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ABSTRACT

Long-Term Observations and Research in Forestry

The contributions of the proceedings of the IUFRO Meeting „Long – Term Observations and Research in Forestry" focus on long term experiments in tropical forests, and on modeling and monitoring aspects. They describe applications to tropical silviculture, plantation management and agroforestry. Topics covered are planning and design of long-term experiments in tropical forest ecosystems, data administration in long-term experiments, optimization of plot size and time frame, case studies, practical aspects of establishing long-term experiments, long-term experiments in related fields, monitoring and assessment of site conditions.

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EDITORIAL

When the International Union of Forest Research Organizations (IUFRO) was founded in 1892, one of the main objectives of this new professional organization was to provide a platform to exchange experience and develop sound methods on how to plan and analyze long term experiments. Information on forest growth was sparse and the shortcut in wood supply rendered the study of tree growth and the effect of silvicultural methods on timber production necessary.

Working with long term experiments in forestry is an aggravating task due to the long rotation periods. Today we have to relate to the data from experiments that were planned and initiated long before statistical methods for experimental designs were available and when the research objectives were rather different from our today's open questions. Experiments we plan today will have to provide data to close the knowledge gaps of the next century. And there is the psychological problem that researchers starting an experiment or conduction measurements during the time the experiment is running will not be able to analyze the data and proof the hypotheses of "their" experiment. They help, however, to provide data for the (unknown) next generation of forest researchers but one.

The research objectives of long term experiments have significantly changed since the foundation of IUFRO. Nowadays the ecological aspects of forest growth are to the fore and many long term experiments are conducted to study the effect on environmental factors on forest and tree vitality. Despite the objectives long term experiments have immense financial implications. It is therefore indispensable to plan experiments on a sound statistical base. The questions related to the experimental design of long term experiments were the key issue of the conference held at the premises of CATIE, Costa Rica, in February 1999. The symposium was organized by IUFRO's Research Group 4.11 (Mathematics, Statistics and Computers) and contributed directly to the very original idea of IUFRO. About 40 scientists coming from 15 countries in Asia, Europe, Latin America and North America participated.

The technical program consisted of three days of technical sessions on modeling, data management and analysis, growth studies and local experiences and case studies. The presentations covered a wide range of aspects of long term research in forestry, showing that the planning and administration of long term observation plots and their data are amongst the greatest challenges and rewards in forest research. A two-day field trip to agroforestry research sites on the Caribbean side of Costa Rica and Panamá followed the technical program.

The symposium in Costa Rica brought together researchers with different professional background and points of view on long term observations and experiments. Due to the open and friendly atmosphere at the meeting many problems of long term experiments and observations could be discussed in a constructive way and many contacts among individuals could be established.

Last but not least I would express my warmest thanks to the local host of the symposium, Dr. Christoph Kleinn. It was his idea to organize the symposium parallel to a IUFRO 1.15 symposium on Multistrata Agroforestry Systems, so that the interdisciplinary exchange could be facilitated by sharing a number of technical and social events. Christoph did an excellent job in organizing the symposium and making it a rewarding event for all participants.

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FOREWORD

There are some very specific characteristics of forestry and forest research: (I) we work on *large* areas, (II) in *long* periods of time, (III) in a *complex* natural and socioeconomic system, and (IV) have the ambition to *sustainably* manage the resource in order to preserve its comprehensive functions for future generations. The combination of these aspects makes forest management a challenge, and defines at the same time the important role that research plays.

In the tropics - as compared to temperate regions - the history of systematic forestry and forest research is much shorter, the silvicultural experiences with the much higher diversity of species is less. Consequently research has high relevance in providing the basis for progress towards a sustainable management. This was the starting point of the idea, that Micheal Köhl, leader of IUFRO S4.11 and I developed, to organize an international IUFRO meeting on "Long-Term Observations and Research in Forestry" in a tropical environment. The objective was to bring together forest researchers and provide a forum for the exchange of ideas and experiences in long term experimentation in forestry. Not only the specific statistical aspects were of interest, but equally the practical experiences.

The present Proceedings Volume gives the papers that were presented during the symposium, organized in four sessions. Some papers are in English, some in Spanish - both official IUFRO languages - reflecting the composition of the audience.

Organizing an international meeting is a task that involves the professional and personal commitment of many people. My special thanks are due to my colleague MBA Ing. David Morales, to Mr. Jan Haas, exchange student from Freiburg, Germany, and to my secretary Mrs. Marianela Araya for their efficient help and the efforts and extra hours they put into the organization. CATIE has all facilities for a good meeting; but it works only when there is a good cooperation and communication structure and atmosphere. My sincere thanks are due to CATIE administration and maintenance staff for their good cooperation and help. This IUFRO S4.11 meeting was simultaneously held with a IUFRO S1.15 agroforestry meeting and a number of sessions were jointly organized. Thanks to Dr. John Beer, Head to the Agroforestry Area of CATIE, and his staff, for a perfect coordination and communication that we had in organizing and implementing two IUFRO meetings simultaneously and at the same venue. Last but not least I thank all participants for their active participation in the event: it is the participants who make a meeting a success.

I hope that this Proceedings Volume helps to maintain the productive and inspiring spirit that was present during the Symposium, that it might be the basis for future meetings and that it finally contributes to improve long term research in forestry.

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PREFACE

THE CURRENT AND FUTURE ROLE OF LONG-TERM OBSERVATIONS IN FORESTRY

In forest sciences, long-term observations, in the form of repeated forest inventories, permanent sample-plots or other methods, have played an important role in establishing guidelines for forest policies and in the development of methods for sustainable forest management.

The global environment is undergoing significant alterations as a result of human activities. These are superimposed on the natural variability of the Earth system, which occurs on variety of time scales of varying durations. The research on these changes is bringing new challenges to the forestry research and environmental monitoring. In addition, the processes for the development of criteria and indicators for sustainable forest management require new information on the status of forest resources and on the impact of forest management on different functions of forests and their sustainability.

Long-term observational series and monitoring are needed both to validate models and remote sensing algorithms of global change research and to guarantee the sustainability of forest management.

In tropical areas, especially in the Neotropics, research efforts involving long-term observations and experiments are very limited. In this context, the organization of the workshop "Long-Term Observations and Research in Forestry" at the headquarters of CATIE in Costa Rica is an important step ahead. On behalf of CATIE, we have been privileged to host this workshop, and we congratulate the congress organizers and to the IUFRO working group on Statistics, Mathematics and Computing for an excellent and opportune iniative.

Dr. Markku Kanninen

Director Research Programme, CATIE

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LONG TERM OBSERVATIONS: FROM TRIALS AND ERRORS TO PROCESS MODELING

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ABSTRACT

The contribution of long-term observations to forest science and management has two sides: descriptive and cognitive. By faithfully describing the stand dynamics of plot sections with various levels of a given treatment (for example, stand density), such observations help us to optimize density, rotation age, or degree of fertilization. However, the value of this picture is limited to the studied plots under conditions that existed in the past. In contrast, the cognitive contribution of permanent plots is relevant to any stand under a wide range of conditions. This side of the permanent plot heritage consists of knowledge about relationships of variables and parameters that can be derived from observed data. Cognitive contribution is flexible and universal because the derived relationships can be assembled into a construction that fits any given situation. While the accumulation of long-term observations is one of the greatest achievements of forest science, our accomplishments in assimilating this information and extracting meaningful relationships are less impressive. As with plot data, empirical models are good only for a description of a given set of data. Existing process-based models produce growth and yield estimates by summing up the outcomes of particular physiological processes in various tree compartments (branches, roots, etc.). The models based on this bottom-up approach are incapable of utilizing our long-term observations. They are inherently incomplete because the actual number of physiological processes is too large to model and some of them are still unknown. However, deficiencies of these physiological models do not mean that we should revert to empirical data-based models. At present, the choice is not so much between empirical and process models as between bottom-up and top-down process models. The top-down approach starts where bottom-up models end: with measured outcomeBtree size or number. Then we infer the chain of processes producing this result, beginning with fundamentals such as multiplicative reproduction. More specific processes are identified by deducing either consequences or components of those at higher levels. This class of model is able to extract knowledge from the wealth of accumulated long-term observations. When, nurtured on these data, our models mature, they will merge to create a virtual forest, a comprehensive model of the processes that generate observed patterns. Such a model would free us from the need to check every step in the real forest. Running this model would solve a given management problem in a second instead of a century.

PERMANENT SAMPLE PLOTS: GLORY OF FOREST SCIENCE

By the middle of the last century, foresters realized that analogies and reasoning were not sufficient to solve forestry problems, including crucial problems of optimal stand density and rotation age. This awareness brought forward a simple and yet profound endeavor: establishment of permanent sample plots divided into sections with different levels of a studied factor, most often density. Permanent plots are the basic method of forest science. This method is unique in its duration and contribution to our science.

Duration

Duration is a particularly remarkable feature. Genetically, we, humans, are almost identical to our close relatives, primates. Yet, there are two striking differences. One is our obvious achievements. Another difference is our attention span, ability to concentrate on a single task, persistence. This inward difference may well be a key reason for the first. With respect to duration or attention span our activities vary drastically. As the epitome of human qualities, science projects are characterized by a greater attention span and concentration than our other undertakings.

Science projects in their turn differ in duration. Long-term observations in forestry are probably the longest projects in all science. In Germany where this method originated, many plots have been continuously observed for more than 100 years. The oldest plots in the United States were established in 1908 (Arizona, Biondi 1996) and 1909 (Pacific Northwest, Williamson 1963). Such a duration is made possible by an outstanding attention span, devotion, and diligence of many people in successive generations. Besides the personal qualities of foresters, this unique duration is a reflection of an unequaled feature of trees: their life span is the longest of all living beings.

Contribution to Forest Science

Much of what is known about tree growth and survival we obtained from permanent plots. Their contribution to our science is comparable with that of the microscope in biology and the telescope for astronomy. As did these devices, permanent plots expand and deepened our capabilities to explore nature. The difference is that permanent plots extend them in time. It is a relatively simple task to measure once a group of trees. By comparing such measurements taken in stands of different ages at different sites, foresters of the pre-permanent plot past (as, for example, Paulsen who constructed the first yield tables in 1795) hoped to obtain the picture of stand development quickly. This shortcut did not work well. The tables based on temporary plots are not too reliable. We are still unable to characterize a site so as to predict accurately future tree growth. To get a true picture of growth, called natural growth series, we still have to do the simplest and most time-consuming job: remeasure the same tagged trees at the same place. What we get after 50 or 100 years is more than 10 or 20 single snapshots. The fact that the measurements done at the same place and with the same trees infuses another dimension into our measurementsBtime. In return for our patience, we get the material that can be trusted as the ultimate arbiter of the theories and models we design.

Long-term observations are important not only in growth and yield research. In a recent summary of long-term studies conducted in the southern United States, Devall and Baldwin (1998) cite dozens of "pay-off's," which include knowledge on dynamics of diseases of southern pines, seed production, effects of vegetation management, and many other aspects of forestry. The value of permanent plots is attested by their wide application throughout the forested world. After its inception, this method was quickly adopted first by European countries and then by all others involved in forest research.

The attention devoted to unifying rules for the establishment and maintenance of permanent plots is another evidence of their value. The first national set of recommendations for long-term thinning trials was the German Working Plan of 1873 (Assmann 1970). In the former Soviet Union there was a sort of law, a national standard (GOST 16128-70) that codified procedures for plot establishment. I am proud to be an author of this standard (Zeide and Martirosov 1970). Foresters were ahead of scientists in other branches of ecology by more than 100 years. While the German Working Plan was installed in 1873 (Assmann 1970), ecologists recognized "the need for long-term quantitative data sets, which have irreplaceable theoretical and applied utility" and embarked on a comparative initiative in 1977 (Bodkin 1977, page 1).

Given the unique nature of permanent plots, the amount of effort concentrated on a given stand, multitude of results, and imposing appearance, permanent plots are more than a method of science; they may be viewed as a cultural phenomenon. Permanent plots deserve to be treasured as living national monuments. It is also appropriate to eulogize them in obituaries as did Feduccia and Mosier (1977) when trees on their plots were destroyed by ice.

Descriptive and Cognitive Aspects of Long-Term Observations

The scientific contribution of long-term observations has two aspects: descriptive and cognitive. Repeated measurements provide a good picture of stand dynamics on plot sections where the studied factor or cause (such as density) varies, while all others are kept equal. This procedure enables us to separate physically the effect of a given factor from the others. Only then do we learn the significance of this factor. There are several problems with this method. Growth factors are so numerous, variable, and closely interrelated as to make their complete separation impossible. The description of studied plots under conditions that existed in the past may not be valid for other stands and conditions.

Fortunately, permanent plots provide more than an inflexible description of past growth in only a few stands. The assumption of a fundamental unity of components that exists behind the apparent diversity of the observed wholes has been one of the most fruitful in all science. While the entire picture of growth (growth curves) may not be applicable even to neighboring stands, its components may be. Stand dynamics is not an inseparable whole. It consists of ingredients common to any stand and is driven by a limited number of factors. After all, the involved chemicals, such as carbon and nitrogen, are identical in all stands. The same is true about reactions involving these elements and their compounds. Similarly, the elements of description are not unique for each stand. For example, it is known that tree dimensions are related allometrically. Regardless of site, species, or age, stem volume is a power function of diameter, rather than exponential or linear. The singularity of stand dynamics in a given stand results not from the uniqueness of the constituent processes but from their combination. We can identify these ingredients and learn how they are combined by deciphering the information hidden in growth series.

This information can be obtained by the analytical separation of studied factors. Unlike physical separation, analytical methods can account for the effects of a single factor as well as for its interactions with other factors. The cognitive contribution of permanent plots consists in providing the data for such analysis. This contribution is relevant to any stand under a wide range of conditions because the component relationships are reusable and can be assembled into a construction that fits any given situation.

PROCESS MODELING: BOTTOM-UP APPROACH

The way to realize the cognitive value of long-term observations is to design and test models of the processes that form stand dynamics. Not all process models are capable of utilizing permanent plot data. Existing process models such as those collected in Dixon et al. (1990) or in Korpilahti (1997) proceed from the particular to the overall result. They "seek to explain growth from the underlying biological, physical and chemical relationships. In what has been called a bottom-up approach, stand growth and volume increment of trees are modeled starting with photosynthesis of a leaf as driven by radiation and temperature, which are subsequently integrated over the foliage in the canopy" (Mohren and Burkhart 1994, page 2). To determine whether this kind of model is capable of recovering growth regularities hidden in long-term observations, let us consider the main features of these bottom-up or inductive models.

Features of Bottom-up Models

- They start with describing physiological processes. Among these are radiation absorption; photosynthesis of shaded and unshaded conditions; transpiration; respiration of foliage, sapwood, heartwood, fine and coarse roots, and other tree compartments; rate of senescence; annual retranslocation of nutrients; amount of nutrients retranslocated from senescing foliage; allocation of resources by tree compartments, concentration of nutrients in each of these, efficiency of carbon conversion; and many others.

- The contribution of each process is expressed in the same units, units of mass. The bottom-up models present the whole as the sum of its parts. In the words of the recognized leaders in the field, process models "treat plants as consisting of elementary units ... The core of such a model is the description of what happens in a single plant element. Models can use various elements, such as bud, leaf, internode, stem segment, etc. A computer program takes care of all the elements and integrates their activities to the functioning of the whole plant" (Sievanen et al. 1997 page 237). As a result, the structure of these models is simple: the constituent processes exist on one level and are connected by addition (or subtraction).

- Even though bottom-up process models are intended to describe biological phenomena, their conceptual frameworkBcarbon balanceBis adopted from physics. "The ideal of a "process-based forest stand growth model" is borrowed from physical engineering" (Makela 1992, page 85).

Usefulness of Bottom-up Models

Inductive process models are praised for their contribution to the understanding of key mechanisms of growth and yet they have limited practical application. The authors of one of the early models write that their model (with 27 parameters) "provides insights into the relationships between processes and suggests principles governing growth, but is unlikely to be useful as a yield predictor; for this purpose a more complex model with more detailed mechanistic descriptions of the various growth processes would be required" (McMurtie and Wolf 1983, page 444). Seven years later, Sievanen and Burk (1990, page 241) admit that "although process-based models have been in widespread use, their usefulness for forest management has yet to be shown." Still, the authors are optimistic because "in principle these models have the potential for being highly applicable in solving various forest management problems." Yet after seven more years, another carbon balance model (with 34 parameters; values some of which are guessed), recently published in Forest Science, again "provides mainly a qualitative description of the growth of an even-aged stand" (Makela 1997, page 22).

Many foresters have tried to realize the promise of the process-based approach to produce meaningful models of wide applicability. Since 1980 determined efforts in this direction have been made by foresters in New Zealand. Several teams of researchers worked on a comprehensive physiological model that included various blocks dealing with the interception of radiant energy, photosynthesis, transpiration, water balance, and other processes. This work was summarized by Goulding (1994, pages 338-339): "Far from being useful outside of the conditions on which a model is based, all the complete models (but not necessarily an individual component) are severely limited to those quite particular situations and assumptions upon which they were developed. ... the New Zealand process models of growth developed are, as yet, invalid for use to aid management."

In their keynote speech that opened a conference entitled "Contrasts between biologically-based process models and management-oriented growth and yield models," Mohren and Burkhart (1994, pages 3-4) arrived at a similar generalization: "It seems unlikely that summary models of growth and yield, not attempting to capture the relevant underlying processes, but providing management information with a known degree of (un)certainty, will ever be replaced by detailed process-based models in making practical forest management decisions."

Paradox of Forest Modeling

The current state of forest modeling is a paradox. In all other areas of science, deeper understanding results in more accurate predictions, wider applicability, and practical usefulness. If knowledge is power, it is first of all the power of prediction. We are able to send rockets to the moon or Mars because we know something about astronomy and the laws of physics. In this respect, forest science appears to be an exception. Despite their limitations, bottom-up models are certainly more meaningful than thoughtless regressions. Yet, they are hopelessly inaccurate and impractical. Conversely, allegedly nonsensical empirical models are superior to these process models when it comes down to the ultimate test: predicting tree and stand growth.

Surely, we can elevate this anomaly into a principle of forest modeling and declare that the primary value of forest process models is "to improve knowledge rather than to accurately or precisely predict outcomes" (Korzukhin et al. 1996, page 884). Do we really need such "improved knowledge"? Since this opposition between improved knowledge and accurate prediction is restricted to forest modeling, it may be possible to resolve the modeling paradox by examining peculiar characteristics of bottom-up models. Because their advantages have been exposed repeatedly (Dixon et al. 1990), below is a summary of their shortcomings.

