thereafter with the youngest plot set up in 1967. Each of these plots was uniquely identified on the ground and can be re-visited. Loosely the term "Permanent Sample Plots (PSP)" is used to describe these experimental plots. The re-measurement programme involved measuring all traceable survivors.

Objectives behind the establishment of these experimental plots were quite varied (Calvert 1992; Mushove *et al.* 1992; Mkosana & Crockford 1995). Primarily, major objectives were those to:

1. Monitor dimensional growth and population dynamics over time;
2. Monitor the effect of induced periodic fires;
3. Investigate coppicing and regenerating ability; and
4. Monitor survival.

In the whole PSP programme, diameter growth data was collected on 79 different species of which only a few are economically important. The commercially utilisable timber tree species that dominate the plot community in the PSP programme include *Baikiaea plurijuga* (57%), *Guibortia coleosperma* (7%), *Pterocarpus angolensis* (6%), *Terminalia sericea* (6%), *Combretum species* (5%), *Burkea africana* (4%), *Ricinodendron rautanenii* (2%) and *Brachystegia speciformis* (1%). The remaining 71 "commercially unimportant" species together accounted for the 12% balance. The inclusion f species of less commercial use was important in order to gain an understanding of their behaviour in the woodland community and the system as a whole (Calvert 1984).

Plot establishment

One would like to know why it was necessary to set up these experimental plots. It is common knowledge that forest managers need to know the production potential of their forests. For the sustainable harvesting of natural forests, managers need to have adequate data from which to derive information on volumes, size distributions, regeneration and growth rates. Long term PSPs were designed to form a basis for providing such valuable information.

The plot establishment protocol was aimed at creating a permanent geographical record for each experimental plot. For each plot marked, a sketch map (not necessarily to scale) of the plot and the forest in which it is located was drawn, indicating the cardinal directions. Details of location and access directions were properly documented and clearly described for easy identification. The experimental sample plot was marked with treated wooden pegs to nark the four corner boundaries. Often on approach to the experimental plot, trees were painted white as an indication of the existence of the experimental area. Most of the PSPs were narrow and linear in shape with some stretching for a few kilometres. This was deliberate in order to capture as much variation as possible across the catena and also to account for as many species as were present. In some instances, the shape and size was determined by the objectives to be addressed. The longest plot was PSP 5 which stretches for 6.4 km long and 10 m wide.

The first plot to monitor diameter growth and species dynamics was established in 1935, known as PSP 1. More plots, either single or in groups were established between 1935 and 1967 to answer specific objectives, For example, 16 of these were to evaluate coppicing ability and artificial regeneration while 18 were for the purpose of observing fluctuations in the dynamics of the woodland communities in terms of growth, structure and species composition. From the documentation available, plot size varied from as little as 0.04 Ha (PSP 14) to as large as 12.9 Ha (PSP 4).

Measurements and maintenance

In each of the experimental plots all trees found were identified and allocated a unique identity code which was maintained at each measurement time. At plot establishment all trees with a minimum diameter size of 2.54 cm at breast height (DBH) were measured. Diameter measurements were taken as it was considered the best indicator for tree growth. Each tree satisfying this minimum diameter size was marked by painting a white band around the stem at DBH to indicate the position at which future measurements were to be taken. A numbered metal tag was then nailed on for easy identification. Any new trees found in the plot thereafter were ignored and no records were taken on them. Diameter measurements taken between 1935 to 1979 were all recorded in empirical inches but thereafter in metric units. All data collected was recorded by species in a master file created for each individual plot. An arbitrary system was adopted for assessing stand parameters such as dominance, bole formation and crown quality.

Base measurements were taken at plot establishment and subsequent measurements were scheduled at five-year intervals unless events dictated. When a plot was due for re-assessment, only tagged trees as identified by the number on the metal label were measured, However, due to priorities and periodic resource shortage, it was not possible to stick to the stipulated five-year measurement time interval. At the time of assessment a record of dead or missing trees was maintained to monitor survival. Since most of the tree species in the PSP programme are slow growing, it was not prudent to take yearly measurements. Below is the measurement schedule for selected PSPs for the period 1935 to 1993.

Table 1: Measurement years for 6 Permanent Sample Plots

PSP/Year	1935	40	45	47	49	51	52	56	57	58	60	61	67	76	93
1i	X	X	X		X		X	X				X		X	X
1ii								X				X		X	X
2					X	X			X			X	X		X
4					X					X	X			X	X
5					X			X			X			X	X
6				X						X	X			X	X

X = measurements carried out

It is evident from the schedule given above that inasmuch as the 5-year interval was more or less maintained for PSP 1, the situation was different with the other plots. For example the interval was 11, 16 and 17 years for PSP 6 for the period 1947-58, 1960-76 and 1976-93 respectively. For PSP 4 the interval was 9 and 16 years during 1949-58 and 1960-76 respectively. The implications of excessively long intervals are obvious. This gave rise to inconsistencies experienced in the scheduling of the measurement programme with the consequence of possible data distortion due to the time interval between assessments which sometimes was either too short or too long. An example of data distortion experienced due to long observation intervals was inconsistencies in tree re-identification. There were cases where trees identified as missing or dead at a previous observation but found re-appearing at the next subsequent observation time. Sometimes tree misidentification due to loss of tags or re-growth led to "apparent" diameter shrinkages. Problems of this nature were more frequent where intervals between observation years happened to be too protracted.

The period after 1976 was characterized by protracted observation intervals due to internal insecurity during Zimbabwe's liberation war which saw most of the experimental sites being abandoned for security reasons. It is for this reason that data collection between this period has to be treated with caution. Chances of missing records or tree misidentification could have been quite high due to lack of close monitoring. Rehabilitation of some of the plots was initiated in the early 1990s, 10 years after independence. Only a few traceable surviving trees were re-identified with the latest measurements taken in 1994.

The maintenance programme involved protecting plots from uncontrolled bush fires and unauthorized harvesting. Periodically, plot boundaries were checked and corner pegs replaced if found vandalised. Tree identity metal tags were replaced when found missing or broken in an attempt to avoid mixing up individual tree records. This programme was maintained reasonably well until at the peak of Zimbabwe's strife for independence in the mid-1970s when no maintenance and measurements could be carried due to internal insecurity.

Summaries on basal areas and diameter increment

Preliminary analysis of PSP data have been carried out on diameter growth of selected species in selected permanent plots. Recently seven of these plots have received attention in which the growth of 33 species was studied. Total basal areas (m^2/ha) and corresponding mean annual diameter increments (mm/yr) were derived. Table 2 below shows the mean annual diameter increments and mean basal areas of 14 selected species from 7 PSPs for the 1935-1993 period.

Table 2: Mean basal areas (m^2/ha) and mean annual diameter increments (mm/yr) for 14 selected species from 7 permanent sample plots

Species	Basal area	Rank BA	Mean	
			Diam incr.	DBH (cm)
Afzelia quanzensis	10.0	1.5	2.1	20.1
Kirkia acuminata	10.0	1.5	1.9	18.3
Erythrophleum africanum	9.2	3.0	1.5	13.7
Burkea africana	8.6	4.5	1.3	14.7
Ricinodendron rautanenii	8.6	4.5	3.4	36.5
Pterocarpus angolensis	8.4	6.0	2.3	26.0
Guibortia coleosperma	8.3	7.0	1.9	14.1
Terminalia sericea	8.0	8.0	1.4	11.6
Baikiaea plurijuga	7.9	9.0	1.5	12.5
Strychnos coccuiloides	7.5	10.0	1.9	10.9
Peltophorum africanum	6.4	11.0	2.2	15.2
Combretum species	6.3	12.0	1.9	9.3
Ziziphus mucronata	6.0	13.0	0.8	7.9
Brachystegia spiciformis	*	14.0	2.9	24.2

* = negligible, species present in only one subplot in PSP 6/1

In terms of mean basal area, *A. quanzensis* and *K. acuminata* each with 10 m^2/Ha basal area dominate the other species. *B. africana* and *Ricinodendron rautanenii* tie the rank in fourth position. The four commercially exploited species *P. angolensis, G. coleosperma, T. sericea* and *B. plurijuga* trail further down the list in sixth, seventh, eighth and ninth position respectively. It can be inferred that the observed rank ordering could have been a result of the absence of large diameter stems due to harvesting of these species. Since basal area directly or indirectly reflects on tree size, it follows from these results that the few *A. quanzensis* and *K. acuminata* trees present were large diameter trees, while *B. plurijuga*, the dominant tree species in plot communities is mainly composed of small diameter trees. The correlation between mean basal area and mean annual diameter increment in that the species characterized by higher basal area and mean annual diameter increment is not obvious except in the case of *Z. mucronata, B. plurijuga, G. coleosperma* and *P. angolensis* whose basal areas of between 6.0 to 8.4 m^2/ha correspond to diameter increments of between 0.8 to 2.3 mm/yr. giving a positive correlation between basal area and mean annual DBH increment.

Models for diameter growth

Four different models for predicting diameter growth described below are as a result of several attempts by the Forestry Commission to get an understanding of the growth dynamics of some selected commercially exploited species growing in the Kalahari Sand Baikiaea forests. From Table 2, it is possible that a relationship between basal area and diameter increment exists, although this may not be quite apparent. It is on this basis that a number of scientists (Calvert 1984; Hofstad 1993; Crockford 1994; Mukwiza 1995; Gumbie & Mukwiza, 1996) attempted to model diameter growth as a function of basal area. Gumbie and Mukwiza (1996) analysed data for *B. plurijuga, G. coleosperma, P. angolensis* and *T. sericea* from 7 selected PSPs and fitted a model of the form:

$$\Delta D = e^{(\alpha + \beta1*BA + \beta2*DBH + \beta3*YR + \beta4*DBH2 + \varepsilon)} \quad (1)$$

while Crockford (1995, unpublished) fitted to the same data a simple stand density model of the form:

$$\Delta D = e^{(\alpha + \beta1*BA + \varepsilon)} \quad (2)$$

where:

ΔD = diameter increment (mm/yr)
BA = basal area (m^2/ha)

DBH = mid-diameter (cm)
YR = year interval between two successive measurement years
DBH2 = square of mid-diameter
ε = random fluctuations
α, $\beta1$, $\beta2$, $\beta3$, $\beta4$ are constants

Crockford (1995) modelled diameter growth averaged over all plots for *B. plurijuga, P. angolensis* and *G. coleosperma* using Model (2) and obtained a goodness of fit coefficient in the range 0-8% showing that the model was imprecise. Fitting Model (1) registered a slight improvement to the fit (Gumbie & Mukwiza 1996). The results from Model (1) presented in Table 3 show regression equations for *B. plurijuga, P. angolensis, G. coleosperma* and *T. sericea* derived from PSP 1 series 1 data. Improvement to the fit ranged between 12 and 22% but was sometimes even higher in other plots. For example using Model (1), the equation for *P. angolensis* in PSP 2 (not shown here) achieved an R^2 value as high as 50%.

Table 3: Regression Models for diameter increment (mm/yr.) for four species in PSP 1 series 1 data

Model: $\Delta D = e^{(\alpha + \beta1*BA + \beta2*DBH + \beta3*YR + \beta4*DBH2 + \varepsilon)}$

Species	Constant	BA	Mid diameter	Year interval	Mid-DBH squared	Adj R^2 (%)
B. plurijuga	1.8	0.01**	-0.00	-0.02**	-1.2E-6	22.0
P. angolensis	2.9	-0.03*	-0.01*	-0.02**	2.1E-5**	12.4
G. coleosperma	0.6	0.2	0.00	-0.05**	7.9E-6	20.0
T. sericea	3.0	-0.5**	0.01	0.03	-4.6E-5*	21.1

* = significant level (P = 0.05); ** = significance level (P = 0.01)

Source: Gumbie & Mukwiza (1996)

Another scientist, Hofstad (1993) analysed the same PSP 1 series 1 data and modelled diameter growth using a probability model in three states:

1. probability of remaining in the same diameter class
2. probability of growing into the next class, or
3. probability of dying

He established equations for each diameter size class to predict probabilities in each state to take the form of:

B. plurijuga: $P_{ij} = a + b*\ln(j)$ (3)

P. angolensis: $P_{ij} = a + b*j + c*j^2 + d*j^3$ (4)

where:

I = state, (i = 1,.....,3)
j = diameter class
P_{ij} = probability that tree in class j stays in state i
a, b, c = regression coefficients

From Model (3) the R^2 observed was about 72% for states 1 and 2 whereas Model (4) gave R^2 coefficient as high as 97%, 80% and 93% for states 1,2 and 3 respectively. Compared with other models, Model (3) and (4) provide better fitting and warranty consideration to improve on.

Conclusion

Modelling to determine the growth dynamics of forests is an important tool to assist forest managers in sustainable forest management and the regulation of harvesting cycles. However, experiences from this PSP data was that data of this kind should be treated with caution due to its long term nature. The need for close monitoring and maintenance were found to be paramount in order to guard against data distortions.

From the experiences outlined above, it has been demonstrated that several attempts were made by various scientists to analyse the more than 50 year old PSP data and some significant success have been achieved, particularly in terms of determining annual diameter increments for most commercially exploitable species, namely *B. plurijuga, P. angolensis, G. coleosperma* and *B. spiciformis*. Not much success has been scored so far in terms of modelling growth dynamics of these species or the forests where they grow in.

The models described above all are preliminary and efforts are still being made to determine and to come up with a practical predictive growth or stand dynamics model. Judging by the level of the prediction coefficient (R^2), it would appear that Hofstad's probability Models (3) and (4) provide a better compromise, but it still remains to be answered whether working with probabilities helps to understand tree growth dynamics.

Basing on the forgoing and as a way forward, scientists are exploring the data further in an attempt to develop growth models for Baikiaea forests. Work undertaken so far by the scientists show promise and is now at an advanced stage. Indications are that the approach to study diameter growth indirectly by modelling changes in basal areas (m^2/ha) may be the answer.

It still remains to be proved whether the mean annual diameter growth or changes in other derived parameters such as mean basal area or volume should be the variables to analyse in order to gain a better understanding of the growth dynamics in such environments.

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The growth and yield of *Terminalia ivorensis* in south-western Nigeria

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Abstract

Growth and yield data from Terminalia ivorensis plantations in Gambari, Oluwa and Sapoba Forest Reserves of the lowland rain forest zone of south-western Nigeria are described. Three permanent sample plots (PSPs) assessed between five and nine times, nine semi-permanent sample plots assessed twice each and fifty temporary sample plots (TSPs) each assessed once were studied to determine variations and trends of stand growth parameters with age. Stem diameter distributions, periodic annual diameter increment and annual stem mortality percentage were also evaluated.

Mean dbh (at different ages) and total crop volume (TCV) at the final assessment ages of the two PSPs at Sapoba were predicted with satisfactory accuracy using graphical relationships of stand growth parameters in TSPs of the same locality. The TCV prediction process involves estimating thinning volumes at different ages and main crop volume at the final age, starting with specified initial values of mean dbh and number of standing stems per hectare.

Introduction

In the early 1960's, Nigerian forestry shifted emphasis towards forest plantation establishment due to the poor results obtained from natural regeneration methods. Most of the forest plantations established so far were those of the two important exotic species, *Tectona grandis* and *Gmelina arborea*, with correspondingly enormous amount of accumulated growth and productivity data. Comparatively limited amount of growth and yield studies have been carried out on the indigenous forest plantation species, such as *Triplochiton scleroxylon, Nauclea diderrichii, Terminalia ivorensis* and *Terminalia superba*.

The aim of this paper is to provide more data and information on the growth and yield of *Terminalia ivorensis* in the lowland rain forest zone of south-western Nigeria. It should be pointed out however that some interesting growth and yield data have been provided on *Terminalia ivorensis* in Nigeria by Lowe (1970), Oji and Nwaigbo (1984), Okojie (1988), Akindele and Owoeye (1991) and Abayomi (1993). Growth and yield studies are invaluable for providing useful data and information for the effective planning and management of forest plantations. They are useful for taking decisions on choice of species, site, silvicultural treatment and rotation age for a specified management objective.

Study Sites

Three sites in south-western Nigeria were covered in the study described in this paper. They are Gambari Forest Reserve in Oyo State, Oluwa Forest Reserve in Ondo State and Sapoba Forest Reserve in Edo State. The characteristics of the three sites have been described by Lowe (1970). Gambari Forest Reserve (latitude 7° 25'N, longitude 3° 53'E) is characterised by an altitude of approximately 90-120 metres above sea level, a mean annual rainfall of about 1270 mm and a gently undulating topography. The soil is brown loam over 1.2 m deep overlying red sandy earth with ironstone concretions below which is clay soil. The top soil is freely draining, fertile and not heavily leached. Soil pH is 6.3-7.0.

Oluwa Forest Reserve is at latitude 6° 50' N, longitude 4° 33' E, an altitude of about 90 metres above sea level, and has a mean annual rainfall of about 1780 mm. The topography is moderately undulating, while the soil is shallow, reddish sandy loam with gravely inclusions and bare rocky outcrops in places. The soil is of poor fertility and is leached, with a pH of 5.5.

Sapoba Forest Reserve (latitude 6° 4'N, longitude 5° 52'E) is characterised by an average annual rainfall of 2280 mm, a more or less fat topography and a reddish, fine sandy loam soil with increasing clay content at lower levels. The soil is freely draining and permeable to depth with accessible water table. After forest clearance, fertility leaches rapidly. Soil pH is 5.0.

Materials and Methods

Growth data for Gambari were from one permanent sample plot (PSP 12) and three temporary sample plots (TSPs). The PSP was established in 1932 in a stand planted in 1926 and assessed nine times between the ages of 6 and 31 years. The PSP was thinned at the ages of 6, 11.5, 20 and 31 years. The plot was 0.7082 ha in size, while the three TSPs varied in size from 0.04 ha to 0.14 ha. The sample plots at Ore in Oluwa Forest Reserve were laid in May 1996 in the P.1966 and P.1967 spacing trials involving four planting espacements, 1.83 m by 1.83 m, 2.74 m by 2.74 m, 4.57 m by 4.57 m and 6.71m by 6.71 m. Thirteen plots were laid and assessed in the P.1967 spacing trial and seven in the P.1966 spacing trial. All the plots measured 0.04 ha with the exception of two measuring 0.09 ha in the P.1966 spacing trial. For Sapoba Forest Reserve, there were three sources of sample plot data. The first source was the five assessments each carried out between the ages of 6 and 25 in two PSPs (PSP 152 and PSP 153) planted in 1956. The second was two assessments each on 27 PSPs of ages between 5 and 41 years.

In each plot all stems were measured for dbh to the nearest 0.1 cm and sample tree measurements taken to determine top height to the nearest 0.1 m. Stand volume was estimated for PSPs according to the Nigerian sample plot procedure (Horne, 1962), while for other plots stand volume was calculated as a product of stand basal area, mean height and a form factor of 0.45, which represents the average for volume sample trees previously measured in the three PSPs.

Summaries of productivity per hectare were prepared for individual plot assessments and graphs prepared to determine the relationship of different stand parameters with age. The variations of growth parameters within and between age classes on given sites were determined graphically for Sapoba Forest Reserve and arithmetically for Ore in Oluwa Forest Reserve. Estimates of periodic annual diameter increment (PADI) were obtained for individual stems in all plots assessed at least twice; the three PSPs and the nine plots assessed twice at Sapoba.

Growth data from the Sapoba TSPs were further analysed to determine graphically the relationships of mean dbh to composite independent variables, namely AHN^{-1} and $100AH^{-1}N^{-0.5}$, where A is age in years, H is top height in meters and N is number of stems per hectare. The two independent variables are hereafter referred to as X_1 and X_2 respectively. This exercise was aimed at predicting mean dbh, different ages, top heights and stockings for given independent plots with a view to future total crop basal areas and volumes of such plots. The derivation of X_1 was based on the assumed positive relationships of mean dbh to age, top height and the reciprocal of stocking, while for X_2, mean dbh was assumed to be positively related to age and negatively related to spacing - top height ratio.

Results and Discussions

The summaries of productivity per hectare of the three PSPs studied are presented in Table 1. Tables 2 to 7 indicate estimates of PADI and annual mortality percentage as well as average and range values of different stand parameters at different ages.