Deficiencies of Bottom-up Models

Models based on the bottom-up approach-

- find no use for long-term observations of commonly measured variables (diameter, height). Instead these models require sophisticated and rarely available information. We do not measure regularly on our plots radiation absorption, transpiration, rate of senescence, and annual retranslocation of nutrients. When occasionally we do, the errors are large. Some of these variables cannot be measured at all so that values have to be guessed;

- are inherently incomplete because the actual number of physiological processes is too large to model and some of them are still unknown. Many important processes are often neglected. Among these are adaptation and reproduction. Thus, the index of Dixon=s et al. (1990) collection of works on forest growth modeling (with 38 contributions) contains no entry on reproductive effort or seed production. Adaptation ("adaptive response") is mentioned but not modeled;

- are justified by the belief that the causes of events lie at smaller scales. This is not necessarily true. There are processes such as self-thinning and succession that emerge at the ecological level. As with any system, the tree is more than the sum of its parts;

- have a solid framework, carbon balance, which is a special case of the law of conservation of matter and energy. As a corollary of a physical law, this concept holds true for everything, everywhere: for trees, for crusteneans, as well as for stones. This framework, however, neglects the most essential thing about treesBthat they are living beings. Biology is something different from physics. A more specific framework focused on trees or plants in general would make our models more pointed and accurate.

Deficiencies of bottom-up models do not mean that we should revert to empirical data-based models. In this situation it is sensible to investigate possibilities of another, top-down approach to growth modeling.

PROCESS MODELING: TOP-DOWN APPROACH

To understand dynamics, we can start with the given outcomeBtree size or numberBand infer the processes that produce this result. This approach to growth modeling can be called top-down or deductive. The processes producing the variables that we measure form a multilayered hierarchy. We will first describe the processes on the most general level and then try, whenever possible, to get down to more specific processes. Only processes that take place in trees and their communities are considered here. Other processes important for tree growth such as climate fluctuations and soil evolution are studied by specialists in those fields. In the future their models may be linked with ours.

General Processes

From what is known about trees and other organisms, we can divide all the processes affecting growth into two opposing groups:

- Innate tendency to grow and multiply, sometimes referred to as biotic potential;
- Growth restraints, which include aging, accelerating allocation of resources to reproduction, competition, and many others.

The simplest manifestation of the multiplicative tendency is an uninhibited cell division. One cell divides into two, then, after the same interval, we have four, eight, sixteen, and so on ad infinitum. Here growth is proportional to the current size of the population. The ubiquity of the exponential function in biology is explained by its being the generalization of this geometric sequence. Restraints that hamper the growth of a given tree follow with necessity from this tendency in other organisms and the finite size of the Earth habitats. This conflict between infinity built into multiplicative reproduction and limited resources available for life entails competition and, as Darwin realized while reading Malthus, natural selection and evolution.

Is it possible to perceive this tendency on our long-term observations? For trees, unlike undisturbed bacteria, the exponential form of the multiplicative tendency is far from evident. In dicotyledon tree species the number of dividing cells (cambium) per unit of stem surface remains constant. And the time interval between the successive divisions of cambium cells is likely to change with age (in the geometric sequence the interval is constant). Another complication is allometric relationships between tree dimensions. Even if mass produced by cell division would increase exponentially, stem diameter, height, or another linear dimension, X, would not. Given these considerations and specifically the allometry of mass and this dimension, we may expect that the annual increment of diameter (or height), $z(X)$, is proportional not to diameter (as is in the exponential case) but to diameter raised to some power, $p > 0$, that reflects the allometry:

$$z(X) \propto X^{p} \qquad (1)$$

Since aging is a key process of growth restraints, tree age may be a convenient proxy for expressing the processes of the second group. It is convenient because other restraints (impediments associated with increasing size, reproduction, and environmental resistance) also increase with age. Still, age is only a proxy representing unavailable variables. As soon as we are able to estimate some of them, we should relieve the burden put on age.

Growth Equations

Having data on completely unrestrained growth, it would be easy to confirm or reject the assumption expressed by equation (1). However, trees do not live in paradise. Those we measure are formed by both opposite forces. At the same time we know that the growth of these real trees is described well by equations developed by generations of foresters and other biologists. Because usually this development consisted in testingBoften using permanent plot dataBvarious algebraic functions having the S-shaped form, these equations are called empirical. In their integral form. these equations (Chapman-Richards, Gompertz, Korf, Hossfeld, and others) show no connection with the general processes.

The differential form is more revealing. By analyzing the structure of growth equations, it was found that all of them can be presented as a product of two modules (Zeide 1993). As age, A, and tree size, X, increase, one, the expansion module, brings the increment up, while the other, the decline module, pushes it down. In all studied equations except Weibull=s, the expansion module presents increment as a power function of X. The decline module has two forms: exponential and power. This may be explained by a greater number of factors that hinder growth: scarcity of resources, competition, reproduction, aging, diseases, herbivory, disturbances, etc. The Bertalanffy, Chapman-Richards, logistic, Gompertz, and other equations belong to the group of exponential decline, ED. The Korf, Hossfeld, Levakovic, and Yoshida equations comprise the group of power decline, PD. These two forms underlying the known growth equations (except Weibull´s) are:

$$ED: \; z(X,A) = e^{m} X^{p} e^{-qA} \qquad PD: \; z(X,A) = e^{m} X^{p} A^{-q} \qquad (2)$$

where m is the scale parameter, $p > 0$ and $q > 0$ are the parameters characterizing the rates of growth expansion and decline, respectively. The difference among equations is in the values of p and q. For example, in Gompertz´s equation $p = 1$, in logistic´s $p = 2$, while in Bertalanffy´s $p = 2/3$. Both forms describe tree growth equally well (Zeide 1993).

Isomorphism of general processes and growth equations

It appears that these two modules of the empirical equations correspond to two general processes introduced on the basis of reasoning alone. As is the first process, the expansion module is driven by tree size. Furthermore, this module is identical with equation (1). The expansion module describes photosynthetic activity, absorption of nutrients, constructive metabolism, anabolism, and other manifestations of the biotic potential. The second, decline module is driven by age and changes in the same direction as does the corresponding restraining processes. This module, therefore, encapsulates growth restraints.

The structure of the tested by practice growth equations gives us some confidence that the general processes we identified are more than figments of our imagination. Another conclusion is that the success of empirical equations in modeling growth is not accidental. Developed mainly to mimic the dynamics of tree and stand growth, these equations express two basic processes of growth. Parameters p and q have biological interpretations and at least their sign can be predicted. While the processes infuse meaning into empirical equations, the equations give shape to the processes, making them if not tangible then at least operational. The isomorphism of the general processes and growth equations also shows the continuity between the top-down approach and past achievements of forestry.

The provided interpretation of equation components is not new. The difference is that in the past scientists tried to ascribe meaning to a specific equation form, rather than to the entire class of sigmoid curves. The best-known among such theoretical growth equations are the logistic and

Bertalanffy equations. Both presented growth as the difference, rather than the product, of two opposing terms. The interpretation of these terms was similar to that discussed above as general processes.

At the same time, attempts to inject too much meaning into growth equations can be counterproductive. It is interesting that the two most meaningful growth equations are at the same time the least successful. The Bertalanffy equation was supplanted by the Chapman-Richards equation. This highly popular successor is a purely empirical equation derived from the Bertalanffy equation when its theoretical background that demanded the fixed parameter values was discarded. The logistic equation with its insistence on $p = 2$ and a fixed position of the inflection point was found to be the least accurate of known growth equations (Zeide 1989). It is rarely used in modeling tree growth. The logistic and Bertalanffy equations are inaccurate because they were designed to have exact parameter values. It seems that pouring more meaning into models (by prescribing parameter values) than they can hold is misguided. By removing the unwarranted restriction, Chapman and Richards unwittingly made their equation not only more accurate than Bertalanffy=s, but more meaningful as well.

Theoretical models attempted to provide a final picture of growth in a single step. Probably, accuracy and generality cannot be attained by one-level models. It may be that only on deeper modeling levels will we be able to deduce exact parameter values. Now we will consider the processes below the general level.

The Chief Shortcoming of Growth Equations

Along with rationalizing past accomplishments (growth equations), the top-down approach can help us to move beyond them and solve presently urgent problems. One such problem is to account for density in our growth predictions. Control of density through initial spacing and thinning has been the major forestry tool to increase tree growth or improve its quality. Yet, existing equations predict growth without considering stand density. At least from the managerial position, this is the chief shortcoming of growth equations. Our analysis showed that growth equations have a sound ecological justification. What is needed is to add to the distilled forms of these equations (ED and PD) a module relating density and growth. Such a combination makes sense because the effect of density cannot be studied without accounting for the effects of age and tree size. The joint growth-density model will be applicable to managed stands.

Since density is one of growth restraints, such a module will start parsing the second group of general processes, growth restraints. They can be subdivided into:

- Intrinsic processes (aging, growth impediments associated with increasing size and accelerating allocation of resources to reproduction);
- Extrinsic processes, also called environmental resistance. As far as trees are concerned, competitive stress is the key process in this subgroup. Stand density is a suitable measure of competitive stress.

Defining Stand Density

The problem is that we still have only a vague idea of what density is. Most density measures proposed by foresters are functions of number of trees per unit area and tree size. Not every combination of these variables characterizes density. For example, canopy closure is not adequate for this purpose. In response to the removal of neighbors, trees quickly and drastically modify the ratio of crown width to stem diameter. As a result, "even with large differences in the intensity of thinning, the degree of ground coverage remains nearly the same" (Assmann 1970, page 110). Basal area, the most commonly used measure of density, is not satisfactory either. According to a popular density guide (Gingrich 1967), stands with a basal area of 17 m^2/ha are considered understocked if the average diameter is greater than 38 cm. When the diameter is less than 8 cm, the stand with the same basal area is classified as overstocked. For the intermediate diameters, it is fully stocked. Although Reineke's (1933) index seems to be more reasonable than other density measures, few if any practical foresters use it and some scientists have reservations about it.

Given these uncertainties, let us set aside these and dozens of other definitions and think what density is. It seems reasonable to assume that stand density is related to the shaded portion of the crown of the average tree: the greater the portion, the denser the stand. Consequently, the stands with equal shaded portions of the crown can be considered equally dense. Shading reduces not only the amount of sunlight but affects the availability of other factors as well. The portion of the crown shaded by neighboring trees is closely related to competition stress. Therefore, the shaded portion of the crown of an average is accepted as a measure of stand density.

However satisfactory the shaded portion may be ecologically, it is not practical because of crown irregularities, shifting branches, changing angle of the sunlight, moving shades, fluxes, light reflections, clouds, and many other reasons. Still, the conclusion that stands with equal shaded crown portions are equally dense provides a direction for constructing a workable measure. We need to design an operational equivalent of the shaded portion, to express it in terms of stable and measurable variables such as diameter of trees and their number.

Assumptions

The derivation of such an equivalent is based on the following assumptions:

- Trees are located regularly so each tree has six closest neighbors.
- All trees have identical cylindrical crowns.
- The light emitted by the sun has a constant angle equal to the mean value of the actual angle.

Only the side surface of the crown cylinder is considered. Its top could be viewed as a part of the upper portion. Alternatively, it may be assumed that the light intercepted by the crown top is used for maintenance needs (respiration, nutrient translocation, etc.) and does not affect diameter increment.

Shaded Portion of the Crown

The amount of light is proportional to the crown face, that is a planar projection (perpendicular to the sun) of the curved surface. The area of this face is proportional to the product of the crown length, C, and width, W. Similarly, the shaded area is proportional to the product of its length, y, and width, x. The shaded portion, S, of the average crown is equal to:

$$S = \frac{xy}{CW} \quad (3)$$

Width of Shaded Area

The expected width, x, is equal to the crown width, W, and the probability that the neighboring trees are between the sun and the central tree. As the sun moves, the width of the shaded area changes periodically, unless the crowns touch each other. In this case the crowns of the six neighboring trees cast shade with the combined length of $6cW$, where c is a coefficient of proportionality. Since this length covers completely the bottom circumference of the crown of the central tree, it is equal to the length of the circle with the radius W:

$$6cW = 2\pi W \tag{4}$$

Therefore, $c = \pi/3$.

In general case when the distance between trees is R, the probability that a given point at the crown bottom is shaded is equal to:

$$\frac{6cW}{2\pi R} = \frac{W}{R} \tag{5}$$

Thus, the expected width of the shaded area is:

$$x = \frac{W^2}{R} \tag{6}$$

Length of Shaded Area

The length of the shaded area, y, increases linearly when distance between trees decreases. The shaded area coincides with the entire area of the crown face and top when $R = 0$. In this case $y = C$. In general,

$$y = C\frac{R_{\max} - R}{R_{\max}} \tag{7}$$

where R_{max} is the distance when the shade of the neighbors touches the bottom of the central tree.

Shaded Proportion as a Function of Distance Between Trees and Crown Width

The proportion of the average crown shaded by neighbors can now be expressed in terms of average distance between trees and crown width:

$$S(R,W) = \frac{W^2 C(R_{\max} - R)}{R_{\max} RCW} = W\left(\frac{1}{R} - \frac{1}{R_{\max}}\right) \tag{8}$$

Shaded Proportion as a Function of Number of Trees and Crown Width

The distance R (in meters) decreases with the increasing number of trees per hectare, N:

$$R = \frac{200}{\sqrt{\pi N}} \tag{9}$$

Using this expression, the shaded portion, $S(N,W)$, of trees located at the distance $R < R_{max}$ can be written as a function of N and W:

$$S(N,W) = \frac{\sqrt{\pi}}{200} W \left(N^{0.5} - N_{\min}^{0.5}\right) \tag{10}$$

where N_{min} is the number of trees per hectare when the distance between them is R_{max}. This distance and the number of trees change with tree size.

Shaded Proportion as a Function of Number of Trees and Average Diameter

Summarizing extensive evidence, White (1981) found that crown width is proportional to tree diameter (at breast height) raised to the power that varies mostly within 0.7-0.9. These values were obtained by ordinary least square regression. Usually R^2 of such relationships is about 0.7-0.8. For calculations aimed at estimating the value of parameters (as opposed to minimizing deviations), a more appropriate method is the reduced major axis technique, RMA (Ricker 1984, Leduc 1987). The RMA power is obtained by dividing the least squares power by the correlation coefficient. Therefore, the RMA parameter is likely to be around 0.9 ((0.7~0.9)//(0.7~0.8)). Niklas (1994), who realized the relevance of the RMA method, reported the power of 0.79 for many angiosperm and gymnosperm tree species. Using the mean value of these estimates (0.9 and 0.79), crown width can be expressed as:

$$W = a_1 D^{0.85} \tag{11}$$

Having this relationship, the shaded crown portion, ***S(N,D)***, can be presented as:

$$S(N,D) = a_2\left(N^{0.5} D^{0.85} - N_{\min}^{0.5} D^{0.85}\right) \tag{12}$$

where $a_2 = a_1/\pi/200$).

Shaded Portion and Stand Density

The shaded portion of the crown of an average tree characterizes the degree of tree crowding, that is stand density. It is convenient to define stand density, ***E***, so that it is: (1) expressed in measurable variables such as number and diameter of stems rather than crown dimensions; (2) related in the simplest possible way to the shaded portion of the crown ; (3) equal to 0 when trees do not retard each other's growth, that is, $E = 0$ when $N = N_{min}$; and (4) equal to 1 when density is maximal, $E = 1$ when $N = N_{max}$. The following expression satisfies these requirements:

$$E = \frac{N^{0.5} D^{0.85} - N_{\min}^{0.5} D^{0.85}}{N_{\max}^{0.5} D^{0.85} - N_{\min}^{0.5} D^{0.85}} \tag{13}$$

This expression can be referred to as a measure of density, an index of density, a quantity, a value, or a yardstick of density. Or we can simply call it density. After all, we say that the length of a table is 1.5 meters, rather than referring to this length as a measure or an index of length.

The proposed measure presumes that stands with equal shaded portions of their crowns are equally dense. Besides the reasoning employed in deriving the measure, this claim can be supported by empirical evidence. In even-aged stands the number of trees decreases with age in response to the increase in tree size. Because the number and size change in opposite directions, certain combinations of these variables in equally dense stands remain constant. Reineke (1933) discovered one of these invariants, the product $ND^{1.605}$. He estimated the power of ***D*** (1.605) using unreported intuitive methods and considered it to be constant for all species and locations. When MacKinney et al. (1937) reanalyzed the same data using standard statistical methods, they arrived at the power of 1.7070. Since the product $N^{0.5}D^{0.85}$ is proportional to the square root of Reineke=s index, it is another density invariant. Because the other terms of the density measure (equation 13) are constant for a given species, the evidence that supports Reineke's equation also substantiates the claim that ***E*** remains constant in equally dense stands.

The shaded portion of the crown can be presented in terms of ***E*** as:

$$S(E) = rE \tag{14}$$

where $r = a_2 (N_{max}^{0.5}D^{0.85} - N_{min}^{0.5}D^{0.85})$ is the parameter relating the shaded portion and stand density.

Further Development

The expression for density we derived and especially its connection with Reineke's index may be neat, but the assumption of cylindrical crown is not. And the disregard of the cylinder top is simply awful. We can improve the situation by assuming conical or bell-shaped crowns. These shapes are more reasonable and take care of the problem of the top. Whether the crown shape is approximated by cone or parabola, the surface of its face is still proportional to the product of the crown length and width of the largest crown diameter. The difference between these two figures is the coefficient of proportionality. For the cone it is 0.5, for the parabola −0.667 (for the square it is 1). Since the shaded area has the same coefficient of proportionality, it cancels out when the shaded portion, S, is calculated. So its expression will be the same (equation (3)). However, the density measure derived for the bell-shaped crown is more complicated and does not resemble Reineke's index.

The assumption that stands with equal portions of shaded crowns are equally dense can also be challenged, especially for intolerant species. In the extreme case of intolerance when all the foliage shaded by neighbors disappears, the shaded crown portion would be the sameBnoneBregardless of density. This hypothetical case suggests that density measure is related to the portion of shaded foliage rather than that of crown surface. There is much more foliage behind the same unit of surface at the top of the crown than at the bottom.

Density Module

Whatever measure of density is chosen, it will used for predicting increment when age and tree size are described by other modules. There are many ways to relate increment and density. Since the amount of available light is related to both variables, it can be used in deriving a relationship between them. It is certainly non-linear because the amount of light depends not only on the shaded area but also on its location on the crown. Shading the bottom part of a crown is not as damaging as shading an equal area at the top, as follows from the exponential pattern of light attenuation (Beer's law).

When the diameter increment of the surviving trees is plotted over density as defined by equation (13), the relationship appears as a descending, concave-up curve, which for practical purposes can be approximated by the negative exponential function:

$$z(E) = e^{-bE} \qquad (15)$$

where $z(E)$ is the component of diameter increment controlled by density (it is the ratio of actual diameter increment to the increment of unshaded trees) and b is parameter.

Adaptation

Surely, many more meaningful and accurate expressions than equation (15) can be designed to relate increment and density. Any of them should address adaptation. Adaptation is the response of living beings, forced by natural selection, to all kinds of restraints. Because these restraints are a response to the proliferation tendency, adaptation is the response of the second order. It deepens further the top-down structure. As a central process of life, adaptation is implicit in any realistic growth model. Yet, none accounts for adaptation explicitly.

There are two kinds of adaptation, genotypic and phenotypic. We are concerned with the ubiquitous phenotypic adaptation, which covers numerous reactions mitigating effects of adverse factors. Development of shade foliage capable of utilizing low intensity light and increasing shoot-root ratio are well-known examples of adaptation to shading. Adaptation includes partial substitution among growth factors, selection of alternative pathways to obtain needed substances, changes in the form of the crown, angle of leaves, position of roots, and many other characteristics. These changes and redistribution of resources tend to make all growth factors limiting.

We can discern adaptation even in such a simplistic approximation as equation (15). If adaptation to density stress were perfect, then regardless of density $z(E) = 1$, which means that the increment of shaded trees is the same as that of unshaded ones. This is possible when $b = 0$. On the other hand, low adaptation implies that the increment is reduced drastically by a slight density increase. A high value of b would reflect this situation. This analysis shows a close connection between b and adaptation, and suggests that some inverse function of b can serve as a measure of adaptation.

Summary of Top-Down Approach to Modeling

The top-down models:

- predict growth from its causes, starting with the fundamental process of multiplicative reproduction;
- use measurable variables (such as stem diameter, number of trees per unit area, or defoliation) to describe predicting processes. These variables are the outcome of many and often conflicting forces and can serve as a proxy for each. The same variable, depending on model form, can push the predicted increment up or bring it down;
- include many processes that restrain growth of a population or an individual organism (which is a population of cells);
- describe these processes in the language of differential equations, that is using not accumulated variables, but the rate at which they change. As far as tree growth is concerned, two differential forms distilled from existing growth equations (Exponential Decline and Power Decline forms) represent well both expansion and restraining trends;
- proceed to uncover more specific processes by deducing either consequences or components of those at higher levels. Thus, adaptation is a consequence of growth restraints (and natural selection). These restraining processes are divided into two component groups: internal and external;
- help to arrive at more precise and meaningful definitions of variables, specifically stand density. Its definition, derived from analysis of size and number of trees per unit area, is used to quantify competitive stress, a decisive component of external restraints. The module driven by density is a natural complement of growth equations.

Advantages of this approach are:

- it guides the construction of meaningful models. Meaningful means the ability to predict the range if not the values of model parameters on the basis of reasoning and biological knowledge. Unlike the conservation laws of physics, multiplicative reproduction and adaptation are certainly biological processes;
- top-down models are complete at each step of development. This feature often results from including two opposing groups of processes, each of which integrates all underlying

physiological processes, and not just a selected few. Slow processes such as soil evolution or geological processes are assumed to be constant and are reflected by the scale parameter;

- the included processes can be viewed as attributes of the whole, rather than additive parts. Top-down models avoid the trap of holding the whole as the sum of the parts;

- as meaningful models are supposed to do, top-down models predict growth at least as accurately as empirical equations. Several factors contribute to this accuracy. Models=s predictors (such as diameter or number of trees) are convenient proxies that consolidate the outcome of numerous ecophysiological processes, many of which cannot be explicated at present. Chances to make an error in estimating these well-defined and easily measured variables are smaller than those involved in assessing or guessing dozens of variables used in physiological models;

- it is simple: number of parameters does not exceed 6 or 7;

- it is practical, that is, capable of accurate predictions of tree and stand growth from readily available forest inventory data;

- by utilizing long-term observations, operating with variables we measure, and building upon existing growth equations, the top-down approach continues forestry tradition.

VIRTUAL FOREST

To be of help to foresters, the density and growth models should be embedded into a larger framework of a general model of stand dynamics. This framework is a parsimonious system of specific process models sufficient to describe stand dynamics and optimize silvicultural operations. In a simple case of even-aged stands, such a system may use as input average stand variables and include a minimum number of specific models. Information on diameter distribution or on sizes and positions of individual trees is not required. The general model will answer common questions of forest management such as when to thin, what residual density should be, which levels of fertilization and pruning pay off, which rotation age is optimal for a given stand, and so on. The system can also suggest an optimal sequence of operations, which takes into account not only normal growth but the probability of common disturbances.

The model is referred to as general because it will consist of specific models. The following may be sufficient for even-aged stands:

- Conventional growth models such as ED and PD, or their improved versions.

- Density model relating density and growth of the main stand. This is a model of intraspecific competition, in which density plays a double role: it represents useful stand volume and harmful stress that reduces growth of individual trees.

- Model of interspecific competition. It is needed to compare the compounded expense to control competitors (such as weeds and hardwoods in pine plantations) with lost growth.

- Mortality model. In addition to silvicultural thinning, number of trees is decreased by density-independent and density-dependent mortality.

- Model of diameter jump, that is, the increase in average diameter caused by the removal of smaller trees, rather than the growth of remaining trees.

- Models of various events affecting tree growth. These can be subdivided into beneficial events (bedding, fertilization, pruning) and detrimental disturbances (ice storm, insect infestation, drought).

- Relational models. These models will relate average diameter and number of trees to volume and economic variables. Average diameter and number of trees are sufficient to either deduce or estimate other stand variables. Stand density is derived from diameter and number of trees. When the diameter is known, much of the variation in average height is explained by density. Diameter, height, and density are sufficient to calculate the total and merchantable volume for a given stand. Knowledge of volume and diameter leads directly to assessing economic variables. Average diameter and density are also the main predictors of diameter distribution.

Together, these models will create a virtual forest, a duplicate of the processes that produce real forests. This virtual forest can be manipulated much more easily than the real ones. As a result, we will be able to "plant" trees in the computer, grow, thin, prune, and play with them, testing our insights about their lives and making forest management more efficient. While growth models aim at liberating us from time-consuming measurements, the construction of the models, on the contrary, is based on constant interaction with long-term data. If we have had a fixed number of questions, one day when the models absorb all regularities of growth from the data, permanent plots would become unnecessary. This is an unlikely prospect. New problems will inevitably arise in the future and permanent plots will be indispensable as ever.

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SESSION I

"LOCAL EXPERIENCES AND CASE STUDIES"

LONG TERM SILVICULTURAL RESEARCH SITES: A CANADIAN EXPERIENCE

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ABSTRACT

Several factors have focused world attention on Canadian forests and Canadian forest practices in recent years. These factors include the sheer size of Canada's forest, and the fact that we are a trading nation and our forest products are shipped worldwide. This international attention is increasingly focused on sustainable development and other complex forestry issues.

To address this complexity, promote cooperation and a long term, multi-disciplinary approach to forest research, the Canadian Forest Service (CFS) organized a national network of research sites known as the Forest Ecosystem Research Network of Sites, or FERNS. These sites are a collection of research activities that investigate sustainable forest management practices and ecosystem processes at the stand level. Each FERNS site must meet specific criteria and have a number of characteristic features.

FERNS promotes this research nationally by improving the links between the sites themselves, preserving the long-term research investment put into these sites and providing a forum for information exchange and data sharing. Future efforts will focus on expanding FERNS internationally to provide these same objectives while providing a framework for sites all over the world with the potential to link to FERNS and become part of a worldwide FERNS network.

The CFS and FERNS recently co-sponsored an international IUFRO workshop to investigate long-term silvicultural research sites. The workshop focused on three key areas: establishment, marking and protecting sites; data base management; and technology transfer and site promotion.

INTRODUCTION

The sheer size of our forest resources, combined with our massive trade in forest products, frequently finds Canada at the center of the growing international debate on the management of the world's forests. Science has a critical and increasing role to play in this debate. As a nation, Canada is being evaluated internationally against complex criteria such as effects of forestry practices on ecosystem productivity, ecosystem processes and long term biological diversity. The complexity of these issues, coupled with the inherent complexity of forest ecosystem themselves, has made multi-disciplinary and multi-partner approaches to forest ecosystem management research the norm of the 1990's.

Across Canada, long-term, multi-disciplinary forest management research sites and studies are already in place. What have been lacking are the linkages between the individual sites, the researchers and those who seek to use research results. To forge those linkages, a network of sites, named the Forest Ecosystem Research Network of Sites (FERNS), was established as the framework for a national suite of research sites that are focused on the development of innovative forest management practices and the understanding of ecosystem processes at the stand level.

The overall goal of FERNS is to provide and promote a network of sites, representative of major Canadian forest ecosystems, for long-term multi-disciplinary research on forest management practices. FERNS has three specific objectives:

1. Promote forest management practices research nationally and internationally;
2. Improve linkages among sites; and
3. Preserve the long-term research investments already made on these sites.

FERNS provides researchers and students with a set of well-characterized and linked sites across Canada on which to work. By providing opportunities for comparative and collaborative research, FERNS also fosters partnerships between governments, universities and industry and serves as a national communication tool between researchers and with forest managers. This communication through FERNS is fostering a sense of community among forest ecosystem management researchers in Canada.

FERNS is helping to protect the investment made in the installation of long-term stand manipulation studies, the gathering of extensive biophysical databases and the conduct of site-specific studies. Although FERNS does not provide funds, the association of each site to the network will enhance its visibility and its ability to attract funding from agencies or from industrial partners.

A new global scientific culture is emerging in which archiving and inter-connectivity of data sets is becoming increasingly important. Researchers are now being encouraged to make their data available for wider distribution once the scientific paper has been published. In the future, FERNS may be able to play an important data management role by providing a means to synthesize and integrate the scientific information across a number of sites.

CHARACTERISTICS AND CRITERIA

Each site possesses a number of characteristic features. For example, the research conducted on FERNS:

- addresses forest harvesting options and ecosystem functioning aimed at sustainable forest management;
- is multi-disciplinary and multi-partnered; and
- is sound ongoing research.

Sites within the FERNS network must be:

- well documented with good historical stand and site information;
- accessible;
- located in a forest that is representative of one of the major forested ecozones in Canada; and
- protected for long-term research values.

In addition, FERNS must include areas of mature forest where natural successional stages can be observed and/or investigated.

CANADIAN FOREST SERVICE ROLE

The Canadian Forest Service (CFS) is the largest national forest science organization in Canada and has a mandate to address both national and international issues affecting forests and forestry practices. In meeting this mandate, CFS recognized the need to bring together key research activities and to provide a framework for a more integrated, Canada-wide approach to forest ecosystem management research among CFS researchers and their partners in industry, provinces and universities. The establishment of FERNS was seen as one way to achieve this integration. In addition to FERNS, CFS has also established the Canadian Forest Researchers Directory as another means to facilitate communication between and among forestry researchers and clients.

The CFS contributes to the coordination and promotion of FERNS, but it must be recognized that the network consists of a collection of local partners across the country who have come together freely to achieve things which exceed what any one of them, individually, could achieve. As such, each site will continue to operate autonomously. Where a benefit can be recognized however, sites may act together as a network.

CURRENT STATUS

There is solid and growing support for FERNS from research partners both inside and outside the CFS. Since an initial set of FERNS sites was announced early in 1997, several new additions have been added to the network and the total sites is now at sixteen with additional sites currently being considered in several provinces and territories.

In August 1997, an Internet web site was launched to profile FERNS. This web site is accessible through the Canadian Forest Service, Pacific Forestry Centre home page at <http://www.pfc.cfs.nrcan.gc.ca> and includes information on individual FERNS sites as well as linkages to collaborators.

FUTURE DIRECTIONS

International Linkages

Building on the demonstrated needs and successes of FERNS, plans are being formulated to expand the network internationally. The US currently has a network of long-term silviculture sites, a European Forest Ecosystem Research Network of Sites (E FERNS) is in place and the Long Term Ecological Research Network offers possible future linkages. We hope to learn more about these existing networks and determine if criteria, objectives and other features are compatible and if further linkages are possible. In addition, through the sharing of information about the set up and operation of FERNS, we anticipate that other countries may consider similar approaches to addressing their forest research challenges.

A recent workshop, the Long Term Silvicultural Research Sites Workshop, provided one means of learning more about managing long term sites. The workshop featured site reports, keynotes and breakout sessions which looked at data management, technology transfer and site promotion and the establishment, marking and protection of sites. Papers from this workshop will be shared as widely as possible, including publication in an upcoming issue of

The Forestry Chronicle. In addition, papers presented at Conferences such as this, will further promote an international awareness of FERNS.

A further potential international direction for FERNS may be as one source of information on reporting to the world on Canada's forest practices. With FERNS investigating issues such as the impacts of forest practices and harvesting options, direct access to researchers conducting this work may be one way to allow science to play a more effective role in the ongoing debate.

Increasing Exposure and Use

Efforts are planned to increase the awareness and use of FERNS within the forestry community. Individual sites tend to be well known by the forest industry in the local area and well used for both the sites' research results and for demonstrations for foreign customers and others. What may be not so well known locally is the similar work being conducted at other FERNS sites across the country. There is a need to expand this awareness to ensure that results from all sites are being used as extensively as possible and that foreign visitors come away with a more complete picture of Canada's research and forestry practices efforts.

We wish to explore ways to connect forest mangers at the local level with relevant research that is being conducted across the country. Possible future activities include field tours or workshops at one site per year. Building on the success of the web site, an electronic "bulletin board" is being considered. This would offer researchers, forest managers and other interested parties an opportunity to ask questions and get answers.

Issues such as data base management are also being explored. We hope to look at questions such as how to collect information and how to maintain, store and synthesize this information. Questions of accessibility, usefulness and timeliness of information will also be looked at so that scientific information can be synthesized and integrated across a number of sites.

Any improvements we can make which will increase the efficiency of people, time and money will be investigated. We are open to suggestions as to how we can make FERNS a more effective network.

FOR FURTHER INFORMATION

For more information about FERNS contact Chris Lee, RPF, FERNS Coordinator, Canadian Forest Service, Pacific Forestry Centre, Victoria British Columbia, Canada. Phone: (250) 363-0600. E-mail: clee@pfc.cfs.nrcan.gc.ca .

For assistance in accessing the FERNS web site contact Chris Lee (as above) or Rod Maides, Communications, Canadian Forest Service, Pacific Forestry Centre, Victoria, British Columbia, Canada. Phone: (250) 363-0737 E-mail: rmaides@pfc.cfs.nrcan.gc.ca

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LONG TERM OBSERVATION OF GALLERY FORESTS IN CENTRAL BRAZIL

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ABSTRACT

Gallery forests in Central Brazil stock along superficial watercourses. They form narrow evergreen and semideciduous forest belts, surrounded by the dry vegetation of the Cerrado savanna. This forest formation fulfills a variety of important ecological and socioeconomic functions. In consequence it enjoys strict legal protection. Nevertheless gallery forests are endangered by several human caused pressures.

Protection efforts need suitable observation instruments to be enabled to fulfill the task effectively and efficiently. The scale of most relevant parameters limits the use of satellite imagery. Cost intensive aerial photos are restricted to very punctual employment. Terrestrial activities however are limited by the extension of the area in which gallery forest are to be found.

An other aspect is the relatively young research in gallery forests. Consequently there is need of deeper knowledge and understanding of the forest formation. This speaks in favor of terrestrial studies to be realized.

The article focuses therefore on the specific problems and conditions of terrestrial observation in gallery forests of Central Brazil. Survey methodologies are presented and discussed under the special aspect of long term observation and research activity.

INTRODUCTION

Central Brazil

The notion Central Brazil here is used synonymous to the geographic extension of the Cerrado savanna in the central regions of Brazil. Cerrado forms the middle section of a huge savanna and dry forest belt crossing South America from the thorny shrub vegetation Caatinga in northeast Brazil towards the Chaco dry forest, reaching the Andean mountains (Hueck, 1966 and Weber, 1968). It separates the Amazonian rain forest from the humid Atlantic forests (Figure 1).

The relief of Central Brazil is characterized by a plateau reaching from 200 m in the west up to 1200 m above sea level in the eastern parts. With an average temperature of 20 °C (Nix, 1983 and CODEPLAN 1984) the climate is described as tropical (Aw) in the lower and tropical height climate (Cwa, Cwb) in more elevated parts. The annual precipitation is about 1600 mm (Ratisbona 1976). 80 % of it falls during the rain season from October to April. High evaporation during dry season almost levels the water balance. Latosols and Litosols are the dominant soils of the Cerrado, while alluvial soils occur along the water courses (CODEPLAN, 1984).

The characteristic vegetation of the area is Cerrado. This general expression stands for a soil dependent vegetation profile from open grassland (Campo Limpo) to dense savanna forest

(Cerradão), as shown in Figure 2. Outside this vegetation profile swamps and gallery forests can be found along watercourses.

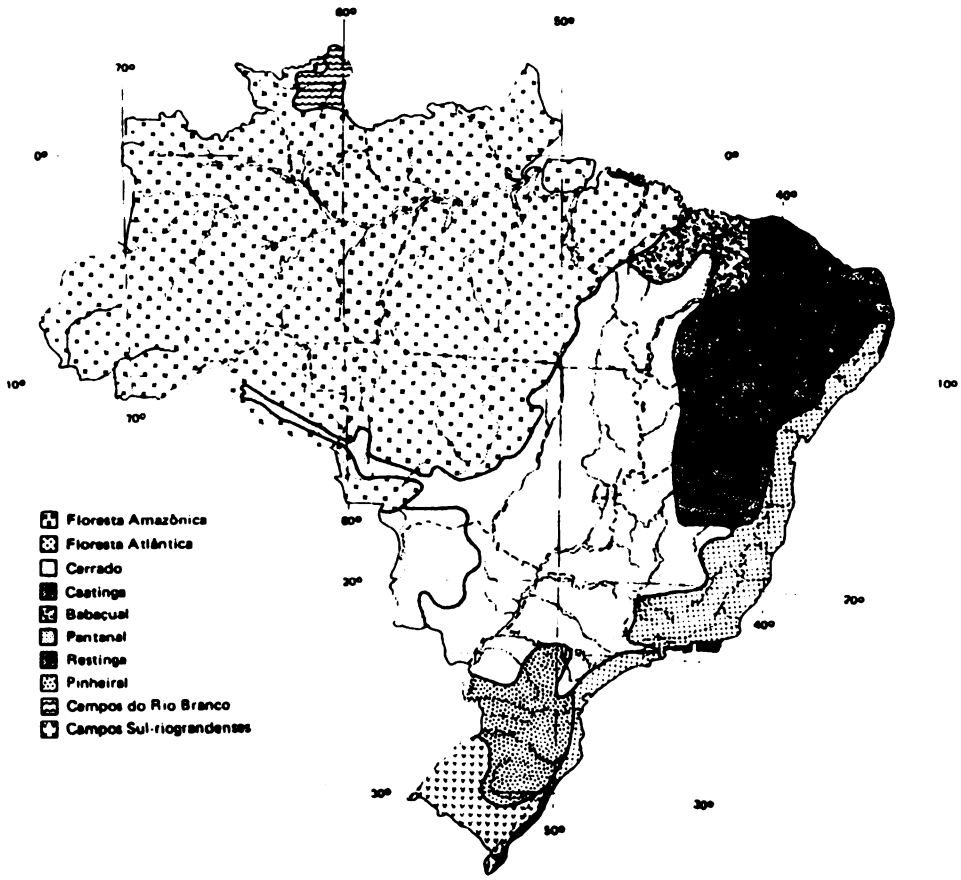

Figure 1: *Geographic extension of the Cerrado savanna, distribution area of Central Brazil's gallery forests (CODEPLAN, 1984).*

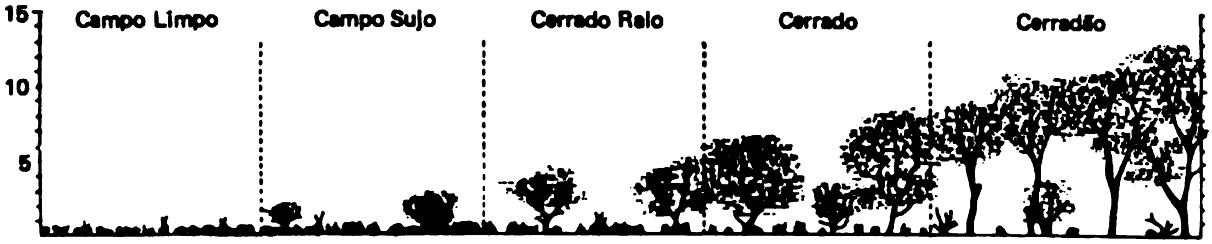

Figure 2: *Soil dependent vegetation profile of Cerrdo savanna vegetation (CODEPLAN, 1984).*

Gallery forests

Gallery forests are defined as tropical or subtropical evergreen and semi deciduous forest vegetation growing as narrow stripes along creeks, rivers and streams in dry areas. They are per definition the only or at least one of the only natural closed forest formations in the area of their distribution, here the Central Brazilian Cerrado (see Figure 3) and stretch the area like veins. Canopy closure reaches from 70 % to 100 % according to CODEPLAN (1984). The forest stripes are 10 to over 500 m wide, depending to the topographic situation and soil-water conditions. In flat topography swamps boarder the forests until Cerrado starts at the limit of the valley bottom.