Table 1: Summaries of productivity per hectare for PSP Nos. 12, 152 and 153

PSP No.	Age (yrs)	No. of stems/ha	Top Ht. (m)	Mean Ht. (m)	Dom. Dbh (cm)	Mean dbh (cm)	Stand basal area (m^2/ha)	Stand vol. o.b (m^3/ha)	Total crop BA (m^2/ha)	Total crop vol. o.b. (m^3/ha)	M.A.I. (m/ha/ yr)
12	6.25	487	15.9	14.8	20.0	16.3	10.16	70.8	16.44	100.9	16.14
	11.67	178	21.9	20.9	28.3	26.1	9.52	81.1	21.37	168.2	14.41
	16.75	152	24.3	23.7	33.8	31.6	11.92	112.4	24.94	213.3	12.73
	26.00	68	(27.8)*	27.4	(39.9)	37.6	7.35	81.2	29.47	283.6	10.91
	26.42	68		27.4	*	37.5	7.51	80.8	29.63	285.5	10.81
	31.42	65		29.6		40.1	8.21	94.9	30.73	303.5	9.66
	36.75	65		26.5		43.3	9.57	99.0	32.09	307.6	8.32
	51.50	65		21.7		53.4	14.56	122.9	37.06	331.5	6.44
	57.08	65		22.3		56.4	16.24	140.6	38.76	310.2	6.12
152	5.67	294	15.6	14.9	23.6	19.9	9.14	76.4	9.14	76.4	13.47
	8.67	156	23.8	22.9	29.3	26.5	8.68	101.4	12.83	144.6	16.68
	18.67	129	26.0	25.8	42.1	39.0	15.41	201.1	20.78	259.0	13.87
	21.59	119	28.5	28.2	44.6	42.4	16.8	241.0	22.56	303.1	14.04
	24.92	109	26.3	26.1	46.4	45.0	17.34	228.9	23.91	302.0	12.12
153	5.67	217	15.2	13.4	23.2	20.3	7.02	54.3	7.02	54.3	9.58
	8.67	126	22.5	22.1	29.9	28.1	7.81	88.2	10.41	112.4	12.93
	18.67	119	26.2	26.1	42.8	40.8	15.56	205.9	18.28	231.4	12.39
	21.59	101	28.8	28.8	44.0	43.6	15.08	219.2	19.76	271.5	12.58
	24.92	86		27.3		46.3	14.48	200.48	21.24	281.6	11.30

* Bracketed figures are pre-thinning estimates of stand parameters.

Stocking

Stocking in terms of numbers of main crop stems per hectare varied as expected between plots, with the general tendency for stocking to decrease with increasing age. PSP 12 had a very high initial stocking of 1594 stems per hectare at age 6.25, but silvicultural thinning brought the stocking down to 68 stems per hectare at age 31.42. The intensities of the four thinning treatments of 12 were high, ranging between 69.4 and 32.0 percents for number of stems and between 57.8 and 24.9 percents for basal area. PSPs 152 and 153 had relatively low initial stockings of about 255 per hectare which dropped averagely to about 124 at age 18.67 years.

It is interesting to note that although the number of trees planted per hectare in the P.1967 spacing trial plots at Ore ranged between 222 and 2986 for the widest and clearest spacings respectively, the May 1996 assessment of 20 sample plots in the two experimental blocks indicated a stocking range of only 75 to 300 stems per hectare (Table 2b). The present average stockings for the four spacings range between 133 and 210 stems per hectare (Table 3b). For the purpose of comparison the ranges of stockings at different ages for TSPs assessed at Sapoba are presented in Table 2a. Rather high stockings were observed for the three TSPs assessed at Gambari (Table 3a). One of the plots had 913 stems per hectare at the age of 25 years with a stand basal area of 67.6 m^2/ha and a stand volume of 553.5 m^3/ha.

Thinning treatment and natural mortality accounted for the decline in stocking with increased plot age. No stem mortality was however observed for PSP 12, which had been regularly and adequately thinned up to the age of 31.42 years. Annual mortality percentages of between 0.5 and 5.0 for number of stems and between 0.2 and 4.1 for stand basal area had been recorded for PSPs 152 and 153. Comparatively high annual stem mortality percentages (3.0 to 5.9) were obtained over a five-year period in the nine unthinned semi-permeable sample plots at Sapoba (Table 6).

Table 2a: Ranges of growth data at different ages for temporary sample plots of Terminalia ivorensis in Sapoba Forest Reserve.

		Age Classes (years)				
Stand Parameter		5	10	20	30	40
No. of stems per ha	Min.	140	115	90	60	40
	Max	650	520	400	260	140
Top Height (m)	Min.	8	12.5	17.5	20	22.5
	Max	17	25	32.5	36	38
Mean Height (m)	Min.	7.5	15	17.5	20	21
	Max	15	23	31	34.5	37
Dominant dbh (cm)	Min.	11.5	20	32	40	45
	Max	22.5	35.5	52	61	66
Mean dbh (cm)	Min.	9	17	26	33	39
	Max	18	22	43	52	57
Basal area (m^2/ha)	Min.	5	6.5	10	12.5	13
	Max	10	17	30	37	40
Main Crop Vol. (m^3/ha)	Min.	25	50	100	125	140
	Max	60	170	400	575	640

Table 2b: Average and range values of growth data for *Terminalia ivorensis* spacing trial plots at Ore

Stand Parameter	P.1967 - Aged 29 years	P. 1966 - Aged 30 years
No. of stems per ha.	179 (75 - 300)	189 (150 - 244)
Top Ht. (m)	23.5 (21.0 - 25.7)	26.6 (23.9 - 29.1)
Mean Ht. (m)	21.4 (18.9 - 25.5)	25.9 (23.3 27.8)
Dom. Dbh (cm)	42.8 (39.1 - 47.7)	48.4 (23.3 - 27.8)
Mean dbh (cm)	38.3 (31.0 - 43.8)	41.9 (36.9 - 50.9)
Basal Area (m^2/ha)	19.8 (10.8 - 28.8)	26.3 (16.9 - 35.1)
Vol. o.b. (m^3/ha)	201.5 (124.5 - 309.3)	305.2 (176.8 - 399.5)

Height growth

A study of the trend of top height growth in the three PSPs indicates that in the first ten years a very high growth rate was obtained. Height growth slowed down in subsequent years. Estimates of top height for PSP 12 at ages 10 and 20 are 18.5 metres and 25.0 metres respectively, the corresponding average estimates for PSPs 152 and 153 being 23.0 metres and 27.0 metres. There appears to be a drop in stand height in each of the three PSPs, at the age of 37 in PSP 12 and about 25 in PSPs 152 and 153.

PSPs 152 and 153 appear to perform better than PSP 12, and their top height figures at different ages fall above the corresponding average estimates for the Sapoba TSPs. Tables 2a and 2b show that at the age of 30 years, the Sapoba TSPs which apparently cover a relatively wide range of site conditions, have a greater variation of top height and mean height than the spacing trial plots at Ore.

Table 3a: Stand growth data from Terminalia ivorensis Temporary Sample Plots in Gambari Forest Reserve.

Age (years)	No. of stems per ha.	Top Ht. (m)	Mean Ht. (m)	Dom. dbh (cm)	Mean dbh (cm)	Basal Area (m^2/ha)	Vol. o.b. (m^3/ha)
7	600	15.4	13.0	22.2	16.2	13.0	76.1
18	375	19.6	18.6	37.0	25.1	18.5	154.8
25	913	21.3	18.2	49.8	30.7	67.6	553.5

Table 3b: Average values of stand parameters for Terminalia ivorensis spacing trial plots at Ore

Plots planted 1967 - Aged 29 years

Spacing (m)	No. of stems per ha.	Top Ht. (m)	Mean Ht. (m)	Dom dbh (cm)	Mean dbh (cm)	Basal area (m^2/ha)	Vol o.b. (m^3/ha)	No. of plot assessed
1.83 x 1.83	200	24.0	22.8	40.4	36.2	19.2	192.1	4
2.74 x 2.74	208	22.4	23.0	45.4	39.4	24.4	252.2	3
4.57 x 4.57	133	24.9	24.1	42.4	38.8	15.1	161.9	3
6.71 x 6.71	167	22.7	21.6	43.8	39.7	20.8	202.9	3

Plots planted 1966 - Aged 30 years

Spacing (m)	No. of stems per ha.	Top Ht. (m)	Mean Ht. (m)	Dom dbh (cm)	Mean dbh (cm)	Basal area (m^2/ha)	Vol o.b. (m^3/ha)	No. of plot assessed
1.83 x 1.83	201	27.9	27.2	50.4	43.2	29.3	358.3	2
2.74 x 2.74	210	27.3	27.2	47.4	40.8	27.4	334.7	2
4.57 x 4.57	163	25.9	23.7	47.3	37.4	17.8	189.4	2
6.71 x 6.71	175	24.4	25.3	57.7	50.5	35.1	399.5	1

Diameter and basal area growth

Dominant dbh and mean dbh growth rates of the three PSPs and most of the other plots are quite impressive. PSPs 152 and 153 appear to perform better than PSP 12 with the mean annual increment of dominant dbh being about 2.2 cm/yr. at age 20. The corresponding estimate for PSP 12 is 1.8 cm/yr., which drops to 1.05 cm/yr. at age 50.

The stand basal area of PSP 12 was kept relatively low through regular thinnings, compared with the maximum basal areas estimated at different ages for the plots at Ore and Sapoba. Four heavy thinnings were carried out on PSP 12 from age 6 to 26, while one or two heavy thinnings were carried out on PSPs 152 and 153. Stand basal area tended to rise steadily in the latter two PSPs with the basal area at the last assessment almost doubling the first assessment. Owing to the relatively low initial stockings of PSPs 152 and 153, some stems had reached over 40.0 cm and 60.0 cm respectively at the ages of 18.67 years and 24.92 years, compared with the corresponding ages of 26 years and 51.5 years for PSP 12.

Periodic growth studies indicate that PADI of individual stems tend generally to increase with increased size class and decrease with increasing age (see Table 5). For instance in PSP 12, at age 6.25, PADI increase from 0.44 cm/yr. for the lower dbh classes to 1.13 cm/yr. for the upper dbh classes, while between ages 6.25 and 51.50 PADI for the upper dbh classes decrease from 1.13 cm/yr. to 0.25 cm/yr. Considering overall average PADI, the estimate for PSPs 152 and 153 at age 5.67 is 1.8 cm/yr., which very nearly doubles the corresponding estimate for PSP 12. However, at the age of 18.67 years, the estimated PADI for PSPs 152 and 153 (0.75 cm/yr.) is only slightly higher than 0.62 cm/yr., which is the corresponding estimate for PSP 12 at age 16.75. Percentage PADI in the semi-permeable sample plots at Sapoba increases from 2.0 to 4.3 between the lower and upper dbh classes at age 9, while the overall average estimate decreased from 3.1 to 1.7 between age 6.3 and age 16.5.