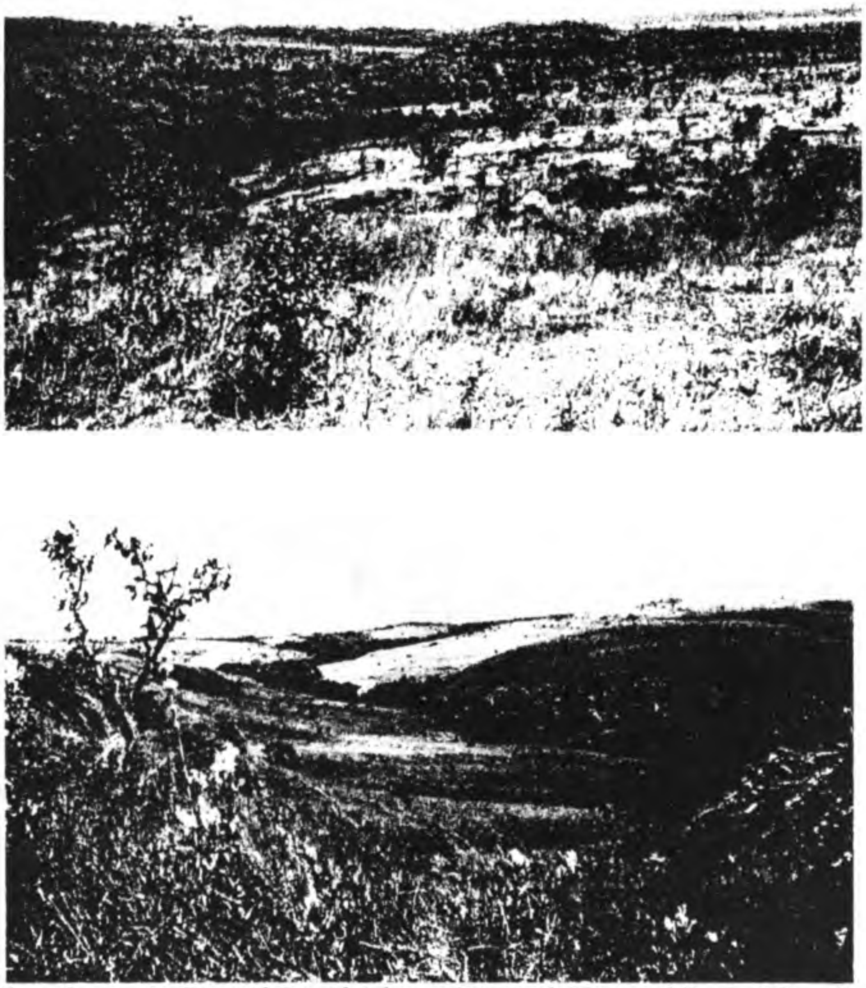

Figure 3: *Gallery forests in Central Brazil (above: Bananal, National Park of Brasilia, below: Pitera, south of National Park Capada dos Veadeiros).*

The forests are classified according to their dimension (Mantovani 1989), water saturation of its soils (Walter and Ribeiro, 1997), water regime and a variety of functions. Such are for example the filter function (Lima, 1989, Rizzi, 1995, Walter, 1962), bank stabilization (Lima, 1989), water reservoir (Rodrigues, 1991), thermal equilibrium (Schiavini, 1992), fodder and refuge for animals (Lima, 1989 and Schiavini 1992), distribution corridor (Schiavini, 1992) and fire barrier (Felfili, 1993).

Due to their important functions and wide devastation the legal protection of gallery forests by the forest law form 1965 was further enforced by the Brazilian constitution from 1988 (Machado, 1989). The forest formation is endangered by illegal utilization, construction of dams and unreasonable water extraction for irrigation.

RESEARCH NEEDS AND LONG TERM OBSERVATION IN GALLERY FORESTS

Scientific research in gallery forests only in the 1980s reached an extend worth mentioning. The published studies however, mainly show the character of snapshots in time and space (Encinas and Kleinn, 1997). Only few studies like that of Felfili (1993) work with the concept of a continuous inventory. She is able to derive results on forest dynamics from two surveys, executed in 1986 and 1991. Therefor Encinas and Kleinn in 1997 can still observe that 'there is a need to better understand the ecological roles of gallery forests'.

Background

The Correio Brailiense, leading newspaper of Brasília, titled a report on a United Nations Conference in Istanbul in 1996: 'Falta de água ameaça grandes cidades [lack of water endangers big cities]'. Intensive irrigation and increasing domestic and industrial water consumption would endanger drinking water supply. The newspaper cites the general secretary of the Habitat II Conference, Wally N'Dor, who foresees the lack of water as decisive problem for the world population in the next century. Goodwyn Obasi, general secretary of the World Meteorological Organization, is cited, who reports an dramatic increase in the search for drinking water.

CASEB (1990) developed in her 'General Plan on Water, Wastewater and Water Pollution' several scenarios on population growth and water consumption in the Federal District. For the year 2015 a deficit of 7500 l/s was calculated what is the double of the consumption in 1990. The report identifies so far unused water resources in the small watercourses and puts emphasis on the significant meaning of gallery forests for water quality.

One significant output of the 'United Nations Conference on Environment and Development' in Rio de Janeiro (UNCED, 1992) was the 'Program of Action for Sustainable Development for Now Into the Twenty-first Century', the so-called Agenda 21. When talking about combating deforestation, managing fragile ecosystems, conservation of biological diversity or protection of the quality and supply of freshwater resources, gallery forests obtain special importance in the Cerrado region of Central Brazil.

Scenarios on the use of gallery forests

Based on this background information, scenarios on the use of gallery forests can be developed that allow to derive future anthropic conflicts and problems.

(A) In areas with denser population, especially in the hinterland of bigger cities, irrigation for horticulture and agriculture is increasing. The water normally is taken directly from watercourses. There is no limitation and control so far. In some areas around the capital already conflicts between users broke up because those living downstream did not find enough water any more. It is obvious that such a decrease in water level may have an effect on the species composition of stocking gallery forest with its very specific growing and regeneration demands on water level and inundation.

(B) To successfully face the increasing drinking water demand the CASBE (1990) plans to construct several dams, e. g. in the valley of the São Bartolomeu river. Huge areas of gallery forest will be completely inundated then. New banks are to be forested to protect the water reservoir. Another possibility would be to implement a management of gallery forests that focuses on the increase of high quality drinking water output from watercourses as done intensively e.g. in the dryer areas of the USA. Roughly speaking this management is based on the reduction of that vegetation that is not needed for water protection or other purposes. This reduces the water consumption of plants growing along the watercourse, increasing the water level in the stream.

(C) At the moment gallery forests are used illegally for clearings to get agricultural land and watering places for animals. Fuel wood and logs of several tree species are extracted. Economic crisis may increase the fuel wood demand as can be observed in all tropical and subtropical countries of the dry belt. It may be favorable in some future to imply sustainable management systems in sharp limits instead of the general prohibition of forestry action in gallery forests. The actual situation results in creeping degradation of gallery forests and finally the reduction of their total area (Salis, 1990, Assis, 1991, Felfili, 1993) and potential functions.

Derivation of research needs

In the following section research needs that require long term observation methods are derived from the above scenarios:

1. To efficiently detect changes in gallery forest cover a monitoring system needs to be implemented. This monitoring shall focus mainly on
   - the total forest area,
   - tree species composition,
   - the various aspects of forest structure and diversity and
   - all kinds of human impact on the gallery forest ecosystem.
2. Ecological requirements and growth of gallery forest tree species can be considered mainly unknown to science and forestry. The effects of decreasing water level in watercourses on the surrounding gallery forest soils and vegetation have to be analyzed. In this context all aspects of forest dynamics have to be studied, as for example:
   - the specific regeneration conditions and requirements,
   - growth of tree species and competition condition among tree species
   - as well as their changes due to changing environment conditions.

According to the different tasks of the research – change detection and ecological studies in a wider sense – the methodological approaches will be named "monitoring" and "long term studies" in the following.

MONITORING

Material and methods

In 1995 and 1996 a research project on gallery forests was executed by the Department of Forest Biometrics of the University of Freiburg, Germany, in cooperation with the Department of Forestry of the University of Brasília, Brazil. The project was funded by the German Agency for Technical Cooperation (GTZ) within their Flanking Program for Tropical Ecology (TÖB). The project carried out intensive surveys in several gallery forests of the Federal District and its nearer surrounding in order to describe the status quo of this forest formation and to develop an adopted monitoring system.

The inventory design followed the concept of continuous forest inventory. Field data were collected on 10 meter wide permanently marked transect stripes which were equally distributed along the gallery forests and reached from forest edge to forest edge. Besides tree data, soil samples were taken with an auger and air temperature and humidity was measured along the transects. Additionally a leveling of the topography was carried out. The methodology is described in detail by Scheuber *et al.* (1997).

By simulation studies different inventory designs for the terrestrial monitoring of gallery forests were tested on their efficiency to derive an adequate method for terrestrial monitoring:

- transect stripes with a width of 2, 4, 6, 8 and 10 meters,
- square plots with 100 m² and 10, 20, 30, 40 and 50 meters distance on transect lines and
- the four nearest trees of each quarter section to points with 10 m distance along the transect lines.

Results and discussion

The enormous extension of the Cerrado makes terrestrial monitoring of gallery forests in this area impossible. Even the work volume with remote sensing methods has to be drastically reduced. In consequence a three stage monitoring system is discussed by Scheuber (1998) as shown in Table 1.

Table 1: *Concept of a three stage monitoring system for gallery forests of Central Brazil.*

Stage	Level	Source of Information	Target Parameter	Output for Next Stage
1	Central Brazil	GIS	potential human pressure	stratification, distribution of samples
		satellite images	change in forest area	localization of samples
2	parts of Central Brazil	aerial photos or high resolution satellite images	change in forest area, degradation	localization of samples
3	gallery forest	terrestrial inventory	change in species composition, forest structure, diversity and site conditions, human activities	comprehensive information for GIS (stage 1)

In a first stage Landsat5 TM or Spot satellite images are used to determine the gallery forest area in different strata with given precision. The forests are stratified according to the potential human pressure by derivation of relevant information from a geographical information system. Distribution of the satellite samples in the strata can be done with a block design or systematically.

In the second stage the single gallery forests are focused. The distribution of samples in this stage is done within the satellite samples of stage one but concentrated on points of special interest, if such additional information is available. This second stage gets important in areas with denser population and related human pressure on the forest formation. Now aerial photos or preferably satellite images with high resolution capacity come into effect. The use of aerial photos is seen critically. They have the advantage of high resolution, but the spatial distribution of gallery forests makes necessary flights inefficient. Satellite data in the near future will be available with a panchromatic resolution of 1 to 5 m what allows the analysis of forest structure. Stereo interpretation makes it possible to measure heights from these images. Further advantage is the spectral information inherent to satellite images (Koch and Fritz, 1998). As the data are digital they can be easily combined with information of geographical information systems. With these means forest borders are determined and types of gallery forest distinguished and stratified. Analyses give information on smaller changes in forest area as well as progressive degradation. Further task of this stage is the distribution of terrestrial trial plots.

The third stage finally works on terrestrial level. The terrestrial inventory method is derived from the results of the above mentioned study. On 5 m wide transect strips tree parameters for trees with dbh ≥ 5 cm, special indicator plants and signs of human activity are assessed. Regeneration data are sampled on smaller subplots. The geographic position of the transects is localized with a global positioning system and permanently marked with invisible sings.

5 m wide transect stripes are chosen because of various reasons:

- They show slightly higher efficiency compared with the other variants tested. The description of the efficiency of the variants was given through the time consumption for assessing a necessary number of sample plots in order to receive an expected maximum error. However, the differences were small and other factors than efficiency were decisive, as for example continuous data along gradients that can be received from transect stripes or greater flexibility. The quarter point method showed tremendous problems at forest border zones and bigger gaps. It was therefor not taken into further consideration.
- The number of trees recorded on the transect was decreasing significantly with the distance from the center line. This was especially true in inundated and very dense parts of forest that were hard to access. It is therefor advisable not to choose too wide transect stripes. On the other hand, if the strips get too small, the relation between time and effort for accessing the transect and information gain is not efficient.

LONG TERM STUDIES

It was already mentioned that long term studies can be seen as new step of research activity in gallery forests of Central Brazil. In consequence data collected now can be used for long term analyses only after a certain period of time. Methods applied and parameters assessed today should therefor meet the needs of tomorrow. This is a big challenge for today's research.

For data analysis in forestry science geo-statistic methods as for example kriging, point field simulations and others are applied frequently in present. These methods, as well as modeling, have special requirements on data from long term observations that unfortunately often are not fulfilled by available data. In this chapter some examples of requirements are given that condition survey methods for long term studies.

In general it is essential to choose representative samples. Parameters and methods have to be described in detail to guarantee the usability of the data in later analyses. Sample plots have to be marked permanently. The points of measurement should be marked if possible (e. g. dbh) to reduce errors that may occur when the trees are re-measured not at exactly the same place in later field work.

Modeling forest dynamics asks for information on regeneration, growth, competition, mortality, the spatial composition of objects and other factors. Especially regeneration data and crown parameters were often not assessed in former surveys. The regeneration process is complex and difficult to describe. But if it is not taken into consideration the model does not describe the whole dynamic process and lacks essential information for sustainable management.

Parameters used for modeling growth and competition are especially diameters in several (relative) tree heights and crown parameters as crown diameter, crown length, crown surface and volume. Crown surface and tree height determine the possible light consumption of a tree in relation to neighboring trees.

The derivation of competition relations between tree individuals needs sample plots that are sufficiently large. This information can only be obtained for the center tree(s) because of boundary effects. The size of boundary area of a sample plot depends on the tree size and the existence of neighboring trees inside the sample plot. Whenever neighbors are standing outside the sample plot, the sample tree is considered border tree because its competition conditions can not be fully determined from the data. Sample size therefor has to take into consideration tree size and boundary effects if the mentioned information shall be input in a model.

The analysis of point fields with geo-statistic methods to derive parameters for simulation obviously requires the coordinates of the objects (trees). Simulation studies can help to make surveys more efficient by reducing time consuming field work.

SUMMARY

The article describes several scenarios on the use of gallery forests and resulting effects. Research needs are derived to meet the related information needs with long term observation methods. Two main directions are identified in this forest formation (1) the monitoring of gallery forests that focuses on change detection and (2) long term studies of ecological issues.

A three stage monitoring system is presented with the use of satellite images in the first, high resolution satellite images or aerial photos in the second and terrestrial monitoring in the third stage. The recommended method for terrestrial monitoring of gallery forests is derived from an intensive two year study in Central Brazil. The use of 5 m wide transect stripes was the most efficient sample plot design.

In contrast to the terrestrial monitoring of gallery forests it can be summarized that long term studies may have other determining factors for adequate and efficient methodology. The assessment of more and difficult parameters on larger sample plots can be more efficient if we take into consideration future questions and possibilities of data analysis. A detailed definition of parameters and methods is essential.

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DYNAMICS OF TROPICAL FORESTS AFTER LOGGING IN OSA PENINSULA, COSTA RICA

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ABSTRACT

Twelve one hectare Permanent Sample Plots have been established in three sites in the Osa Peninsula, southern Costa Rica. Trees greater than 10 cm DBH have been measured in five occasions after logging. Current Annual Increment (CAI) of commercial tree species was determined. Annual increments greater than 3 cm were eliminated from the database. Static moments of each diameter class of 10 cm were determined, which is defined as the center of the distribution of increments. The sum of residuals of each observation relative to the moment is zero. For each period, models to predict CAI were fitted by the least squares method, both from the population of observations and from the static moments. No statistically significant difference was found between the models. The latter one were used to compare CAI in different periods, resulting in the following:

PERIOD	LENGTH	CAI EQUATION (d IN mm)	SURFACE	r SQUARE
1992 to 1993	0.5 yr.	$1.1444\ d^{\wedge 1/3} - 0.0121\ d$	2210.32	0.98
1992 to 1994	1.5 yr.	$0.3303\ d^{\wedge 2/3} - 0.0331\ d$	2971.70	1
1992 to 1995	2.5 yr.	$0.3530\ d^{\wedge 2/3} - 0.0344\ d$	2971.70	0.97
1992 to 1998	5 yr.	$0.3288\ d^{\wedge 2/3} - 0.037\ d$	2648.38	1

The surface under the model line, calculated by integration of the equation, seems to be useful to represent the growth of forest. In this case the surface determined from the 2.5 years after logging, is 35 percent greater than that from 5 years after. From the results it is obvious that competition conditions, climate, ann other factors, or the interaction of some of those variables, determine changes in the growth rate through time. Since CAI is used to determine cut cycle in forest management, it is convenient to adjust the time between successive harvests, using actual information from the forest under consideration, or from other forests with similar ecological and management conditions.

INTRODUCTION

One of the basic principles and challenges in sustainable forest management is to harvest a volume equivalent to growth in a given period of time, which is called Cut Cycle (CC). In forest management, the importance of dynamic studies lies in obtaining information of increment in order to generate knowledge on growth so that reasonable decisions on CC can be taken.

This paper introduces a method how to determine and describe forest stand growth.

MATERIALS AND METHODS

Twelve one-hectare Permanent Sample Plots (PSP) have been established in three sites in the Osa Peninsula, southern Costa Rica. Trees, including palms, greater than 10 cm DBH have been taxonomically identified; diameter and total height measured. The crown position, as Alder and Synnott (1992) proposed, was determined. For almost all the species, the ecological strategy was defined (Halle et all, 1978). Their potential use as commercial and no-known value classified the species.

PSP were established in 1990 and measured in several occaions. For this study five measurements was used. Current Annual Increment (CAI) of commercial tree species was determined. Some outliers were eliminated from the database because the increment was greater than the mean of increments plus three times the standard deviation, that is, more than three centimeters. Reduction in the number of trees for analysis was caused by mortality, 1.5 percent per year. At the time of the last measurement one of the sites had been logged and virtually all the PSPs destroyed. Baseline data of the study plots are given in Table 1.

Table 1: *Baseline data of the study plots.*

YEAR	TIME AFTER HARVEST	TREES FOR ANALYSIS
1992	Immediately	
1993	6 months	1706
1994	1.5 years	1700
1995	2.5 years	1644
1998	5 years	1022

Source: Valerio *et al.* 1995

The total of the analyzed cases were 6072. Analysis of each period have been done separately.

Static moments of each diameter class of 10 cm were determined, which is defined as the center of the distribution of increments of the class. The sum of relative distances from each observation to the static moment is zero, as presented in Figure 1.

$$\sum_{i=1}^{n}(d_i-d_m+I_i-I_m)=0$$

where:

- d_i: the diameter corresponding to each CAI.
- d_m: the average diameter of the class
- I_i: each CAI.
- I_m: the average CAI of the class

The static moment is proposed as the best representation of the magnitude of increment in the diameter class because the sum of the deviations (residuals) from it is zero. That means that variation generated by other factors, different from dimension of the trees, is absorbed. The model will then be fitted only with respect to this factor.

For each period models to predict CAI were fitted by the least squares method, both, from the observations and from the static moments. The models follow the Von Bertalanffy equation as presented by del Valle, (1986). There is no statistically significant difference between models, as can be seen from Figure 2 (statistic parameters are shown in Annex 2). In order to compare the growth rate of different periods the model of moments will be used.

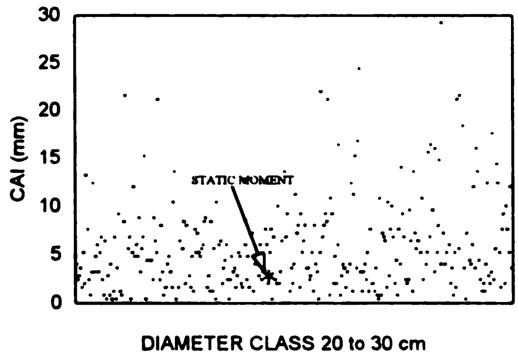

Figure 1: *Distribution of CAIs and the static moment of the class.*

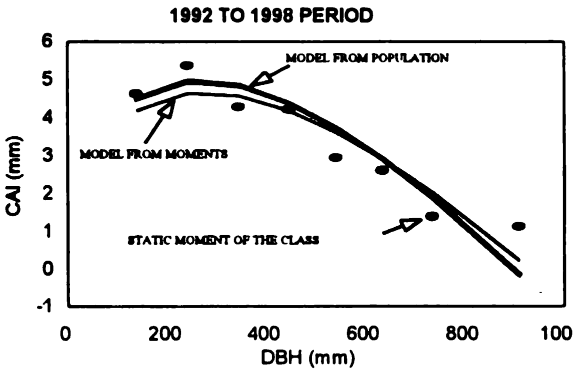

Figure 2: *Static moments of diameter classes and models of CAI.*

In order to compare the growth rate in different periods, the surface under the model line for each period was calculated by integration between diameters of 100 and 900 millimeters. This surface **represents** the magnitude of growth only.

RESULTS

The model fitted from the 6072 individual observations explains around four percent of variation (as given in Annex 1). The models fitted based on the static moments explain almost all the variation. The model equations and corresponding r-square by period, are given in Table 2.

The corresponding statistics are presented in Annex 2 and the curves are presented in Figure 3. Table 3 shows the integrated equations and the corresponding area under the curve.

Table 2: *Baseline data of the study plots.*

PERIOD	CAI EQUATION (d IN mm)	r SQUARE
1992 to 1993	$1.1444\ d^{\wedge 1/3} - 0.0121\ d$	0.94
1992 to 1994	$0.3303\ d^{\wedge 2/3} - 0.0331\ d$	0.93
1992 to 1995	$0.3530\ d^{\wedge 2/3} - 0.0344\ d$	0.96
1992 to 1998	$0.3288\ d^{\wedge 2/3} - 0.037\ d$	0.85

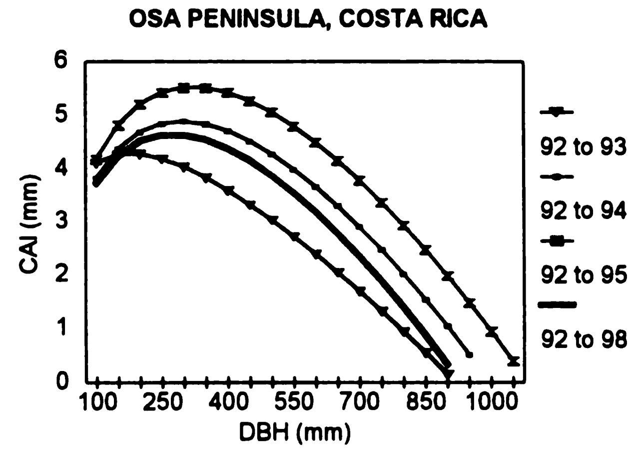

Figure 3: *Curves of CAI for the analyzed periods.*

Table 3: *Integrated equations and the corresponding area under the curve.*

PERIOD	EQUATION	SURFACE (mm^2)
1992 to 1993	$0.8583d^{\wedge 4/3} - 0.0061d^2$	2210
1992 to 1994	$0.1982d^{\wedge 5/3} - 0.0165d^2$	2972
1992 to 1995	$0.2118d^{\wedge 5/3} - 0.0172d^2$	3566
1992 to 1998	$0.1973d^{\wedge 5/3} - 0.0169d^2$	2648

The area under the curve of the 2.5 years after logging period is 35 per cent greater than that for the 5 years period. For a given forest structure this may be interpreted as a difference in the CC.

CONCLUSION

It seems that factors as levels of competition, climate, and possibly some more variables determine different rates of growth in different periods after logging.

RECOMMENDATIONS

Since CAI is used to determine cut cycle in forest management, it seems justified to adjust the time between successive harvests, using actual information from the particular forest under consideration or from other forests with similar ecological and management conditions. In order to compare trends in growth rates CAI information from non-harvested forests in equivalent ecological conditions can be obtained. To determine actual differences in CC caused by changes in growth rate one can simulate the forest growth using the 1992 to 1995 and the 1992 to 1998 period equations.

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Annex 1

Regression Statistics	*6072 CASES*
Multiple R	0.1899
R Square	0.0361
Adjusted R Square	0.0359
Standard Error	4.7079
Observations	6072

Analysis of Variance	*df*	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regression	1	5000.92	5000.92	225.63	0.00
Residual	6070	134538.23	22.1645		
Total	6071	138684.833			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95.00%*	*Upper 95.00%*
x1	-0.0361	0.0009	-38.1102	0	-0.0379	-0.0342
x2	0.3530	0.0073	48.4211	0	0.3387	0.3673

Annex 2

Regression Statistics	92 to 93
Multiple R	0.215331
R Square	0.0463678
Adjusted R Square	0.0458081
Standard Error	4.73377664
Observations	1706

Analysis of Variance	df	Sum of Squares	Mean Square	F	Significance F
Regression	1	1856.6605	1856.6605	82.85467	2.3989 E-19
Residual	1704	38184.32	22.40864		
Total	1705	40042.009			

	Coefficients	Standard Error	t Statistic	P-value	Lower 95.00%	Upper 95.00%
x1	-0.0131816	0.0008765	-15.03879	0	-0.0149	-0.011462
x2	1.21161174	0.048498	24.982636778	0	1.116489538	1.30673393

Regression Output:	92 to 93	
Constant		0
Std Err of Y Est		0.383195156589735
R Squared		0.941869847046851
No. of Observations		7
Degrees of Freedom		5
X Coefficient(s)	-0.0121244159762686	1.1444310313995
Std Err of Coef.	0.000969098766146352	0.0658135807878616

Regression Statistics	92 to 93
Multiple R	0.99007465
R Square	0.98024782
Adjusted R Square	0.97629737
Standard Error	0.38319515
Observations	7

Analysis of Variance	df	Sum of Squares	Mean Square	F	Significance F
Regression	1	12.38068	12.3806784	84.314918	0.000256978
Residual	5	0.7341926	0.146838528		
Total	6	12.63015			

	Coefficients	Standard Error	t Statistic	P-value	Lower 95.00%	Upper 95.00%
X1	-0.012124	0.000969	-12.5110212	1.5945E-5	-0.01461556	-0.0096
X2	1.144431	0.065814	17.38897987	2.3187E-6	0.9752518	1.31361

Regression Statistics	92 to 94
Multiple R	0.174748
R Square	0.03053687
Adjusted R Square	0.0299659
Standard Error	4.8143643
Observations	1700

Analysis of Variance	df	Sum of Squares	Mean Square	F	Significance F
Regression	1	1236.9726	1236.97258	53.368152	4.23465E-13
Residual	1698	39356.42	23.1781		
Total	1699	40507.506			

	Coefficients	Standard Error	t Statistic	P-value	Lower 95.00%	Upper 95.00%
X1	-0.035841	0.001846	-19.417881	0	-0.0394612	-0.03222
X2	0.35361996	0.0141878	24.92416	0	0.325792474	0.381447

Regression Output: 92 to 94

Annex 2 (continued)

Constant		0
Std Err of Y Est		0.438253623316958
R Squared		0.931169485552603
No. of Observations		8
Degrees of Freedom		6
X Coefficient(s)	-0.0330752560721473	0.330346799850203
Std Err of Coef.	0.00206494042590701	0.0179498585675598

Regression Statistics	*92 to 94*
Multiple R	1.009661
R Square	1.01941548
Adjusted R Square	1.0226513
Standard Error	0.43825362
Observations	8

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regression	1	17.0676	17.0676	88.863	8.102 E-05
Residual	6	1.152397	0.1920662		
Total	7	16.74254			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95.00%*	*Upper 95.00%*
X1	-0.033075	0.0020649	-16.017535	8.9789E-7	-0.0381	-0.028
X2	0.3303468	0.0179499	18.403866	3.4655E-7	0.286425	0.374268

Regression Statistics	*92 to 95*
Multiple R	0.14692946
R Square	0.021588
Adjusted R Square	0.0209924
Standard Error	4.69482198
Observations	1644

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regression	1	798.73578	798.735787	36.238055	2.14968E-9
Residual	1642	36191.902	22.0413534		
Total	1643	36998.606			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95.00%*	*Upper 95.00%*
x1	-0.03450343	0.00183	-18.8341	0	-0.0380966	-0.03091
x2	0.354680438	0.01407	25.206634	0	0.3270816	0.382279

Regression Output:	92 to 95	
Constant		0
Std Err of Y Est		0.318747288799167
R Squared		0.959348721165108
No. of Observations		9
Degrees of Freedom		7
X Coefficient(s)	-0.0343673261386205	0.352992522124339
Std Err of Coef.	0.00144052296672139	0.0127143140516717

Regression Statistics	*92 to 95*
Multiple R	0.98442
R Square	0.96908445
Adjusted R Square	0.96466794
Standard Error	0.318747

Annex 2 (continued)

Observations	9					
Analysis of Variance	***df***	***Sum of Squares***	***Mean Square***	***F***	***Significance F***	
Regression	1	16.95424	16.95424488	166.87276	3.87152E-6	
Residual	7	0.7111988	0.101599834			
Total	8	17.4951				
	Coefficients	***Standard Error***	***t Statistic***	***P-value***	***Lower 95.00%***	***Upper 95.00%***
x1	-0.0343673	0.00144	-23.857534	1.0148E-8	-0.03777	-0.03096
x2	0.35299252	0.012714	27.7633949	3.057E-9	0.3229279	0.383057

Regression Statistics	***92 to 98***
Multiple R	0.2426422
R Square	0.058875
Adjusted R Square	0.05795
Standard Error	4.32473
Observations	1022

Analysis of Variance						
	df	***Sum of Squares***	***Mean Square***	***F***	***Significance F***	
Regression	1	1179.61	1179.6145	63.0697	5.2437E-15	
Residual	1020	19077.396	18.7033292			
Total	1021	20035.832				
	Coefficients	***Standard Error***	***t Statistic***	***P-value***	***Lower 95.00%***	***Upper 95.00%***
x1	-0.03727	0.00204	-18.2689972	0	-0.041276	-0.033269
x2	0.35956	0.01582	22.72748	0	0.3285	0.3906

Regression Output:	92 to98	
Constant		0
Std Err of Y Est		0.653477675107172
R Squared		0.84789207175714
No. of Observations		8
Degrees of Freedom		6
X Coefficient(s)	-0.0337054409600801	0.328892631397467
Std Err of Coef.	0.00332779148826972	0.0285853775518567

Regression Statistics	***92 to 98***
Multiple R	0.999999999
R Square	0.999999999
Adjusted R Square	0.999999999
Standard Error	7.61 E-15
Observations	8

Analysis of Variance						
	df	***Sum of Squares***	***Mean Square***	***F***	***Significance F***	
Regression	1	16.324	16.324	2.82E+29	3.01E-87	
Residual	6	3.47E-28	5.79 E-29			
Total	7	16.324				
	Coefficients	***Standard Error***	***t Statistic***	***P-value***	***Lower 95.00%***	***Upper 95.00%***
x1	-0.0337	3.87 E-17	-18.698966	0	-0.0337	-0.0337
x2	0.32889263	3.328E-16	988175	0	0.32889	0.32889

LA INVESTIGACIÓN DE INFOR: HACIA EL CONOCIMIENTO DEL EUCALIPTO EN CHILE

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ABSTRACT

The plantations of *Eucalyptus* in Chile constitute the more productive forest culture and the second species after radiata pine respecting planted surface, totalizing about 317..000 he. These plantations are mostly used by the pulp industry, with and average cutting cycle of 10 to 12 years. Clearly, this great extension of plantations demands the knowledge of how it grows, and which is the best genetic material to use in Chile. This must be a high quality information, essential for management planning of forest plantations.

Since the 80's, INFOR has made research destined to generate a genetic improvement program and the background information for management planning of *Eucalyptus*. Through this experience INFOR has developed a considerable amount of trials, sample plots and strategic information, whose description appears in this work.

The information collected from permanent sample plots and other different trials has generated the first studies about growth characteristics of *Eucalyptus* in Chile. Also this knowledge will allow to produce more accurate growth projections through the improvement of the developed growth models, and will constitute a decision support system for the management of *Eucalyptus* plantations.

The existing growth model for *Eucalyptus* that is presented in this work is integrated by the following variables: top height, basal area, stocking and volume per hectare. Also it is complemented by diameter distribution module. The model works under different conditions of site quality and initial stocking. To ensure representative results and improve projections, are necessary new measurements of permanent sample plots.

Finally, other product of this research is the preliminary identification of similar growth zones for *Eucalyptus* in Chile.

KEYWORDS: eucalypt, growth, growth model, research, genetic improvement

RESUMEN

Las plantaciones de eucalipto en Chile constituyen el cultivo forestal más productivo y la segunda especie después del pino insigne en cuanto a superficie plantada, totalizando del orden de 317.000 ha (INFOR, 1997), cuyo uso principal esta en la industria de la pulpa. La gran extensión de plantaciones demanda el conocimiento de cómo crece el eucalipto y del mejor material genético, información de alta calidad y fundamental para la toma de decisiones y optimización de los procesos productivos del sector forestal.

Desde la década de los 80 el Instituto Forestal (INFOR) ha realizado la investigación destinada a generar un programa de mejora genética y antecedentes para el manejo eficiente del eucalipto. Dicha experiencia le ha permitido dotarse de una considerable cantidad de ensayos, parcelas de investigación e información técnica estratégica para la obtención de los productos asociados a esas líneas de estudio, cuya descripción se presenta en este trabajo.

El análisis de la información recolectada desde parcelas permanentes y otros diferentes ensayos ha permitido generar los primeros antecedentes acerca de procedencias y progenies adecuadas para Chile y sobre las características de crecimiento para *Eucalyptus*, permitiendo producir modelos de mayor confiabilidad. Este conocimiento permitirá establecer a priori selecciones de procedencias y progenies, opciones de establecimiento y manejo, predecir el desarrollo de rodales y proyectar futuras producciones volumétricas a través del ajuste y utilización de modelos de tipo estadístico-matemáticos.

El modelo de crecimiento para Eucalipto (simulador de rodal) que se presentan en esta oportunidad se compone de: Crecimiento en altura, mortalidad natural, rendimiento y crecimiento para área basal, y predicción para volumen, para diferentes condiciones de Sitio y Densidad. Se hace hincapié en las falencias de información, y la necesidad de contar con nuevas mediciones. Finalmente, se presentan otros productos de estas investigaciones: *Simulador del crecimiento para eucalipto, Zonas de establecimiento potencial para eucalipto, Funciones de crecimiento y rendimiento, Zonas de isocrecimiento potencial para eucalipto, Procedencias, familias e individuos seleccionados para E. globulus y E. nitens.*

INTRODUCCIÓN

La gran superficie plantada, el rápido crecimiento demostrado, su adaptabilidad a diversas condiciones de suelo y clima, y sus propiedades madereras, han transformado a las especies del género ***Eucalyptus*** en un recurso de importancia económica en Chile. El uso racional y eficiente de este recurso hace necesario y urgente la investigación en relación con su adaptabilidad, capacidad de respuesta a diferentes esquemas de manejo forestal y tratamientos. Las actuales tasa de consumo y forestación, requieren, además, de algún tipo de instrumento que permita conocer, anticipadamente, los rendimientos volumétricos y tipo de productos que se pueden esperar de un rodal de eucalipto a una edad determinada.

El Instituto Forestal a partir de los años 60 instaló en Chile una serie de distintos tipos de ensayos a lo largo del país utilizando, entre otras, especies del género ***Eucalyptus***. El objetivo de estos fue el obtener información acerca del crecimiento inicial de distintas especies. A partir de los resultados de estos ensayos, en 1989 se instalaron unidades experimentales cuyo primer objetivo fue el identificar la adaptabilidad de distintas procedencias y progenies de eucalipto, a las diversas condiciones ecológicas del país. El resultado de ello fue la selección de aquellas especies y procedencias más promisorias para cada área de interés forestal.

En vista de los resultados obtenidos en crecimiento y rendimiento desde los primeros ensayos y otros antecedentes, se inició una nueva línea de estudio orientada a obtener de las plantaciones de eucalipto su máximo retorno económico. Este estudio abarca el comportamiento, crecimiento y respuestas al manejo de las especies de eucalipto seleccionadas. Entre los temas abordados se incluyó la determinación de relaciones funcionales biométricas, funciones de rendimiento, modelos de conicidad y zonas de isocrecimiento.

La búsqueda de información se realiza principalmente en rodales jóvenes de eucalipto (menores a 10 años) y en rodales adultos de edades superiores a los 25-30 años. Esta situación se debe a que actualmente los rodales de eucalipto son cosechados a temprana edad para ser destinados a producción de pulpa. Mientras que por otro lado, existen pocos rodales adultos que por diversas razones no han sido cosechados, los que entregan antecedentes acerca de las asíntotas en crecimiento. Existe, por lo tanto, una escasez de datos entre los 10 a 25 años, la cual puede ser solucionada con la mantención y medición de parcelas permanentes por un período mayor que el de cosecha actual.