Table 4: Annual mortality percentages at different assessments of *Terminalia ivorensis* sample plots in Sapoba Forest Reserve.

1. PSP No. 152, *Terminalia ivorensis* P.1956

			Annual mortality percentage			
Period No.	Initial age (yrs)	Final age (yrs)	Lower dbh classes	Middle dbh classes	Upper dbh classes	Overall average
1	5.67	8.67	0.0	0.0	0.0	0.0
2	8.67	18.67	3.1	1.5	0.0	1.5
3	18.67	21.59	9.1	0.0	0.0	2.6
4	21.59	24.92	6.0	2.9	0.0	2.5

2. PSP No. 153, *Terminalia ivorensis*, P.1956

			Annual mortality percentage			
Period No.	Initial age (yrs)	Final age (yrs)	Lower dbh classes	Middle dbh classes	Upper dbh classes	Overall average
1	5.67	8.67	0.0	0.9	0.0	0.5
2	8.67	18.67	4.3	0.0	0.0	0.6
3	18.67	21.59	1.7	1.8	0.0	5.0
4	21.59	24.92	11.3	1.6	4.3	4.4

3. Semi-permanent sample plots of *T. ivorensis* assessed in 1977 and 1982

				Annual mortality percentage			
Group No.	No. of plots	Initial average (yrs)	Final average (yrs)	Lower dbh classes	Middle dbh classes	Upper dbh classes	Overall average
1	3	9.3	14.3	12.6	5.1	0.0	5.9
2	2	12.0	17.0	13.2	3.8	0.0	5.5
3	4	16.5	21.5	7.9	0.0	1.1	3.0

Table 5: Periodic annual diameter increments of individual stems of *Terminalia ivorensis* sample plots

1. PSP no. 12, *Terminalia ivorensis* P.1926, Gambari Forest Reserve

			Periodic annual diameter increment (cm)			
Period No.	Initial age (yrs)	Final age (yrs)	Lower dbh classes	Middle dbh classes	Upper dbh classes	Overall average
1	6.25	11.67	0.44	1.43	1.13	0.92
2	11.67	16.75	0.58	0.93	1.31	0.89
3	16.75	26.00	0.44	0.63	0.88	0.62
4	26.42	31.42	0.60	0.46	0.44	0.50
5	31.42	36.75	0.57	0.58	0.71	0.61
6	38.75	51.50	0.31	0.76	0.74	0.58
7	51.50	57.08	0.08	0.21	0.25	0.16

2. PSP No. 152, *Terminalia ivorensis,* P.1956, Sapoba Forest Reserve

			Periodic annual diameter increment (cm)			
Period No.	Initial age (yrs)	Final age (yrs)	Lower dbh classes	Middle dbh classes	Upper dbh classes	Overall average
1	5.67	8.67	1.0	1.8	2.1	1.6
2	8.67	18.67	0.6	1.3	1.6	1.1
3	18.67	21.59	0.3	0.9	1.3	0.9
4	21.59	24.94	0.2	0.5	0.9	0.5

3. PSP No. 153, *Terminalia ivorensis,* P.1956, Sapoba Forest Reserve

			Periodic annual diameter increment (cm)			
Period No.	Initial age (yrs)	Final age (yrs)	Lower dbh classes	Middle dbh classes	Upper dbh classes	Overall average
1	5.67	8.67	1.1	2.4	2.7	2.0
2	8.67	18.67	0.8	1.2	1.6	1.2
3	18.67	21.59	0.3	0.9	1.1	0.7
4	21.59	24.92	0.1	0.6	1.1	0.7

4. Semi-permanent sample plots of *Terminalia ivorensis* at Sapoba

				Percentage annual diameter increment (%)			
Group No.	No. of plots	Initial average (yrs)	Final average (yrs)	Lower dbh classes	Middle dbh classes	Upper dbh classes	Overall average
1	3	9.3	14.3	2.0	3.0	4.3	3.1
2	2	12.0	17.0	1.2	2.9	3.6	2.6
3	4	16.5	21.5	0.6	1.8	2.6	1.7

Volume production

Whereas stand volume in PSP 12 tended to be constant over the first 25 years of growth due to regular heavy thinning treatments, stand volumes of the other two PSPs tended to triple or quadruple over the same growth period. Total crop volume production increased steadily as expected in all three PSPs, increasing about three times in PSP 13 and between four and five times in PSPs 152 and 153 from age 5 to 25. The trend of the MAI figures in Table 1 indicates that a maximum MAI of between 16 and 17 m^3/ha/yr is probably attained at about the age of 5 years in Gambari Forest Reserve, while a maximum MAI of approximately 15 m^3/ha/yr is attained at about age 10 in Sapoba Forest Reserve.

An attempt to predict mean dbh and total crop volume in PSPs 152 and 153 from the relationships of growth parameters in the Sapoba TSPs produced fairly satisfactory results. Mean dbh values of all five assessments of the two PSPs except the first, and perhaps also the second assessment could be predicted with a reasonable degree of accuracy from the graphical relationship of either X_1 or X_2 with mean dbh. The following regression equation of the logarithm of mean dbh over the reciprocal of X_2 was found to be much more reliable than the corresponding equation for X_1. Whereas X_2 predicts mean dbh fairly well for all assessments except the first two for PSP No. 152, variable X_1 fails to predict mean dbh well for almost all the assessments of the two PSPs.

$$\text{Log } D = 1.582284 - 0.13248X_1 \qquad (r^2 = 0.60084)$$

$$\text{Log } D = 1.746079 - 1.10785X_2 \qquad (r^2 = 0.722538)$$

Predictions of final total crop volume (TCV) from known values of initial mean dbh and number of main crop stems per hectare gave negative deviation percentages of 7.6 and 12.7 for PSP No. 152 and PSP No. 153 respectively. The following models developed for *Terminalia ivorensis* plots at Sapoba were used for the TCV predictions.

1. An average curve relating mean dbh t variable X_1 (C1)
2. A table relating percentage number per hectare of smallest stems to percentage basal area per hectare of smallest stems at different levels of the former (between 5 and 70) and for different age classes (T1).
3. A top height/age curve (C2).
4. A mean height/mean dbh curve (C3).

The following procedure was adopted to arrive at an estimate of TCV at age 24.92 years for each PSP with the help of the above listed models.

1. Calculated the main crop basal area at the initial assessment from known mean dbh and known number of stems per hectare.
2. Estimate total thinning basal area per hectare at first assessment with the help of T1, assuming that the drop from the number of main crop stems per hectare at age 5.67 to the number of main crop stems at age 8.67 is due to the removal of the smallest stems as thinnings at age 5.67.
3. Estimate the mean height of thinnings from the calculated mean dbh of thinnings at age 5.67 using C3.
4. Calculate the total thinning volume from the product of thinning basal area, thinning average height and assumed form factor estimate (0.45 for *Terminalia ivorensis* at Sapoba).
5. Similarly determine total thinning volumes for ages 8.67, 18.67 and 21.59 as has been done with steps 2 to 4.
6. Predict main crop volume per hectare at age 24.92 and with the help of C2, C1 and C3, and add to it all estimates of thinning volumes per hectare to obtain total crop volume at the final age.

Conclusion

Some indications have been given in this paper of the variations and trends of growth and productivity of *Terminalia ivorensis* in South-western Nigeria. A method has also been developed using TSP data to predict the future total crop volume productions of a forest plantation stand from specified initial values of mean dbh and number of main crop stems per hectare. The method presupposes a given thinning schedule for the stand throughout the rotation, and depends on the application of a set of graphical and tabular methods of growth parameter relationships. It is important to note however that more growth data should be collected and analysed for varying age, site and stocking conditions in order to improve on the level of accuracy and precision achieved in the present study.

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Development and potentials of *Lophira alata* Banks ex Gaertin.f in the humid forest zone of south-east Nigeria

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Abstract

Lophira alata, an erstwhile little exploited indigenous timber species of the West and Central African lowland forest is now well exploited for its "iron wood". Pole-size trees are also exploited for minor construction purposes.

Recalcitrant seed is easily germinated so forest plantations can be established, but the need to generate adequate growth data, conserve and evaluate the available general gene pool of this species is stressed. This step is necessary if the exploitation of timber in the face of research neglect, which has been the bane with the other major forest species such as Iroko should not be allowed to happen with L. alata.

Critical however, is the need to apply sustainable methods for present exploitation in the forests.

Preliminary field trial in Onne (Southeast Nigeria) reveals substantial growth after five (5) years. A mean annual height of 1.58 m and a mean dbh of 1.5 cm per year was observed. This is comparable to growth data known for some other native fast growing species such as Obeche (Triplochiton scleroxylon), Terminalia species and other hard woods in this sub-region.

A multi-locational (regional) network approach is suggested for generating growth and yield data for Lophira alata. This is vital for the development of this species.

This is fully discussed in the light of the potentials to ensure the continued availability of iron wood in the future.

Introduction

With continued ill-planned forest exploitation programs currently being practiced in West and Central Africa, the future of natural forests in this sub-region is not assured. Substantial conservation effort is needed. Additionally, there will be more need to select and develop trees and forests that are managed for production purposes to reduce pressure on the remaining natural forests and to provide raw materials in forms more suitable for commercial use and the needs of human society (BANRC 1991).

In Nigeria, efforts on forest plantation establishment to address future timber and industrial raw material needs was initiated in the 1960s on *Triplochiton scleroxylon* (Obeche), *Nauclea diderrichii* (Opepe), *Terminalia ivorensis* (Afara), *T. superba* and other exotic species (i.e. *Gmelina arborea, Eucalyptus* species and *Tectona grandis*) within the southern forest areas.

Substantial data are today available on the growth and yield of these species (Abayomi 1998, Okojie 1988 and Oji & Nwaigbo 1984).

The Species

Lophira alata, the West African iron wood is endemic in the rainforest of West and Central Africa (Figure 1). It is the hardest wood in West and central Africa, and possess substantial qualities including termite resistance. It belongs to the family Ochnaceae and the forest relative of the savanna species *Lophira lanceolata*. It grows to about 60 m height and possess botanical features as described by Keay (1989).

Table 1 enumerates available information on uses and indigenous knowledge in Nigeria. Uses range from heavy duty construction and medicinal uses to light construction (see Dalziel 1937). Recently, use has increased from timber, fuelwood and construction poles.

Table 1: Indigenous knowledge on use of *Lophira alata*

Part of plant	Use	Country
Stem bark	Fever	Nigeria
Stem bark	Gastrointestinal troubles	Nigeria
Root bark	Jaundice (Yellow Fever)	Nigeria
Mature leaves	Wash for women in childbirth	Nigeria
Mature leaves	Used as mulch for termite control	Nigeria
Young leaves (red)	Infusion used as lotion	Nigeria
Young leaves (red)	Respiratory problems	Nigeria
Young stem	Chew stick	Nigeria

Seed Germination

Availability of quality seed is a major determining factor in the successful establishment of forest tree species (Ladipo *et al.* 1994). *L. alata* seed is recalcitrant so storage is not possible. Results obtained by Ladipo (in prep) has shown that pre-treatments will significantly enhance germination (see figure 2).

a) Seed soaking in cold water for between 4-24 hours will enhance germination.
b) Sowing of seeds at a depth of between 1-2 cm in soil will encourage earlier germination.
c) Seed placement will significantly affect the germination of *.L. alata* seed.
d) When trees are close in proximity, no substantial mother-tree effect on seed germination will be observed; thus indicating probable out-crossing of this species.

Growth of *Lophira alata*

The trial was carried out at the International Institute of Tropical Agriculture (IITA) Onne Station near Port Harcourt, in Southeastern Nigeria (Figure 3).

The mean annual rainfall of 2400 mm is monomodal (Ruhigwa *et al.*, 1995). The rainy season starts in March and ends in November. Relative humidity remains high throughout the year with mean values between 62-87%. Temperatures range from 23.1 to 30.2 °C. Sunshine averages 4.2 hours per day ranging from 2.0 hours in September to 6.1 hours in February. The soil at the experimental site is an Ultisol derived from coastal sediments and classified as loamy, siliceous, isohyperthenic, typic paleudult (Hulugalle *et al.* 1990). The soil is deep, well drained with good physical properties but low in nutrients (Ruhigwa *et al.* 1995).

Seed was collected from 4 different mother trees within the vicinity of the IITA campus and raised immediately in 1990. Seedlings were planted in the ICRAF/IITA arboretum in a single tree plot within one block of 28 trees spaced at 4 m x 4 m.

Assessments of height growth, diameter increment and branching were carried out annually. The 5 year data generated in 1996 is presented.

Results and Discussions

Lophira alata is well adapted to this site. Survival and growth was encouraging (see Table 2). *L. alata* made an annual increment of 1.5 cm. Branch no. was 0.72 branches produced per year (year^{-1}). This result is similar to the report of Abayomi (1993) who reviewed past reports and reported similar annual increments for *Terminalia ivorensis*. Reports on *Triplochiton scleroxylon* growth was also similar (Abayomi 1993).

Table 2: Growth and development of *Lophira alata* in S.E. Nigeria

Variable	Max.	Mean	Annual increment (yr^{-1})	SE±
Plant height (m)	9.2	7.9	1.58m	0.145
Diameter at dbh (cm)	12.4	7.5	1.5cm	0.36
No. of branches (no.)	7	3.6	0.72	0.26

Potentials of *Lophira alata*

L. alata has become a much exploited species and young trees are also exploited for rural domestic uses (see Table 1). The present investigation has revealed that *L. alata* has encouraging potentials for plantation culture in the southeast of Nigeria. This, coupled with the ease of seed germination will ensure availability of propagules for plantation culture. This situation will probably be the same in the other areas in West and central Africa with similar climatic conditions (see Figure 1).

Needs for Genetic Resources Conservation

Subsequent genetic improvement of *L. alata* will require conserved genetic resources. This and the resources of its wild relative *L. lanceolata* is vital if the future of iron wood is to be assured in West and Central Africa. For the above, an in-situ and ex-situ approach should be taken. This is so since seed is recalcitrant and only live forest trees can be conserved (in-situ) or field progeny or provenance trials converted to conservation stands (ex-situ).

Research Needs

The present paper reports only preliminary or the indicative potential of *Lophira alata* in S.E. Nigeria. The need for a robustly designed and replicated network type trials is vital if adequate data will be acquired on the growth on yield of this species at various sites within its natural range. This should be a CIFOR/NARS and NGO initiative. Additionally, the need for developing a truly sustainable method for the exploitation of the West African iron wood is important for the future of this species. The usual late and reconstruction approach put up for iroko should not be repeated here.

Conclusions

Forestry research efforts particularly on some major species is needed. With current situations, the future of global timber supply is not assured. Careful, well coordinated management of these major tree species including *L. alata* of current or future harvest potential could play an important part in reducing deforestation pressure on the remaining vegetation. The situation with Iroko (*M. excelsa*) and Obeche (*T. scleroxylon*) in West and Central Africa should not be allowed to happen to the other species to ensure forest and individual species sustainability for the future.

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Diameter growth in a miombo woodland in Central Mozambique

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Abstract

A research area was established in central Mozambique in a miombo woodland to monitor growth and regeneration of tree species, based on four permanent sample plots. The area is particularly dominated by Millettia stuhlmannii, a first class commercial timber species. In this paper, preliminary results of diameter increment based on a two year study period are presented. Correlations are produced between diameter increment and other state variables like initial diameter, crown form and stem form. Comparing the results with other equivalent regions, it is concluded that diameter increments obtained can be utilized for local decisions where no more accurate results are available. More intense and longer observations are encouraged to improve the precision of the figures obtained.

1. Introduction

Diameter growth in tropical forests has been widely studied since it represents one of the major factors influencing volume and biomass growth and t is one of the easiest and accurately measurable variables (Dawkins 1956, Vanclay 1994, Sitoe 1992, 1993). Permanent sample plots have been established all over the world to study the variation of this parameter.

This study presents preliminary results of diameter growth based on four 100x100 permanent sample plots measured annually in a semi-deciduous miombo woodland. Miombo woodlands are the main vegetation type of Mozambique and are the source of the majority of the timber merchantable in domestic and international markets. The lack of basic data on growth and regeneration on this type of forests has been used as excuse for not drawing management plans and consequently, not managing these forests.

Analysis of structure and composition have been already done for the area and the results show the need of silvicultural intervention. Uncontrolled fire has been identified as the key factor limiting regeneration and studies are being proposed to analyze more details about factors affecting regeneration and growth (Sitoe, in press).

2. Study site

The study site is located in the central region of Mozambique, at the Barue Plateau, in a deciduous miombo woodland. *Millettia stuhlmannii* is the dominant species in the area with 23% of the 12 m2/ha in basal area. It is one of the most important commercial timber species, classified as first class by national forest legislation. Other species in the area include *Pseudolachnostylis maprouneifolia, Diplorhynchus condylocarpon, Bauhinia thonningii* among others. In total, fifty seven woody species were found among big trees, lianas and shrubs (Sitoe, in press). The climate is tropical, modified by the altitude, of about 650 m.a.s.l. The mean annual precipitation is 1591 with most of the rain falling during the hot summer between October and April. Average annual temperature is 22.3 °C (FAO, 1984). Soils are sandy-clayey-loamy with low fertility and pH varying from 4.8 to 7.4 (Cossa, 1995).

3. Methods

Four 100x100 m permanent sample plots separated 80m from each other were established in mid 94 to monitor growth and regeneration. The area were logged two years ago. All trees dbh equal or more than 10 cm was uniquely identified and marked a semi-circumference in the measurement point. Diameter at breast height (dbh) was recorded annually using diameter tapes and individual trees records were maintained on the data base. Annual diameter increment was calculated for individual trees measured in the first and last mensuration using the following formula:

$$iD = (d3-d1)/2$$

where iD is the annual diameter increment in cm/yr, d1 and d3 are the initial and final dbh in cm, and 2 is the period of two years between mensurations of d1 and d3.

Eleven trees were excluded from diameter calculations because of the mensuration error that resulted in extraordinary large diameter variation. All trees that fall into the interval between -3 and 3 cm/yr were considered for this analysis.

Other variables like crown form and stem quality were visually evaluated using a 5 level scale where level 1 was the best and level 5 the worst. This variables was used to derive the correlation between diameter increment and the state of the tree.

4. Results and discussions

Diameter increment ranged from -1.45 to 2.07 cm/yr with more than 90% occurring in the interval 0-1 (Figure 1). General median diameter increment is 0.33 cm/yr. There is an evidence of a positive skewness on the diameter distribution that was also found by Kohyama and Hara (1989), Sitoe (1992) and other authors (Table 1).

Table 1. Central tendency measurements for diameter growth (cm/year) for woody vegetation in the sample plots at Mussianhalo study site, Barue, Manica.

Life form*	Minimum	Median	Maximum	C.V.	Mean
Shrubs	-0.11	0.24	0.95	75.3	0.30
Intermediates	-1.45	0.30	1.31	95.0	0.33
Canopy	-1.08	0.37	2.07	89.5	0.41
General	-1.45	0.33	2.07	90.1	0.38

Canopy: height>10m; Intermediates: height 3-10; Shrubs: height<3m.

Close results were found in different regions in the tropics: Sitoe (1992) based in a six years data found a median of 0.5 cm/yr. in a tropical rain forest in Central America; Sitoe (1993) found in a Central American tropical dry forest a median of 0.15 cm/yr. in a study based on four plots with four years; Silva *et. al.* (1994) found in the Brazilian Amazon, in a study based on ten years, average diameter increments between 0.4 and 0.6 cm/yr.

Comparing diameter increments among plant file forms, it is found that canopy species are fast growing compared to intermediates and shrubs. No statistical comparison was performed.

Table 2 shows the diameter increment for those species represented by at least ten individuals. The first observation is that almost all species have a mean diameter greater than the median. This result reflects the asymmetry of the diameter distribution. The minimum median (0.09 cm/yr) was found in the multi-stemed intermediate tree *Strychnos madagascariensis* while the maximum median (0.55 cm/yr.) was found in the thorny canopy species *Ziziphus mucronata. Millettia stuhlmannii*, the most common commercial and dominant species has a median of 38 cm/yr. For this species, the only one with representative number of trees in a large diameter range, a dependence between initial dbh and dbh increment was investigated. Figure 2 shows how median diameter increment by diameter class varies. There is an apparent tendency of increasing the diameter increment in the considered range. In the considered interval the diameter increment tends to be continuously increasing. Analysis held in Central American forests had an maximum diameter increment around 30-40 cm and then decreased (Sitoe 1992, 1993). Diameter increment models discussed by Vanclay (1994) indicates a general tendency for many species in different sites, to have the maximum increment around 30-50 cm dbh. Diameter classes higher than 45 were considered not significant since they are represented by only one or two trees and were not plotted. Increasing the significance of higher diameters would reveal the real tendency to a maximum followed by a decrease. Other species, or group of species did not show any specific tendency and diameter increment varied inconsistently with dbh.