Actualmente se esta trabajando en el diseño y validación de estos modelos y funciones y en el ajuste de nuevos modelos. Por otro lado, se ha iniciado la segunda fase del programa de mejora genética para algunas especies de eucalipto y cómo relacionar o incorporar la variable genética en los modelos de crecimiento utilizados.

El estudio se ha centrado en las principales especies de eucalipto utilizadas en el país. Estas corresponden a ***E. globulus***, ***E. nitens*** y ***E. camaldulensis***. De estas, ***E. globulus*** concentra el mayor porcentaje de investigación, seguida de ***E. nitens***.

PROGRAMA DE MEJORAMIENTO GENÉTICO

En 1962, el Instituto Forestal inició un programa de Introducción de Especies el cual sirvió de base para implementar las primeras líneas de investigación de mejoramiento genético. La importancia de los resultados obtenidos con los ensayos iniciales de Introducción de Especies fueron complementados con estudios de variabilidad de las especies más promisorias. Es así como en 1968, se inicia la instalación de ensayos de procedencias con ***E. regnans*** (1969), ***E. obliqua*** (1970), ***E. globulus*** y ***E. nitens*** (1981), ***E. camaldulensis*** y ***E. fastigata*** (1984), ***E. resinífera*** y ***E. viminalis*** (1987). Estos ensayos fueron establecidos en una variedad de sitios que abarcan una gran superficie del país (INFOR, 1990; INFOR, 1992). En el Anexo N°1 se sintetizan los principales resultados para ***Eucalyptus*** en los ensayos de Introducción de Especies. Los resultados reportados en 1988 señalaron que el mejor potencial de crecimiento lo presentaba ***E. globulus*** ssp. ***globulus*** con dos procedencias, una local[1] (Ñuble) y otra originada en Tasmania (Prado, 1988).

Actualmente se está trabajando en la selección genética de procedencias, progenies (familias) e incluso individuos para distintas especies del género según la zona edafoclimática adecuada para su desarrollo.

Si bien la estrategia de mejoramiento genético con eucalipto se define en primera instancia en 1988, es durante 1992 que esta línea toma un gran impulso, al poner en marcha un proyecto de Mejora Genética del ***Eucalyptus*** con la participación de las principales empresas del Sector Forestal

[1]***Eucalyptus*** existentes en el país sin procedencia conocida, originados a partir de individuos introducidos el siglo pasado.

Chileno, debido a la creciente demanda mundial por madera de fibra corta para la industria de pulpa y papel. Adicionalmente, este recurso es para pequeños propietarios una fuente de ingresos por su venta como materia prima para la producción de pulpa o para combustible, constituyendo pequeños bosquetes una inversión a mediano plazo o un ahorro frente a imprevistos.

Con esta investigación se pretende aumentar la producción y calidad de las futuras plantaciones en el país a través de la aplicación de técnicas de mejora genética forestal, con el fin de asegurar la competitividad de la industria nacional en los mercados mundiales y de lograr la incorporación de terrenos marginales a la productividad.

OBJETIVOS DESARROLLADOS EN EL PROGRAMA DE MEJORAMIENTO GENÉTICO DE INFOR

1.- Creación y Ampliación de la Base Genética en especies del Género *Eucalyptus*

El primer paso en esta selección depurada ha sido la introducción de colecciones de la distribución natural de distintas especies desde Australia. Esta labor se ha efectuado en ***Eucalyptus globulus*** ssp *globulus*, *E. camaldulensis*, *E. nitens*, *E. delegatensis*, *E. sideroxylon*, *E. cladocalyx* y *E. viminalis*. Para probar el efecto sitio, se han establecido ensayos en distintos lugares, afines con los requerimientos ambientales de las especies. Es así como actualmente existen 31 ensayos de procedencias distribuidos a lo largo del país (Cuadro N°1).

El programa general de mejoramiento genético del ***Eucalyptus*** (Figura N°1) establecido por INFOR se basa en la selección de individuos en poblaciones naturales de la especie, y el posterior establecimiento de poblaciones base (ensayos de procedencias y progenies), las que constituirán el material genético puesto a resguardo y a partir del cual se hacen las pruebas genéticas para las selección de familias o individuos con determinada característica productiva. Estas poblaciones base pueden ser dinámicas en especies como el ***E. globulus***, donde es factible la selección de individuos en plantaciones artificiales (comerciales o ensayos existentes) que enriquecen la gama genética con la adaptabilidad. Las etapas sucesivas son de una selección más estricta a la vez que requieren de una intensificación del trabajo (Creación de Areas Productoras de Semillas) y el desarrollo de técnicas apropiadas de propagación vegetativa (Huertos semilleros clonales, plantaciones clonales, etc.).

El tipo de selección utilizado en este programa corresponde al denominado de Selección Recurrente el cual se basa en la alimentación constante con nuevos genotipos, los que provienen de nuevas selecciones en otras poblaciones, como huertos semilleros de semillas o clonales, individuos generados a partir de polinización controlada, etc. También se incluye el establecimiento de poblaciones con un grado de selección cada vez más elevado que permita obtener una población de producción depurada.

El principal aporte de INFOR lo constituye la adquisición de las colecciones de semillas de las especies involucradas en este programa. En el año 1988 se adquirió una colección de la distribución natural de ***E. globulus*** en Australia (Gardiner and Crawford, 1988), constituida por 215 progenies que involucraban 35 procedencias. A partir de 1989 se establecieron cuatro ensayos de procedencias y progenies (poblaciones base) en cuatro zonas del país a los que se agregaron como testigos progenies de ***E. globulus*** de raza local.

Con posterioridad en el año 1993 se amplió esta base genética de acuerdo a los resultados en los ensayos previamente establecidos. El total de las progenies introducidas señalan a esta base genética como una de las mayores fuera del lugar de origen, Australia. En el Cuadro N°2 se presentan las mejores procedencias de ***E. globulus*** para Chile definidas de acuerdo a los resultados de los primeros ensayos de progenie.

Actualmente en el país las grandes plantaciones que se establecen son para la producción de fibra corta dado que el rango en que varía la densidad de la madera de esta especie es siempre aceptable para estos fines. El uso de la madera como aserrable está más restringido dado que falta un mayor desarrollo de técnicas de aserrío y secado obteniéndose productos de calidad deficiente o de alto costo. Las plantaciones de mayor edad se destinan a la producción de chapas a través del desfoliado y debobinado, técnicas que se encuentran adecuadamente desarrolladas por las empresas forestales.

Por mucho tiempo el cultivo del eucalipto fue considerado de tipo rústico. Sin embargo, actualmente se realizan fuertes inversiones en fertilización, trabajo intensivo del suelo y control de maleza, obteniéndose un alto rendimiento productivo que justifica la inversión realizada. Evaluaciones económicas hechas por INFOR hablan de Tasas Internas de Retorno (TIR) que superan el 16% y pudiendo llegar a 22% en el caso de los mejores sitios. Cabe señalar que estas evaluaciones se realizaron sin considerar el uso de semilla mejorada.

Cuadro 1: *ENSAYOS DE PROGENIE DE MEJORAMIENTO GENÉTICO*

Nº Ensayo	Nombre Predio	Especie	Año Plantación	Superficie (Ha)	Comuna, Región	Latitud	Longitud
1	Tres Arroyos	*E. viminalis*	1993	2,5	Coyahique, XI	45°45'	72°03'
2	El Monte	*E. viminalis*	1993	3,7	Los Lagos, X	39°48'	72°45'
3	Las Totoras	*E. viminalis*	1993	4,1	Collipulli, IX	37°48'	72°29'
4	Agua Amarilla	*E. cladocalyx*	1993	1,0	Los Vilos, IV	31°55'	71°00'
5	Bellavista	*E. cladocalyx*	1993	1,0	Illapel, IV	31°38'	71°10'
6	Agua Amarilla	*E. sideroxylon*	1993	1,0	Los Vilos, IV	31°55'	71°00'
7	Bellavista	*E. sideroxylon*	1993	1,0	Illapel, IV	31°38'	71°10'
8	San Agustín	*E. globulus*	1989	6,5	Cauquenes, VII	35°47'	72°05'
9	San Agustín 2	*E. globulus*	1994	3,0	Cauquenes, VII	35°47'	72°05'
10	Los Hermanos	*E. globulus*	1989	5,5	Los Álamos, VIII	37°41'	73°66'
11	Los Copihues	*E. globulus*	1989	6,4	Paillaco, X	40°01'	73°00'
12	Tanume	*E. globulus*	1991	2,5	Pichilemu, VI	34°13'	71°54'
13	Verdun	*E. globulus*	1994	3,5	Mulchén, VIII	37°50'9"	72°44'59"
14	Pancul	*E. globulus*	1994	4,9	Carahue, IX	38°45'9"	73°07'27"
15	H. Gómez	*E. globulus*	1994	2,5	La Unión, X	40°07'12"	73°06'12"
16	El Bajo	*E. nitens*	1990	2,8	Mañihuales, XI	45°00'	72°20'
17	Esc. Agrícola	*E. nitens*	1992	1,0	Coyahique, XI	45°33'	72°02'
18	El Durazno	*E. nitens*	1991	2,5	S.Carlos, VIII	36°26'	71°35'
19	San Lorenzo	*E. nitens*	1990	4,0	Quilleco, VIII	37°30'	71°45'
20	El Morro	*E. nitens*	1990	5,2	Mulchén,VIII	37°55'	72°00'
21	Vista Alegre	*E. nitens*	1990	4,5	Mafil, X	39°60'	72°50'
22	E. Guillermo	*E. nitens*	1992	1,5	Mañihuales, XI	45°20'	72°10'
23	Coihue Sur	*E. nitens*	1996	3,0	Mulchén, VIII	37°45'	72°06'
24	Las Mellizas	*E. nitens*	1996	2,5	Tucapel, VIII	37°12'	71°54'
25	Taico	*E. nitens*	1996	2,0	Paillaco, X	40°02'	72°35
26	Bayona	*E. delegatensis*	1992	1,4	Lautaro, IX	38°25'	72°00'
27	Longotma	*E. camaldulensis*	1989	5,0	La Ligua, V	32°21'	71°26'
28	Mel-Mel	*E. camaldulensis*	1989	5,0	Casablanca, V	33°32'	71°26'
29	Tantehue	*E. camaldulensis*	1991	2,5	Melipilla, R.M.	33°47'	71°13'
30	La Paila	*E. camaldulensis*	1991	2,0	Lolol, VI	34°43'	71°39'
31	Huinganal	*E. camaldulensis*	1996		Cabrero, VIII		

E. globulus **presenta baja resistencia al frío quedando marginado de ser establecido en extensiones de aptitud forestal localizadas por sobre los 800 msnm. Por ello, en Chile se esta utilizando *E. nitens*, especie de alta productividad (m^3/ha). Con el fin de suplir esta deficiencia de *E. globulus*, en 1989 se introdujo al país una colección de *E. globulus* a partir de progenies ubicadas en lugares de altura en Tasmania y otra de toda la distribución natural de *E. nitens*.**

El esquema de mejoramiento para *E. nitens* se basa en el mismo de *E. globulus* sin embargo la variación estaría en que la base de selección de individuos además de ser volumen y forma de fuste incluirá la característica de densidad de la madera a la edad de rotación, la cual es menor que en el caso de *E. globulus*.

Con posterioridad se amplio la base genética de *E. nitens* (1995), pero ahora restringida sólo a las procedencias que tuvieron los mejores resultados en los ensayos establecidos en 1990 (Cuadro N°3). Bajo este prisma se trajo un mayor número de progenies (familias) para cada procedencia elegida.

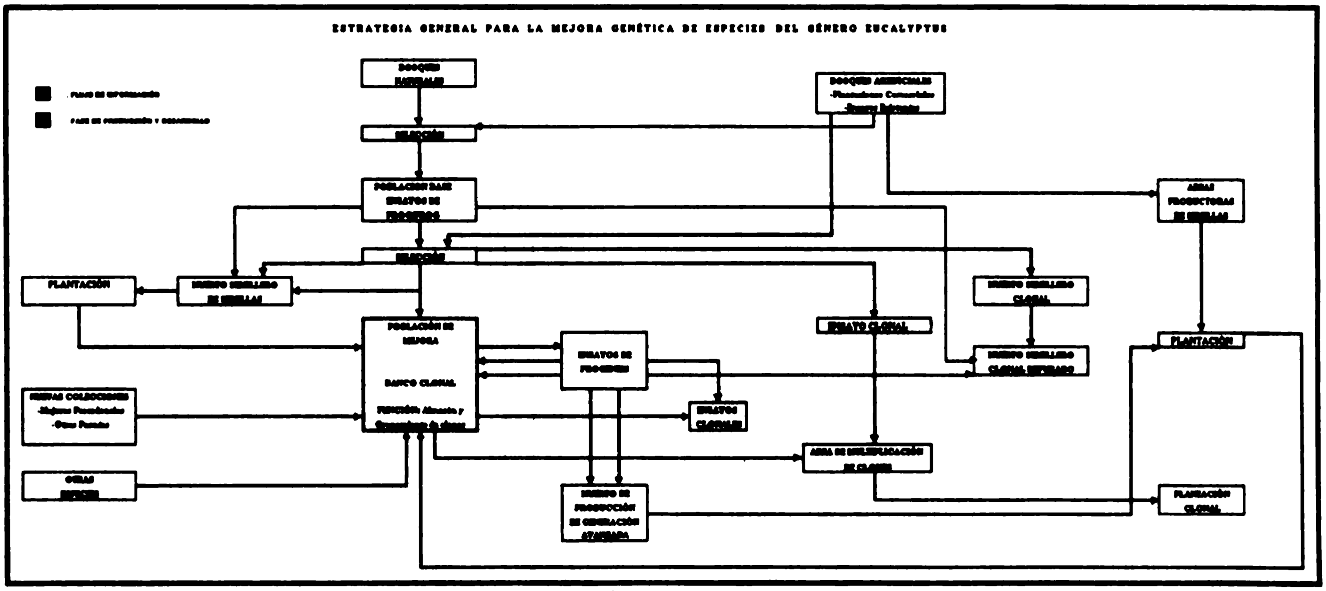


Figura 1: *Diagrama estrategia mejoramiento genético*

Cuadro 2: *Mejores procedencias de E. globulus para Chile*

PROCEDENCIAS	VARIACIÓN	Variación Longitud
Otway Region (Otway and Lorne), VICTORIA	38°25' y 38°49'	143°25' y 143°57'
Cape Barren, TASMANIA	40°21' y 40°26'	148°03' y 148°13'
Flinders Island, TASMANIA	39°45' y 40°16'	147°57' y 148°04'
Geevestone, Dover, Moogara TASMANIA	42°48' y 43°17'	146°46' y 146°59'
Hently River, TASMANIA	41°56'	145°12'
Jeeralang Region TASMANIA	38°22' y 38°34'	146°31' y 146°41
Toora, VICTORIA	38°37'	146°21'
Jericho Region, TASMANIA	42°25'	147°16'
Nugent Region, TASMANIA	42°42' y 42°44'	147°51' y 147°53'
King Island, TASMANIA	39°56' y 40°02'	143°52' y 144°03'

Cuadro 3: *Mejores procedencias de E. nitens para Chile*

Procedencias	Variación Latitud (S)	Variación Longitud (E)
Toorongo Plateau, VICTORIA	37°47' y 37°54'	146°00' y 146°16'
Rubicon, VICTORIA	37°18'	145°49'
Macalister, VICTORIA	37°29'	146°25'
Errinundra SF, VICTORIA	37°13' y 37°15'	148°54' y 149°02'
Tallaganda, NEW SOUTH WALES	35°52' y 36°00'	149°28' y 149°54'
Barrington Tops, NEW SOUTH WALES	31°55'	151°30'

En el programa de mejoramiento genético se introdujeron, además, amplias colecciones de la distribución natural de especies alternativas como son: ***E. camaldulensis***, adaptado a condiciones más áridas al igual que ***E. cladocalyx*** y ***E. sideroxylon***, especies cuyos principal objetivo de producción son recursos dendroenergéticos, forraje, polines, protección y recuperación de áreas degradadas. Por otra parte, también se introdujo ***E. delegatensis*** por ser una especie de buen crecimiento, adaptabilidad a altas pluviometrías y ***E. viminalis***, que se constituye en una de las especies del género con mayor adaptación al frío y con características pulpables interesantes.

Además de las mejores procedencias, fue posible determinar áreas potenciales de crecimiento para las principales especies de eucalipto: ***E. globulus***, ***E. nitens*** y ***E. camaldulensis***. Como ejemplo, en la Figura N°2 se presenta las áreas aptas de plantación para ***E. nitens*** en la VIII Región del país.

2.- Transformación de Ensayos de Procedencias y Progenies en Áreas Productoras de Semillas.

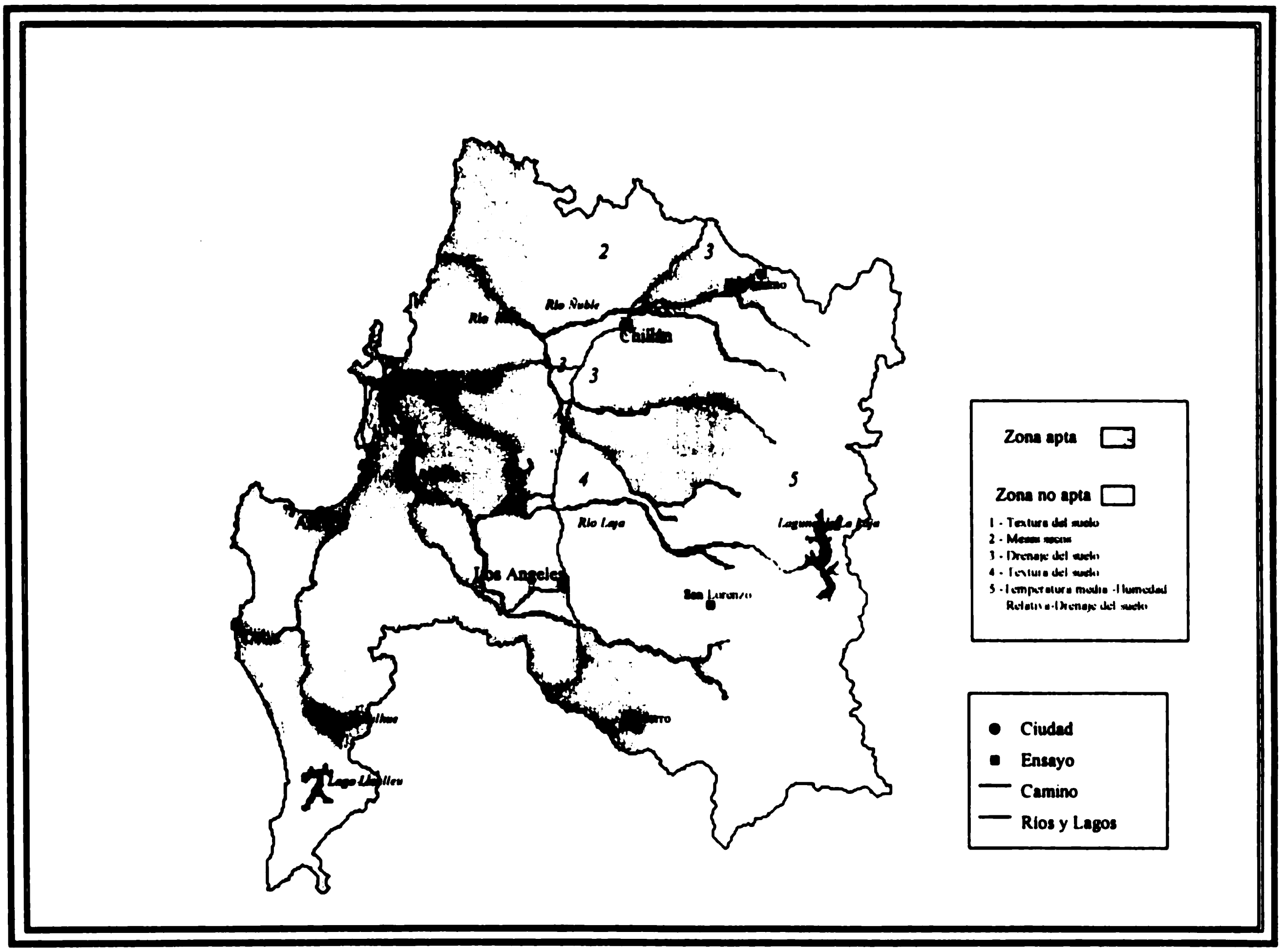
Est técnica se constituye en un método de obtención de semilla mejorada de corto plazo. La formación de áreas productoras es una interesante fuente de ingreso sobretodo de especies cuyo valor de la semilla es alto como el caso de ***E. nitens***. Por otra parte este producto está garantizado al provenir de un organismo de investigación reconocido y que cuenta con la experiencia e infraestructura como para certificar adecuadamente la calidad de germinación y genética de la semilla.