Correlation analysis between diameter increment and the state variables show statistical significance with Spearman $15<|r|<29$. Crown form had the highest correlation with $r=-0.28$. It seems that those trees with an abundant crown have a higher diameter increment. Similar correlations have been described in other regions. Vanclay (1994) refers to the strong correlation between crown characteristics and diameter growth as common.

Table 2. Diameter increment cm/year of all tree species that had 10 or more stems in the plots.

Species	#stems	Mean	Maxim	Minim	Median
Bauhinia galpinnii	22	0.36	0.95	-0.08	0.30
Bauhinia thonninguii	64	0.42	1.88	-0.03	0.40
Burkea africana	19	0.37	0.91	0.02	0.32
Combretum sp.	29	0.30	0.88	0.03	0.19
Crossopterix febrifuga	23	0.27	1.13	-1.45	0.32
Diplorhynchus condylocarpon	69	0.39	1.31	-1.18	032
Hymenocardia acida	10	0.24	0.45	0.03	0.25
Markhamia obtusifolia	11	0.17	0.62	-0.83	0.16
Millettia stuhlmannii	146	0.45	1.54	-0.08	0.38
Parinari curatellifolia	14	0.24	0.80	0.00	0.29
Pseudolachnostylis maprouneifolia	49	0.33	0.86	0.00	0.29
Pterocarpus rotundifolius	28	0.45	0.94	0.00	0.38
Strychnos madagascariensis	17	0.15	0.64	-0.05	0.09
Terminalia sambesiaca	26	0.47	1.26	0.00	0.45
Terminalia sericea	14	0.48	1.19	0.00	0.42
Ziziphus mucronata	12	0.52	0.83	0.00	0.55

5. Conclusions

The results found in this study are preliminary, however, can be comparable with results derived from other similar areas during longer periods. This suggests that diameter increments obtained can be used with certain confidence while more accurate results are to be produced. However, intense observations and longer periods would produce much accurate and viable results.

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TROPIS: Tree Growth and Permanent Plot Information System

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Abstract

TROPIS, the Tree Growth and Permanent Plot Information System, contains five elements: (1) a network of people willing to share permanent plot data and tree growth information (serviced by newsletters and information sources hosted at http://www.cifor.or.id/tropis or available from CIFOR), (2) an index to, or metadatabase of, people and institutions holding permanent plot data, (3) a database management system (MIRA) to assist more efficient data management, (4) a system (WORLD) to identify comparable sites in other regions, allowing data from elsewhere to be used when no local growth information exists, and (5) an inference system (PLANTGRO) to allow growth estimates to be made in the absence of empirical data. Most of these components are still under development, but the first two elements are operational. The index or metadatabase currently contains references to 10,000 plots with 2000 species contributed by 100 collaborators, and is growing at about 1000 plots per month. Searches of the database are welcomed, and may be directed to the author.

Introduction

TROPIS is the acronym for the Tree Growth and Permanent Plot Information System sponsored by CIFOR, the Center for International Forestry Research, to promote more effective use of existing data and knowledge about tree growth. Several recent reviews report a paucity of long-term studies in terrestrial ecology (e.g., Strayer *et al.* 1986, Tilman 1989); this presumably relates more to the availability of data from long term permanent plots, rather than the existence of such studies. TROPIS attempts to redress this situation by drawing attention to existing studies. TROPIS is concerned primarily with information about permanent plots and tree growth in both planted and natural forests throughout the world. It has five components:

1. a network of people willing to share permanent plot data and tree growth information;
2. an index (metadatabase) to people and institutions with permanent plots;
3. a database management system to promote more efficient data management;
4. a way to find comparable sites elsewhere, so that observations can be supplemented or contrasted with other data; and
5. an inference system to allow growth estimates to be made in the absence of empirical data.

The network

TROPIS is about people, and about information. So unless they request otherwise, all contributors and clients of TROPIS are placed on the mailing list of *TROPIS-Update*, a twice-a-year information sheet informing of recent developments and progress. At present, *TROPIS-Update* goes to 200 people by email, and to 200 people by regular mail. Others are also welcome to subscribe, and may do so by sending an email to listserv@cgnet.com with the message subscribe tropis or by contacting the author.

TROPIS also provides information via the internet, at http://www.cifor.or.id/tropis in Indonesia, and at http://www.cgiar.org/cifor/tropis in the USA (both sites are the same, so choose the nearest or fastest site). At these sites, in addition to the latest information on TROPIS, how to contribute, and how to search TROPIS, you will find pointers to other sources of long-term permanent plot data. Although these other sources may serve different objectives and have different scales, they are consistent with the TROPIS objective to make better use of existing data. If you are aware of monitoring efforts not documented in the TROPIS Internet pages, please bring them to the attention of the author.

The index

The core of TROPIS is the index to (or metadatabase of) people and their plots, maintained in a relational database. The database is designed to fulfill two primary needs:

1. to provide for efficient cross-checking, error-checking and updating,
2. to facilitate searches for plots matching a wide range of specified criteria, including, but not limited to location, forest type, taxa, plot area, measurement history, etc.

The database structure is outlined in Figure 1, and in the data entry form in the appendix. the database is essentially hierarchical: the key element of the database is the informant. Each informant may contribute information on many plot series, each of which has consistent objectives. In turn, each series may comprise many plots, each of which may have a different location, a different size, etc. And each plot may contain many species. A series may be a thinning or spacing experiment, some species or provenance trials, a continuous forest inventory system, or any other aggregation of plots convenient to the informant. Plots need not be current, and abandoned plots may be included provided that the location is known and the plot data remain accessible. In addition to details of the informant, we try to record details of additional contact people associated with plots, to maintain continuity when people transfer or retire. Thus the relational structure revealed in Figure 1 may appear complex, but ensures data integrity.

At present, searches are possible only via mail, fax or email requests to the TROPIS-coordinator at CIFOR, but it is anticipated that self-service on-line searching will be made available next year (assisted searches will continue to be available for those without Internet access).Clients may search for plots with specified taxa, locations (latitude/longitude or place name), silvicultural treatment, or other specified criteria and combinations. Some requests previously fulfilled include searches for

- plots with particular species and/or locations (regions, latitudes, elevations, etc.);
- plots planted with two species and a range of spacing and thinning treatments; and
- plots in logged natural forest with several remeasures spanning at least 40 years.

The main outcome of such searches is a list of people to contact, with details of the nature and amount of relevant data held. A catalogue of past searches is also maintained, so that clients with similar requests can be advised of their common interests.

TROPIS currently contains references to over 10,000 plots with over 2,000 species contributed by 100 individuals in all parts of the world.

Database management

Several sources, including some of the early contributions to TROPIS, indicate that many researchers have some difficulty in compiling field data into an efficient database. Informal surveys of contributors who store data as paper or word-processor files revealed difficulties with basic technical aspects of database design, often rather similar in nature. TROPIS attempts to eliminate some of this unnecessary duplication by providing a standard database system free to any contributor who requests it. Such standard database systems have been proposed before, often with limited success, but one such system, MIRA (Ugalde 1988, 1989), has been used extensively in Latin America for several years, and appears to meet the basic requirements of many TROPIS participants. Thus CIFOR has sponsored the development of a new version of MIRA, based on a standard platform (MS-Foxpro) and made multi-lingual (English, Spanish, and French, plus the ability to customize to a fourth language). The prototype is now undergoing testing, and the package is expected to be available next year.

Comparable sites

Researchers studying tree growth are often handicapped by the paucity of data, or by the absence of independent data to corroborate their findings. Tree ring analysis is not always possible, and in such cases, growth data must be obtained from direct measurement. Reliable growth estimates require permanent plots that have been remeasured regularly for long periods, and these are not always available. However, there are many plots world-wide, and some of these may be used if an objective basis such as homoclime analysis can be used to select comparable growing conditions. Such analyses are commonly undertaken to assist species and provenance selection (e.g.,. Booth 1990a, 1991), but the issue of identifying comparable plots is analogous. Thus TROPIS will include a new version of WORLD (Booth 1990b) to enable such comparisons to be completed efficiently. This work is still in progress, but will be available by mail, fax, email and on-line when completed.

Objective inferences

Homoclime analyses are useful when data are available from comparable sites elsewhere, but this is not always the case. In some cases, despite judicious searches, no comparable data can be located, and yet it may still necessary to make some forecast about the suitability of a species on a given site. Despite this difficult situation, it may still be possible to provide a reasonable estimate, by making expert inferences from existing knowledge about the site and about the species under consideration. The PLANTGRO system (Hackett 1991) has been used with some success for agricultural crops, and is being enhanced so that inferences about tree growth can be made in the absence of empirical data. A preliminary version of PLANTGRO for trees is currently being tested. It too, will be made available by mail, fax, email and internet in due course.

How to participate

The objective of TROPIS is to help people learn more about trees and forests, and to help them manage these resources better. Anyone may contribute information on their permanent plots to the TROPIS system, provided that they agree in principle to share their data with others; subject of course, to a mutually satisfactory agreement between the data owner and the intending user. Conversely, anyone may use any of the five components of the system, provided that they agree to provide information on any permanent plots that they have, and respect the rights of other contributors.

Subscriptions to *TROPIS-Update* may be emailed directly to the listserver, or directed to the author, and anyone with internet access may browse the TROPIS internet pages. Information about permanent plots is welcomed from anyone with the appropriate authority, and may be submitted to the author using the form in the appendix, or using the form found in the TROPIS internet pages. At present, searches of the index must be directed via the author, but on-line searching should become available soon. The other components, MIRA, WORLD and PLANTGRO, are not yet available for general use, but will be made available soon. Their availability will be announced in *TROPIS-Update*.