3.- Micropropagación

Meiante la técnica de micropropagación de árboles selectos de los ensayos de progenie se han determinado protocolos de desinfección y producción y elongación de brotes para las especies más atractivas del programa: ***E. globulus***, ***E. nitens*** y ***E. camaldulensis***. La principal dificultad en la aplicación de esta técnica se presentó en la fase de endurecimiento. El protocolo de aclimatación a condiciones de campo ha sido infructuoso hasta el momento.

4.- Macropropagación

La producción masiva de clones de eucaliptos para ser utilizadas en forma operacional en plantaciones aún no es una realidad en Chile. La mayoría de los esfuerzos se concentran en el desarrollo de protocolos que permitan obtener adecuadas tasas de enraizamiento en estacas de individuos seleccionados de ***E. globulus*** y ***E. nitens***, principalmente. Se reconoce que sólo una pequeña proporción de los individuos posee una capacidad de enraizamiento apropiada para la propagación masiva por estacas, trabajándose en la identificación de ellos y en el desarrollo de técnicas de rejuvenecimiento que permitan su adecuada propagación (Ipinza y Gutiérrez, 1992).



<u>Figura 2:</u> *Ensayos con E. nitens (INFOR) en la VIII región y lugares potenciales de plantación de acuerdo a características edafoclimáticas*

ESTABLECIMIENTO DE RODALES

Junto con la investigación sobre procedencias y progenies, el estudio de INFOR acerca de las técnicas de establecimiento a arrojado importantes resultados que han redundado en altas tasas de sobrevivencia inicial (mayores al 95%) e importantes magnitudes de crecimiento en los primeros años. Adecuadas dosis de fertilización, unido al control de la competencia, preparación intensiva del suelo (Subsolado) y una adecuada planta obtenida desde vivero aseguran tasas de retorno cercanas al 18%.

MODELO DE CRECIMIENTO PARA EUCALIPTO

Los modelos de crecimiento y rendimiento se han constituido en una herramienta esencial para la planificación del manejo forestal. En Chile el conocimiento de la Biometría del eucalipto eran de carácter local o extrapolados de situaciones de otros países. Para la modelación del crecimiento de estas especies y su uso en las decisiones de manejo, fue necesario reunir antecedentes a nivel general y específico.

La investigación se basó en: diseño y uso de una red de ensayos, relaciones y modelos para estimar volumen por árbol, hectárea y producto, funciones de ahusamiento y funciones diamétricas, y generación de modelos de crecimiento en área basal, altura dominante, mortalidad y volumen.

Toda la información generada y analizada fue integrada en un modelo de simulación de rendimiento y crecimiento, llamado ***EUCA2.1***, el cual tiene la capacidad de proyectar el crecimiento de varios rodales. Cada rodal se representa por un conjunto de variables, las cuales corresponden a: Altura media dominante, Area basal (m^2/ha), Volumen (m^3/ha), Número de árboles por hectárea, Diámetro cuadrático medio (cm), Crecimiento marginal anual del área basal (m^2/ha/año) y Crecimiento medio anual del área basal (m^2/ha/año).

El objetivo del modelo es cuantificar y proyectar el rendimiento de rodales de eucalipto dadas condiciones iniciales como densidad, área basal y sitio. Los rendimientos volumétricos observados varían entre los 10 a 40 m^3/ha/año a los 10 años de edad.

Algunas limitaciones de la información disponible, hacen evidente la necesidad de aumentar el número y proseguir la medición de las parcelas permanentes, lo que además, será útil en la evaluación y potencial desarrollo posterior del modelo, debido a la sensibilidad de las especies estudiadas a variaciones climáticas y factores de micrositio.

Los datos provienen de parcelas permanentes y ensayos con eucalipto. El número total de parcelas permanentes utilizadas en el análisis asciende a 215, distribuidas sobre una superficie de 1.000 km. de longitud y una extensión latitudinal entre los 33°S y 41°S. Cerca del 80 % de los datos corresponden a ***E. globulus***, y casi la totalidad del resto es ***Eucalyptus nitens***. La base de datos recolecta aproximadamente 36.000 observaciones al año. El rango de validez del modelo se encuentra entre los 3 y 15 años de edad, debido a la escasez de información para edades menores y mayores (Zunino y Ferrando, 1997).

Crecimiento en altura

Se utilizó la información de las parcelas permanentes y ensayos para determinar ecuaciones de crecimiento en altura, basadas en los modelos tradicionales. La información permitió hacer una evaluación general del modelo existente el cual arrojó buenos resultados a pesar del estrecho margen de edades (Figura N°3). Se ha utilizado el modelo de Indice de Sitio desarrollado por García (1995) para ***E. globulus*** y ***E. nitens***:

$$S = 75{,}3 \,\{1 - [1 - (H/75{,}3)^{0{,}863}]^{tc/t}\}^{1/0{,}863} \quad (1)$$

$$H = 75{,}3 \,\{1 - [1 - (S/75{,}3)^{0{,}863}]^{t/tc}\}^{1/0{,}863} \quad (2)$$

Donde :

H = Altura dominante (m), de los 100 árboles mayores por hectárea.
S = Indice de Sitio. Para edad clave de 10 años.
T = Edad en años.
Tc = Edad índice o clave; 10 años.

El sitio (S) esta representado por la altura dominante del rodal a una edad clave determinada (Indice de sitio). Al usar la edad clave de 10 años, que está más cercana a las edades de rotación actuales, y calcular *S* con el modelo (1) para las parcelas permanentes, se obtuvo un rango de Indices de Sitios que abarca mayoritariamente los valores entre 13 a 36 m. Este rango tiende a coincidir con el presentado en una clasificación realizada en Portugal para ***E. globulus*** (Tome *et al.*, 1995). En el Cuadro N°4 se aprecia la clasificación de sitio realizada con la información.

Mortalidad natural

Existe una escasa mortalidad natural, por lo menos bajo los 15 años de edad. Esto siempre y cuando se omitan situaciones anormales, como condiciones climáticas severas (sequías o heladas extremas).

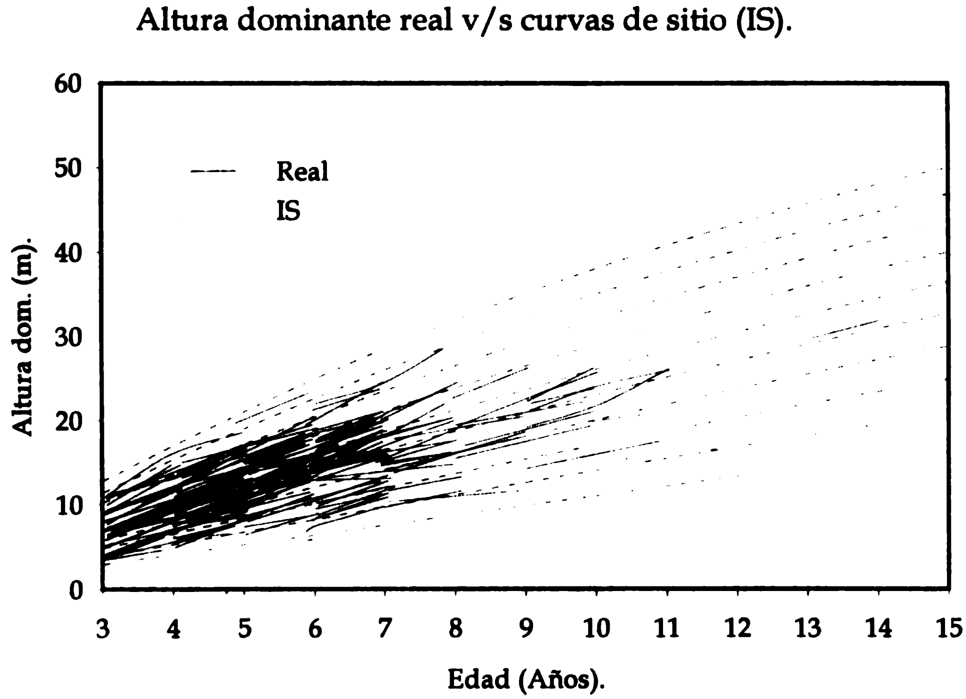


Figura 3: *Series De Crecimiento En Altura Dominante y Altura Dominante v/s Edad.*

Para obtener una aproximación del comportamiento de la mortalidad entre los 3 y 15 años de edad se recurrió, previa depuración, a la información histórica existente en las bases de INFOR para ***E. globulus*** y ***E. nitens***. La estimación de parámetros se llevó a cabo mediante mínimos cuadrados - no lineal. Con estos datos se han probado diversos modelos citados en la literatura, presentando el mejor resultado (Figura N°4) el modelo:

$$N_2 = N_1 (t_2 / t_1)^{B1} \, EXP[(B0 + B2\, S)(t_2 - t_1)] \qquad (3)$$

Donde : N_2 = Número de arboles por hectárea en t_2.

N_1 = Número de arboles por hectárea en t_1.

t_n = Edad del rodal en periodo n.

S = Indice de Sitio (m).

B0, B1, B2 = Parámetros.

Cuadro 4: *Categorías De Indices De Sitio*

Clase de Indice de Sitio (edad clave 10 años)	Rango de altura dominante (m)
I	>32
II	28 - 32
III	24 - 28
IV	20 - 24
V	16 - 20
VI	< 16

Modelo compatible de rendimiento y crecimiento para Area Basal

Se trabajó con varios modelos de área basal analizando su compatibilidad como ecuaciones de rendimiento y de crecimiento, de manera de utilizar al máximo la información disponible de las parcelas permanentes. La estimación de parámetros se llevó a cabo mediante mínimos cuadrados - no lineal.

El modelo seleccionado correspondió a:

$$\mathbf{B = EXP(B0 + B1\ h + B2\ n + B3\ h\ n)} \quad \mathbf{(4)}$$

Donde: n = $100 / \sqrt{(N)}$

H = $1/(H + 1{,}3)$
N = Número de árboles por hectárea.
H = Altura dominante (m), de los 100 árboles mayores por hectárea.
B = Area basal (m^2 / ha).
B0, B1, B2, B3 = Parámetros.

Este modelo fue mejorado incorporando la variable Edad en forma de 1/E (E = Edad en años). Así la adición de esta nueva variable, más las originales, originó el modelo definitivo:

$$\mathbf{B = EXP[B0 + B1\ h + B2\ h\ (1/E) + B3\ n\ (1/E)]} \quad \mathbf{(5)}$$

El desempeño de la ecuación (5) al ser utilizada como modelo de crecimiento (6) corresponde a (Figura N°5):

$$\mathbf{B_2 = B_1\ (1 + \Delta B)} \quad \mathbf{(6)}$$

$$\mathbf{\Delta B = [\ B(2) - B(1)\ ]\ /\ B(1)}$$

Donde : B_2 = Area basal estimada a la edad 2.

B_1 = Area basal real o inicial a la edad 1.
ΔB = Incremento proporcional en área basal calculado con (5).
B(2) = Ecuación (5) evaluada en edad 2, altura 2 y densidad 2 (estimadas).
B(1) = Ecuación (5) evaluada en edad 1, altura 1 y densidad 1 (condiciones iniciales medidas).

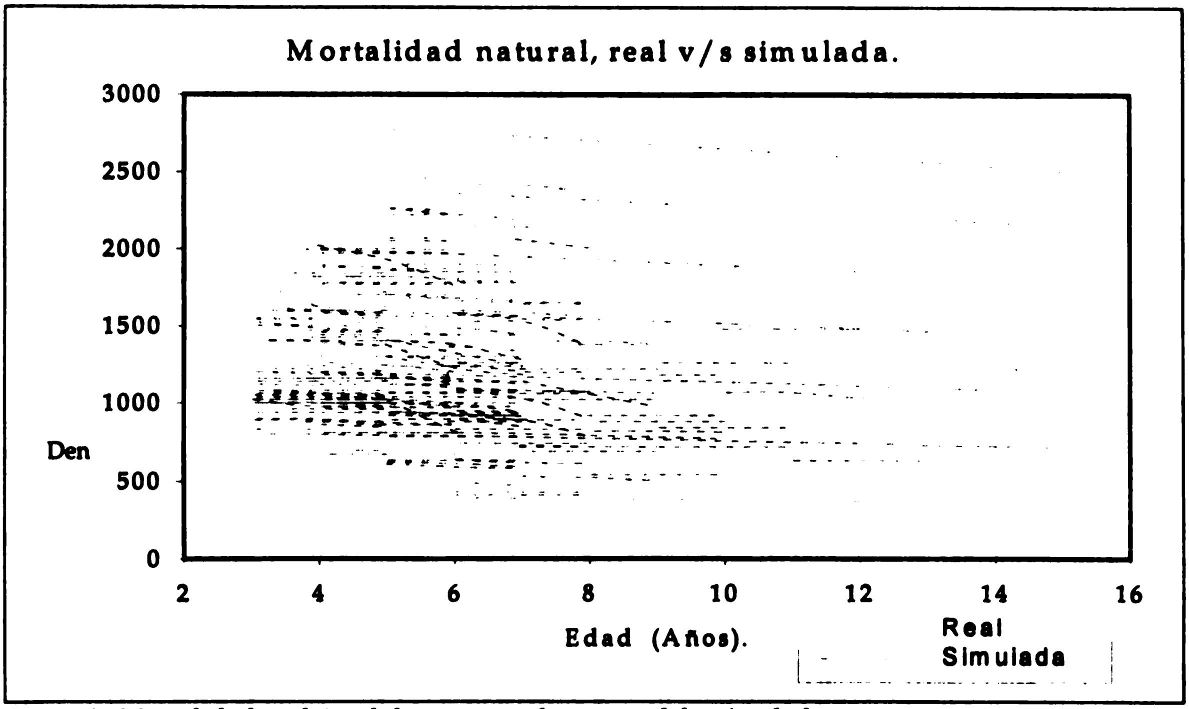


Figura 4: *Mortalidad real (medida) y estimada por modelo v/s edad*

Además, implícitamente se evalúa la capacidad predictora de las ecuaciones de crecimiento en altura (2) y de mortalidad natural (3) dadas condiciones iniciales medidas (edad 1, altura 1, densidad 1).

Modelo de predicción para Volumen

Una amplia variedad de modelos estimadores de volumen del rodal se encuentran en la literatura. Entre ellos se probó el siguiente:

$$V/B = B0 + B1\ H \qquad (7)$$

Donde V = Volumen (m^3 /ha).

B = Area basal (m^2 /ha).

H = Altura dominante (m).

El modelo seleccionado es una modificación de (7), ya que se incorporaron al análisis nuevas variables explicatorias. Así el set de variables iniciales fue el siguiente: H, $H/N^{1/2}$, NH/B, 1/H y H/N (N= N° arb/ha). Los volúmenes por hectárea de cada parcela permanente fueron computados a través de la función de volumen conjunta para árbol individual de ***E. globulus*** y ***E. nitens*** (Bahamóndez *et al.*, 1995). Se trabajó con los datos combinados de las 2 especies, al no presentar diferencias claras entre ambas.

La forma final del modelo se presenta a continuación:

$$V/B = B0 + B1\ H + B2\ (H/\sqrt{N}) + B3\ (1/H) \qquad (8)$$

V = Volumen sólido sin corteza (m^3 ssc/ha), para un índice de utilización de 5 cm.

Al simular el comportamiento del volumen total para diferentes sitios y densidades (dentro de los rangos), se obtienen las curvas expuestas en la Figura N°6, las que se comparan con las series de datos reales.

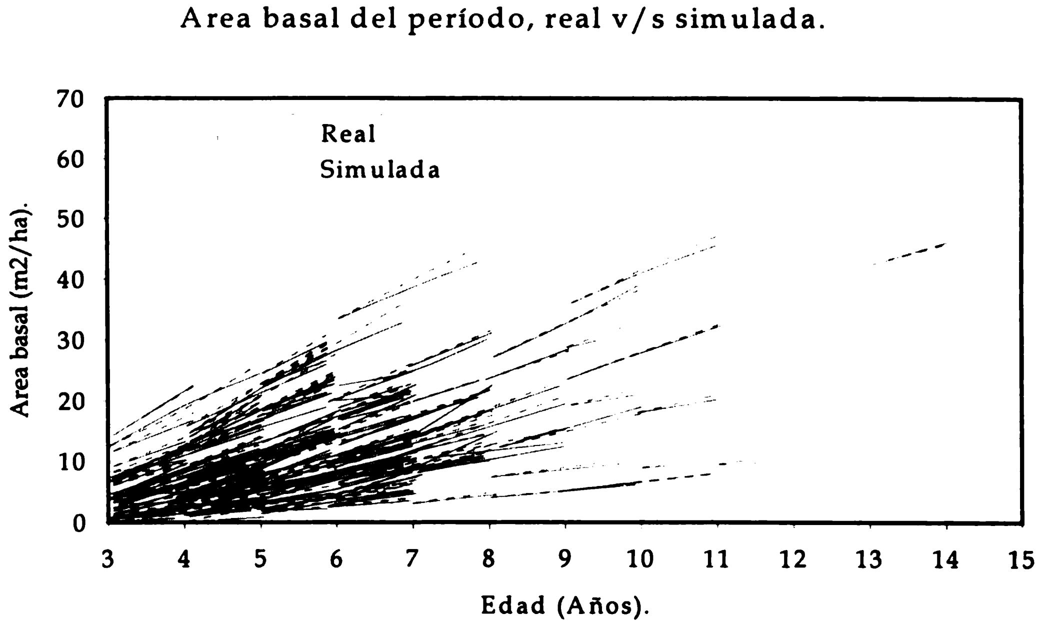


Figura 5: Series de crecimiento real y estimadas por (6) v/s edad.