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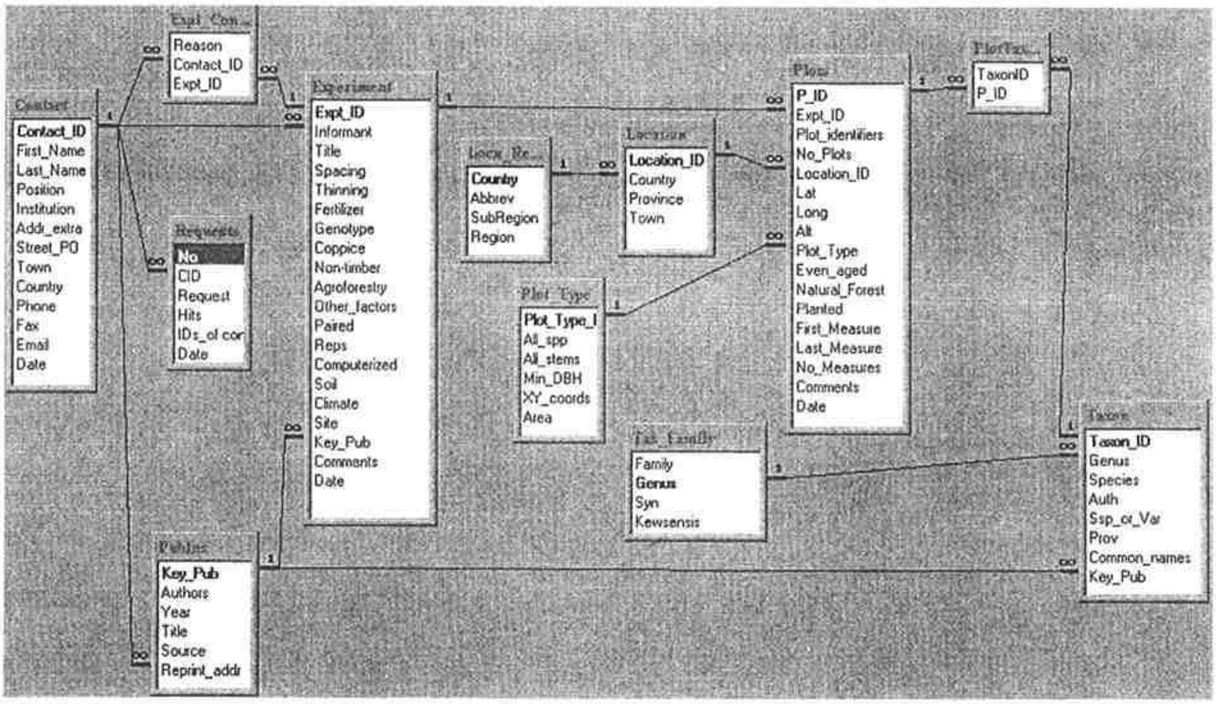

Figure 1. Structure of the TROPIS metadatabase.

TROPIS: An index to permanent plots in the tropics.

Please complete this form for all plots you know about: Copy as necessary. If you need more space, add an extra page.

If you would prefer to create an ASCII or dbase file directly, please contact Jerry Vanclay for more details.

About yourself

Your name: ______________________________ Position: ____________________

Institute: ____

Town: ______________________________ Country:

____

Phone: __________________ Fax: __________________ E-mail: ____________________

Other people associated with these plots: ____________________________________

Are they the: owner / initiator / collaborator / DB manager / user ? (circle one)

About the Experiment or Plot Series

Experiment Identifier: ____

Title: ____

Tick if it examines: Spacing ☐ Thinning / logging / treatment ☐ Fertilizing ☐ Genotype ☐

Non-timber products ☐ Agroforestry ☐ Coppice ☐ Other (State) ______________

Are there paired treatment - control plots? Yes / No How many replications ?

How are data stored ? Paper / ASCII file / Spreadsheet / Database

Details recorded: **Soil:** None / Some / Detailed; **Climate:** None / Some / Detailed;

Site: None / Some / Detailed

Key Reference (Full citation: author, date, title, source): ____________________________

____

Comments: ____

____

Plot Details (N.B. Each experiment/series may have many plot records)

Identifier for this record: Number of plots:

Location: Country: ______________ Province: ______________ Nearest Town: ____________

Latitude: _____°_____'_____"N/S Longitude: _____°_____'_____"E/W Elevation: ____________(m ASL)

Plot Area: ____________(ha) Minimum DBH: ____________(cm) Stem maps or X.Y. coords? Y / N

Tick if all tree species are measured ☐ if all stems above min DBH are measured ☐

List of Plot Identifiers : ____

Tick if plot is evenaged ☐ is natural forest ☐

Year planted First measured Last measured

Number of measures : ____________________

Species present on plot: ____

Comments: ____

Please return to Jerry Vanclay, CIFOR, P.O. Box 6596 JKPWB, Jakarta 10065, Indonesia

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STANDPAK

A decision support system for managing forest stands

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Abstract

STANDPAK is a computer simulation package developed by the New Zealand Forest Research Institute and can be used to predict the quantity and quality of wood yield from a managed forest stand. The package is comprehensive and is organised in modules to facilitate the evaluation of forest stands by predicting the effects of site, stocking and silvicultural treatments on stand growth, log yield and grades, understorey grazing and cash flow. This paper will present the flow of information between the modules of STANDPAK in general, and examine in detail sets of models used in the Stand Growth and Diameter Distributions modules. The benefit of, and opportunities for applying the STANDPAK modelling framework to predict the performance of tropical moist forests will be explored.

Introduction

Tropical moist forests in West Africa, especially those not in designated Government reserves, tend to be over exploited, and are therefore unable to provide regular flows of merchantable timber. These degraded forests will need to be left undisturbed for decades or hundreds of years before they can be sustainable managed. Local communities, therefore, prefer to convert degraded forests into enterprises such as oil palm, cocoa or coffee plantations that are able to provide economic returns in the short to medium term. Another option is to convert degraded forests using fast growing tropical species such as *Triplochiton scleroxylon* or *Tectona grandis* which have proven to yield merchantable volumes of timber by age 25 years (SODEFOR, KFW and GTZ 1996). Economic returns from such plantations in the moist tropics would compare favorably with plantation forestry enterprises in temperate regions such as New Zealand, where fast growing and high yielding species such as *Pinus radiata* (radiata pine) form the basis of a lucrative plantation forest industry.

The development of plantation forestry in the tropics requires that research in all aspects of tree growth and wood processing needs to be carried out. The research would include the effect of site, stocking and silvicultural treatment on tree and stand growth, wood quality, processing, marketing and agroforestry. A modelling framework approach that is capable of integrating current and future research on plantation forestry in the tropics into a useful management tool is required to enable forest managers evaluate options quickly, and to select options that maximise economic returns to the owners of the forest.

The development of such a decision support tool for tropical plantation forestry would be challenging since an appropriate modelling framework needs to be defined and agreed upon by researchers in the tropics, and the complex interactions that govern stand growth and wood quality specified and quantified. A modelling approach used by the New Zealand Forestry Institute to integrate knowledge on the growth and management of radiata pine a comprehensive decision support tool could be adopted for modelling forest plantations in the tropics.

In New Zealand a suit of computer programs called STANDPAK (Whiteside 1989) was developed for radiata pine in the '80s by a team comprising researchers and industry representatives. The programs can be used to predict the effects of silvicultural treatments on stand growth, log yield and grades, understorey grazing and cash flow. This paper will present a brief overview of the modules used in STANDPAK, and then describe in some detail sets of models used in two of the modules, the

Stand Growth module and the Diameter Distribution module. The benefit of, and opportunities for applying the STANDPAK modelling framework to predict moist tropical forest stand performance will be explored.

STANDPAK Modules

STANDPAK comprises a number of interrelated modules (West 1993) which perform specific tasks, and produces reports which may serve as input to other modules. The modules and linkages are shown in Figure 1.

The Stand Growth module predicts the effect of site and silvicultural treatments, such as thinning and pruning on stand growth, stocking and yield from age three to maturity. Diameter over stubs, a variable that is influenced by the frequency of pruning, and determines the size of the defective core of a tree, is also predicted.

The Diameter Distribution module uses information on height, age, diameter at breast height and basal area from the Stand Growth module to predict the distribution of stand diameter and yield of timber in each diameter class.

Using a specified cutting strategy, the trees in a diameter class are cut by the Log Making module. This module assigns to each log cut quality parameters (defective core, branch size, distance between branch whorls, wood density and sweep).

The Log Grading module uses the quality parameters assigned to each log from the previous module, and user specified grading system to grade logs. Considerable flexibility is provided in the way a log might be graded. Grading specifications can use parameters such as the small end diameter of the log, length, sweep, branch size, internode length, and whether the log is pruned or unpruned.

For each grade of log the Sawlog Evaluation module uses saw patterns and mill type to predict physical yields and residual log values. The monetary value of the saw log can be estimated using timber prices and sawing cost.

The profitability of understorey grazing can be assessed in the Agroforestry module. The reduction in pasture production and quality due to thinning and pruning, and the subsequent reduction in livestock carrying capacity can be estimated at any stage of the development of forest stand.

The Harvesting Cost module estimates the cost of harvesting and transportation for a clear felling operation. This information is used for economic analysis.

The Economic Analysis module uses the annual cash flow generated by the stand to calculate internal rate of return, net present value and break even price for a range of discount rates.

Models of the Stand and Growth Diameter Distribution Modules

Most of the models used in STANDPAK have been developed using data obtained from permanent sample plots (PSP) for radiata pine. The use of STANDPAK for other species requires, as a minimum, the specification and estimation of equations of the Stand Growth and Diameter Distribution modules. The main features of these modules are discussed in this section.

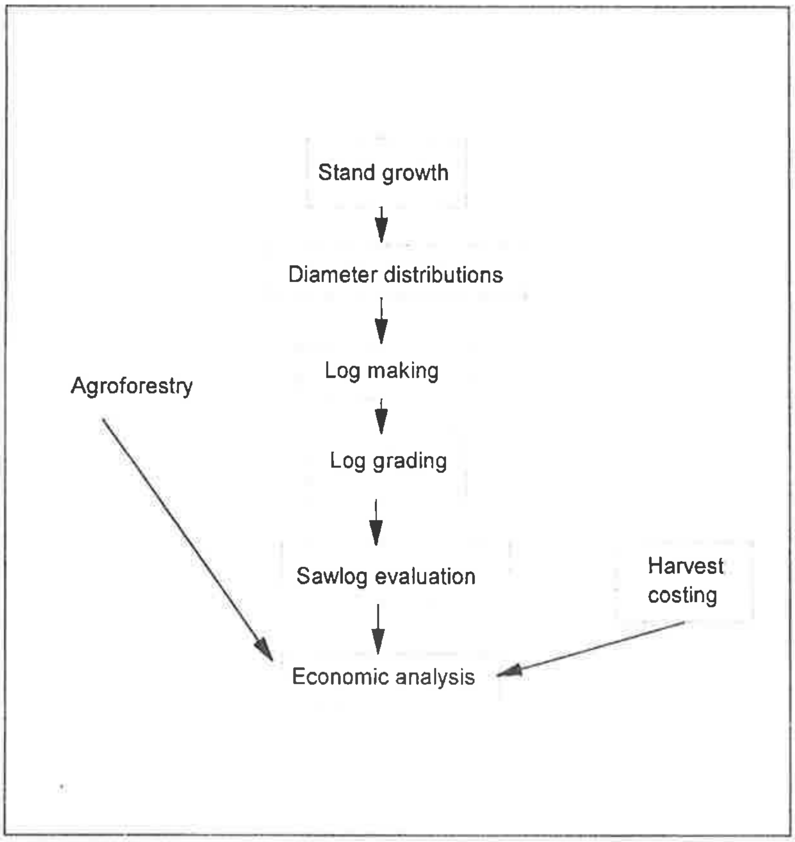

Figure 1: STANDPAK modules and linkages (West, 1993)

Stand Growth Module

The Stand Growth module contains growth and height models which can be used to describe the development of the forest stand. The models are generally non-linear regression models that relate height, basal area and volume to a number of stand variables. The main models and variables used are:

(a) Height equation:

Height = *f*(Site Index, Age)

(b) Basal area increment equation (BA_INCR):

BA_INCR = f(Site Index, Basal Area, Stocking)

(c) Volume equation:

Volume/Basal_Area ratio = *f*(Height, Stocking)

Where site index is defined as the mean top height of a stand of radiata pine at 20 years of age.

In radiata pine, most silvicultural treatments such as pruning and thinning are completed by the time the stand reaches a height of 18 m (approximately by 12 years of age). This phase of growth is described by "Model 23-Early". In this model the basal area equation is defined by the ratio of stem diameter at breast height (DBH) and stand height (Ht):

DBH/Ht = *f*(Stocking, Age)

Separate functions have developed for high, medium and low fertility sites. This feature is useful for modelling the development of forests on farm sites which tend to be fertile due to their long history of fertilizer application.

Diameter Distributions Module

In STANDPAK the distribution of stem diameter is predicted using data from the Stand Growth module. The proportion of trees in a given DBH class is assumed to follow a Weibull distribution which has the following functional form:

Weibull Distribution

$Y = 1 - \mathrm{Exp}^{(-(x - c)/a)b}$

x = a tree DBH
Y = Prop. of trees with DBH less than x
a, b, c = estimated parameters

Users can supply values for the parameters of the Weibull distribution, or STANDPAK can also estimate the parameters of the Weibull distribution from the minimum DBH, the maximum DBH and the variance of the DBH. Regression models have been developed to predict the required DBH values as follows:

Minimum DBH = *f*(Mean TopHeight, DBH. Age, Stocking, Basal Area)

Maximum DBH = *f*(Mean TopHeight, DBH, Age, Stocking, Basal Area)

Variance = *f*(Minimum DBH, Maximum DBH)

The height of trees in a DBH class is estimated as a function of DBH:

Height = *f*(DBH)

Prospects for using STANDPAK in Tropical Moist Forests

Modelling a single species even-aged stand

STANDPAK was developed in New Zealand to model an even-aged stand of radiata pine. In its present form STANDPAK cannot be used to model tropical moist forests. However, the concepts, modular structure and linkages of STANDPAK (Figure 1) can be adopted and used to model an even-aged single species forest stand in the tropics. For example the models contained in the Stand Growth and Diameter Distribution modules of STANDPAK can be re-estimated using the permanent sample plot data from tropical plantations. Qualitative parameters suitable for tropical trees and wood use can also be defined and used in the Log Making module to cut trees into logs.

Modelling uneven-aged stands

Considerable effort has gone into using sample plot data to develop growth models for a single tree and a whole stand of uneven-aged tropical moist forests (Vanclay 1994; Alder 1995). Models have been developed for single and mixed species, and for describing diameter increments. A modelling approach that represents a whole stand as a matrix that defines the transition of trees between diameter classes over time has considerable appeal for forest management (Buongiorno & Mitchie 1980). These matrix models can also handle mixed species, recruitment and harvesting. The structure of a matrix model is simple, where the states of a forest system are represented by a diameter distribution of trees, and coefficients used to describe the movement of trees between diameter classes over time. Mathematical programming techniques can easily be incorporated into a matrix model to develop optimal forest management plans.

It appears that the easiest way to use the STANDPAK modelling approach for an uneven-aged stand is to replace the Stand Growth and Diameter Distribution modules with a matrix type model. The matrix model will yield the distribution of tree diameter over time; tree heights and volume can be estimated as functions of diameter. The other modules can be re-specified to model tropical situations. Also mathematical programming techniques can be incorporated into matrix models for the development of optimal forest plans to enhance the Economic Analysis module of STANDPAK.

Conclusion

A suit of programs, STANDPAK, developed by the New Zealand Forest Research Institute for predicting growth, and for providing economic analysis of silvicultural treatments of a stand of radiata pine was outlined to illustrate the modular structure of the programs and to indicate information flows between the modules. Even though STANDPAK in its present form is not suitable for use with tropical plantation species, the modelling approach and the organisation of modules contained in STANDPAK could be easily adopted by research institutions as a format for developing a decision support system to aid the management of forest plantations in the moist tropics.

The use of concepts contained in STANDPAK to model uneven-aged stands of forests would be more difficult. Accounting for species composition would also increase the complexity of models. An approach that was suggested was to replace the Stand Growth and Diameter Distribution modules of STANDPAK with a matrix model of the uneven-aged and mixed species forest stand. The development of functions to characterise the impact of treatments on the quality of logs from an uneven-aged mixed species forest stand could prove challenging.

References

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Appendices

Appendix I: Conference Programme

Monday, 11 November Arrival and registration of participants
Tuesday, 12 November
Registration continues 08:00

Opening ceremony

Introduction of chairman 09:30

Welcome address by the Hon. Minister of Environment, Science and Technology 09:35

Opening address by the Hon. Minister of Lands & Forestry 09:40

Cocoa break 10:00

Technical sessions

1. Inventory methods

Inventory for forest management planning: Jenny Wong 11:00
Questions and opportunities in long term growth studies: Sixty years in Budongo forest, Uganda: Doug Sheil 11:30

Break for lunch 12:15

Revised permanent sample plot procedures for high forest in Ghana: Kofi Affum Baffoe 14:00
Rapid assessment for forest management on Mt. Cameroon: Nouhou Ndam and others. 14:30
Continuous forest inventory in Nigeria: Richard Lowe 15:00

Cocoa break 15:30

Forest inventory practices in Nigeria: Shadrach Akindele* 16:00
Getting the most out of your permanent plot data: Jerry Vanclay 16:30
Chairman's closing remarks 17:00

Welcome reception 19:30

Wednesday, 13 November

2. Growth Studies in Tropical Moist Forests

Productivity of a managed evergreen forest ten years after thinning: Yapo forest: N'guessan Kanga Anatole 09:00
The effect of climber cutting on species composition and structure in some PSPs in southern Cameroon: Marc Parren 09:30
Contribution of big trees to total forest production: a case study in Tai National Park: Renaat van Rompaey and others 10:00

Cocoa break 10:30

Growth patterns and composition trends in mixed evergreen forests in South Africa: Coert Geldenhuys 11:00
Growth, regeneration and mortality in managed natural forest in southern Cameroon: Roger Bibani Mbarga and Wyb Jonkers* 11:30

Models for basal area dynamics of mixed tropical forest: Neo-tropical experience and prospects for application in Ghana: Denis Alder 12:00

Break for lunch 12:30

Crown dimensions and sectional area growth of some mixed tropical forest trees in Ghana: E. G. Foli, A. Ofosu-Asiedu, V.K. Agyeman and A.R. Adam 14:00
A matrix model for tropical moist forest in the Central African Republic: Vincent Favrichon 14:30
Growth models for Nigeria's tropical moist forest: Shadrach Akindele[*] 15:00

Cocoa break 15:30

Diameter and height of Okoume (*Aucoumea klaineana*) forests of Ghaillu, Congo: Jean Loumeto 16:00
Using economic and biological criteria to group tree species of African tropical forests with cluster analysis: Richard Eba'a Atyi[*] 16:30
Forest management in Equatorial Guinea: Jaime Malonga Oko and Frank Stenmanns 17:00
Chairman's closing remarks 17:30

Thursday, 14 November

Case studies in Miombo, Secondary and Plantation forests

Experience with permanent plot data from the Baikiaea woodland of Zimbabwe: Chemist Gumbie & L. Tawonezvi 09:00
Diameter growth in a dry miombo woodland in Central Mozambique: Samuel Soto 09:30
Tree growth on abandoned farms at Mt. Cameroon: Nouhou Ndam and others 10:00

Cocoa break 10:30

Growth and yield studies in plantation grown *Triplochiton scleroxylon* in South West Nigeria: Philip Kio and Sagary Nokoe[*] 11:00
Growth studies in experimental plots of Irobo and Mopri twelve years after thinning: Bernard Dupuy 11:30
Development of the potentials of *Lophira alata* in the humid forest zone of south east Nigeria: David Ladipo 12:00

Break for lunch 12:30

Growth and yield of *Terminalia ivorensis* in south west Nigeria: John Abayomi, A. Oyedeji & B. Oyeleye[*] 14:00
Demonstration of STANDPAK and its application for growth prediction, log grading, agroforestry and economic analysis: Chris Dake 14:30
TROPIS: Tree growth and permanent plot information system: Jerry Vanclay 15:00
Chairman's closing remarks 15:30

Cocoa break 16:00
Closing ceremony 16:30
Farewell party 19:30

Friday - Sunday, 15-17 November

Field trips to Bobiri (Ghana) and Bossematie (Côte d'Ivoire) forests

Monday Thursday, 18- 21 November ***Training Workshop for selected participants***

Appendix II: Conference Participants

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