En el Cuadro N°5 se compara el incremento medio anual (IMA) a los 10 años, entregados por una primera versión del simulador de crecimiento (***EUCA2.1***). Como producto de las simulaciones para el volumen total se han acotado clases para el IMA (incremento medio anual) a los 10 años de edad (Cuadro N°6). De estas se desprende que los incrementos volumétricos medios anuales pueden variar en un amplio rango, afirmación que es corroborada por las observaciones en terreno. Esta característica se ve acentuada por el efecto del micrositio sobre el crecimiento del rodal. En la Figura N°7 se presentan diferentes rendimientos volumétricos estimados (IMA) para varias combinaciones de sitio y densidad.

Cuadro 5: *IMA (m^3/ha/año) Estimado A Los 10 Años.*

Sitio (m)	15	22	30
Arb./ha	***EUCA2.1***	***EUCA2.1***	***EUCA2.1***
1.000	6,0	16,7	32,3
1.500	6,5	18,3	35,3
2.000	6,9	19,3	37,2

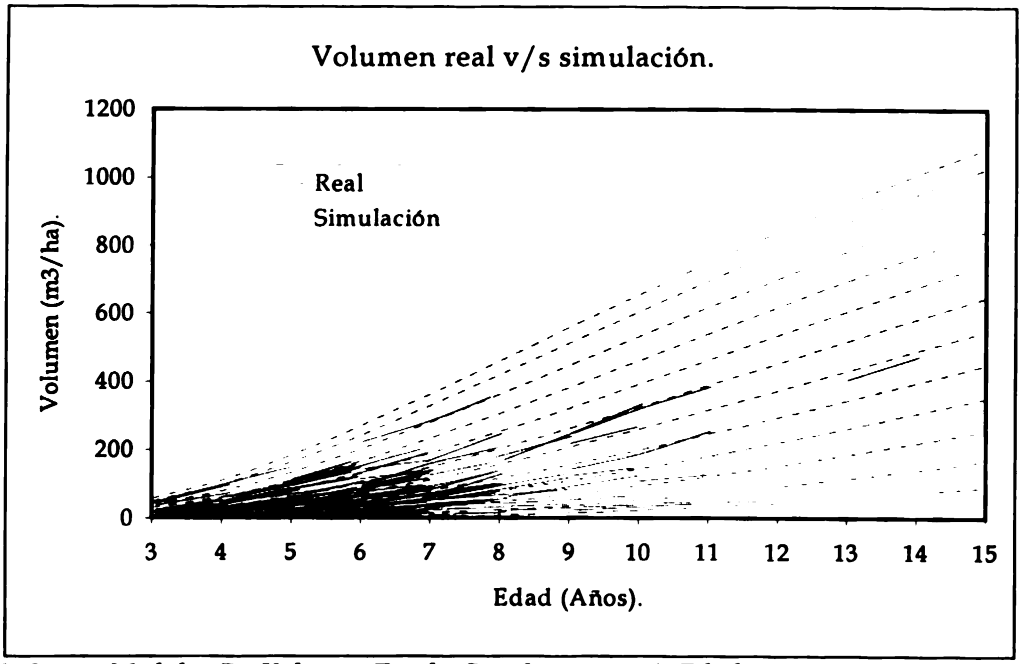


Figura 6: *Series Medidas De Volumen Total y Simulaciones, v/s Edad.*

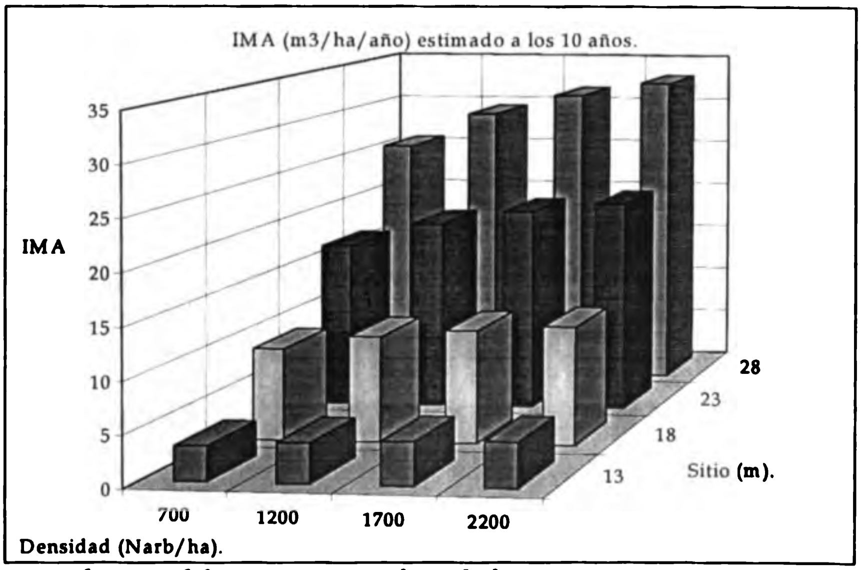


Figura 7: *IMA estimado para diferentes sitios y densidades.*

Cuadro 6: *Clases De IMA (m^3/ha/año) Estimado A Los 10 Años.*

Clase de IMA	(m^3/ha/año)
I	>40
II	30 - 40
III	20 - 30
IV	10 - 20
V	<10

Simulador de Rendimiento y Crecimiento

En la Figura N°8 se presenta el simulador de eucalipto generado por INFOR, el que integra el conjunto de modelos desarrollados, mientras que en la Figura N°9 se expone una salida del simulador con las variables que describen el rodal.

Zonas de Isocrecimiento

Para la definición de las zonas potenciales de crecimiento, se identificaron los principales requerimientos de cada una de las especies, su tasa de crecimiento así como las características edáficas y climáticas de la zona de estudio. Los antecedentes básicos que se utilizaron son los proporcionados por los ensayos instalados, los que se complementaron con datos recopilados bibliográficamente. Se ha definido a los 10 años como la edad base del estudio para eucalipto, (Índice de Sitio) por lo que a esa edad se ha proyectado la información de crecimiento y rendimiento reunida, por región y por especie, con el objetivo de determinar, en combinación con las características edafoclimáticas de cada zona, las zonas de igual crecimiento para eucalipto.

En la fase final del estudio se realizaron todas las correcciones de crecimiento derivadas de la temporada de mediciones del año 1997, cuya información, más la recopilada durante 1995 y 1996, permitió el reajuste de los modelos utilizados y la nueva proyección a los 10 años requerida en relación con los volúmenes producidos por las plantaciones de eucalipto. Luego de este trabajo se relacionó las zonas edafoclimáticas y el crecimiento proyectado (Pinilla y Ferrando, 1997). En la Figura N°10 se presenta un ejemplo de las zonas de isocrecimiento definidas por el crecimiento observado y las áreas edafoclimáticas.

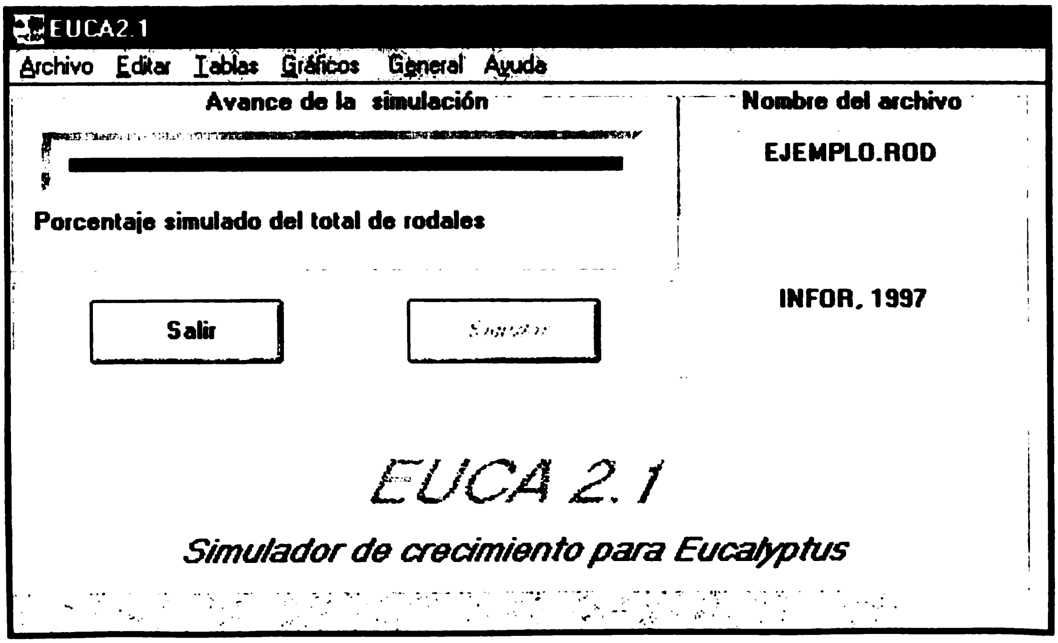


Figura 8: *Simulador De Crecimiento (EUCA2.1)*

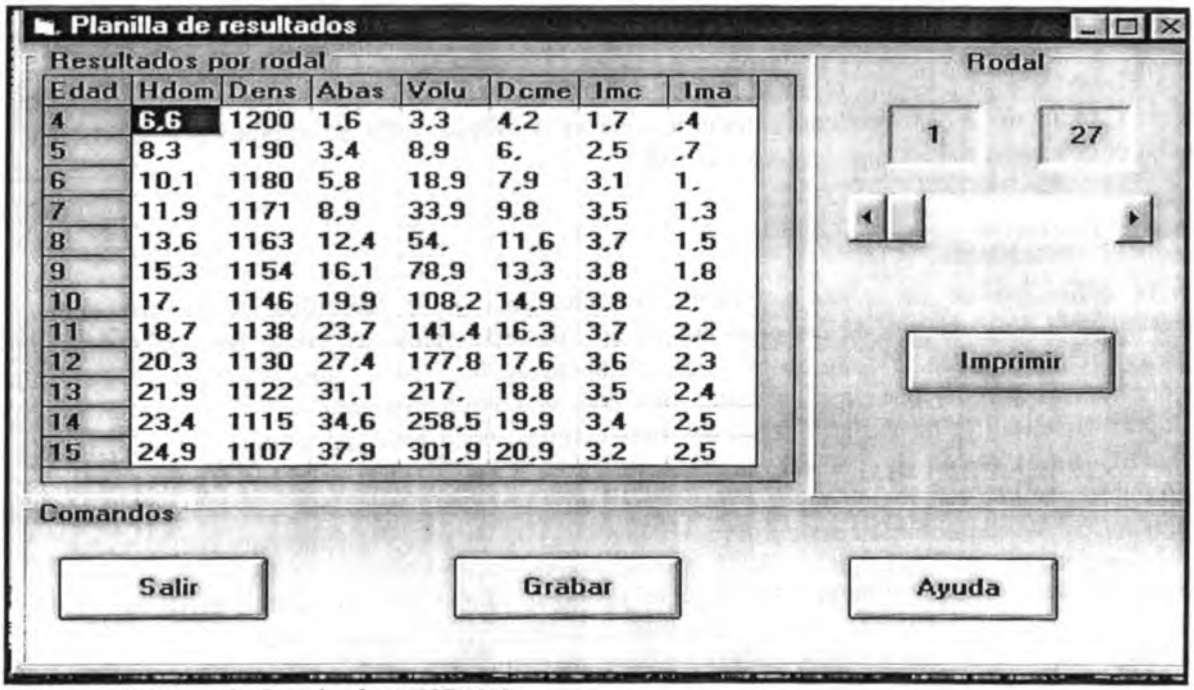


Figura 9: *Ejemplo Resultados EUCA2.1*

Algunos Alcances Sobre El Modelo De Crecimiento Desarrollado

Se plantea que en principio, como requerimiento de información para la modelación del crecimiento, bastaría con pares de mediciones separadas por intervalos de tiempo en distintas parcelas, cubriendo un rango de edades, densidades y calidades de sitio (García; 1994).

Sin embargo, también se afirma que sería deseable tener 3 o más mediciones sucesivas para comprobar su consistencia, detectar errores y los efectos por variaciones climáticas extremas, lo que requiere abarcar un cierto número de años para obtener resultados representativos.

Todo lo mencionado con anterioridad hace evidente la necesidad de efectuar nuevas mediciones en las parcelas permanentes, abarcando y reforzando el rango de edades entre 8 y 15 años, que actualmente presenta una escasez de observaciones. También se lograría una evaluación más completa de las ecuaciones de crecimiento en altura (Sitio).

Independiente de las falencias o limitantes en la información de que se disponga para la producción de un modelo de crecimiento, las proyecciones que se realicen con este deben ser conservadoras. Esto es importante en especies como ***Eucalyptus***, que ha demostrado ser sensible al efecto micrositio, produciéndoce diferencias de crecimiento en puntos separados por pequeñas distancias, lo que dificulta el estudio para determinar zonas de crecimiento, requiriendo de un número mayor de parcelas permanentes que las actualmente disponibles.

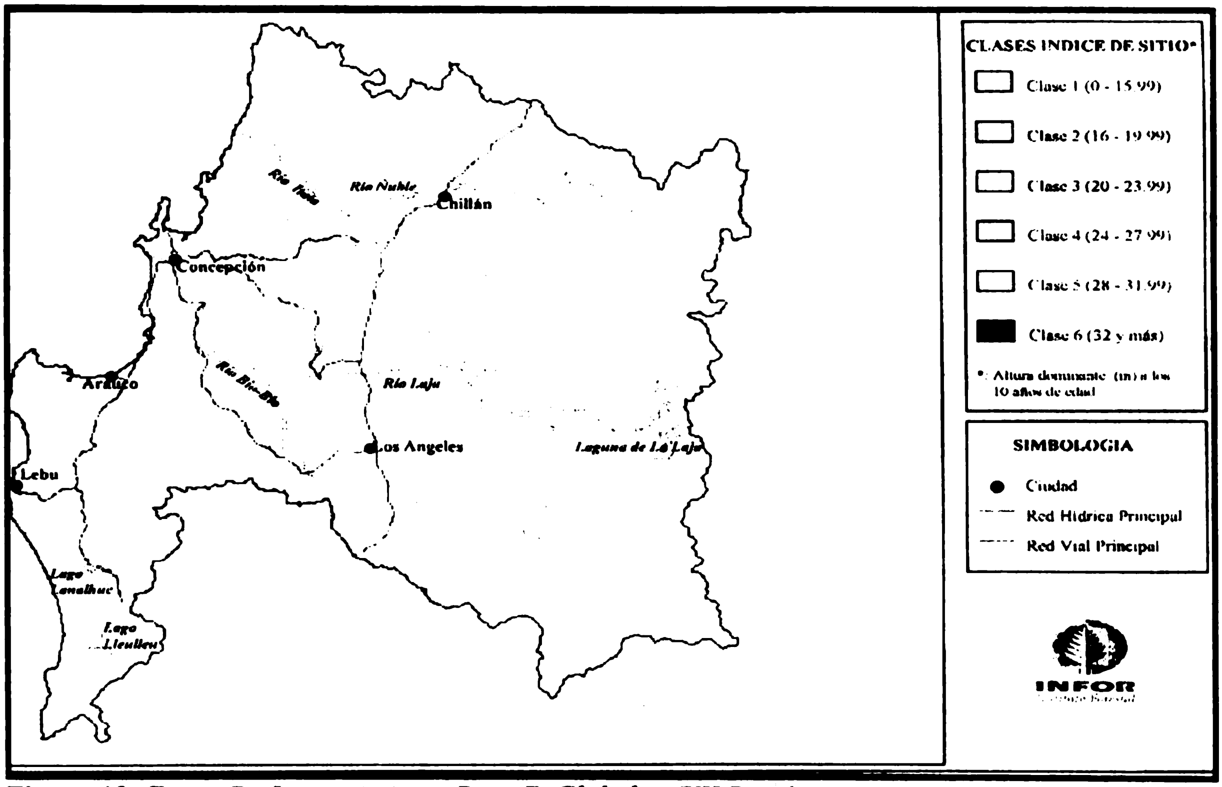


Figura 10: *Zonas De Isocrecimiento Para E. Globulus (VII Región)*

CONCLUSIONES

- Existen diferencias estadísticamente significativas de crecimiento y supervivencia entre procedencias y progenies de eucaliptos establecidos en Chile, lo que representa un antecedente básico para optimizar el uso de estas especies.

- La definición de especies como las mejores procedencias asociadas a ellas permite incorporar a la producción terrenos marginales y llevar a un potencial máximo de productividad de los mejores sitios.

- Los programas de mejoramiento genético han contribuido al desarrollo tecnológico del país, al generar una serie de innovaciones tecnológicas que tiene un efecto multiplicador importante.

- El uso de semilla con algún grado de mejora es probable que afecte positivamente la tasa de plantación con las especies del género *Eucalyptus*.

- En la mayoría de los casos de las especies de *Eucalyptus*, para el éxito de las forestaciones en Chile, es fundamental emplear técnicas intensivas de establecimiento y las procedencias adecuadas con capacidad de adaptación a los sitios.

- Los ensayos de establecimiento deben ser usados, además, en la modelación de la función de inicialización del modelo de crecimiento, es decir, entre los 0 y 3 años. Esta modelación debe relacionar el crecimiento inicial con variables del sitio, geográficas, topográficas y otras de similar orden, con el objetivo de generar las variables inicializadoras del modelo de crecimiento (área basal, altura dominante, índice de sitio, etc.).

- Se requiere aumentar en cantidad y calidad la red de parcelas permanentes y de los distintos tipos de ensayos, junto con ello el número de mediciones.

- Es aconsejable generar un modelo de crecimiento y rendimiento separado para ***E. globulus*** y ***E. nitens***, dadas las distintas características de crecimiento.

- El modelo de crecimiento y rendimiento debería ser utilizado en simular distintas combinaciones de densidad, rendimiento y costos asociados para determinar densidades óptimas para eucalipto.

- Desde las parcelas permanentes es posible establecer ciertas relaciones funcionales que pueden ser utilizadas para obtener tendencias desde los ensayos de genética, y con ello determinar si existe concordancia entre variables de crecimiento y rendimiento y el ranking de progenies existente para ***E. globulus*** y ***E. nitens***.

- Se debe investigar, de acuerdo con la información generada desde los ensayos de genética, si la variable de orden genético se debe incorporar al modelo de crecimiento y rendimiento, o si bien, es un factor importante al momento de inicializar el modelo (área basal, altura dominante, índice de sitio, densidad, Progenie?).

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ANEXO N°1

Ensayos de introducción de especies con *Eucalyptus sp.* (Fuente: INFOR (1986).)

Especies Ensayadas	DAP (cm)	Altura (m)	Densidad (arb/ha)	AB (m^2/ha)	Volumen (m^3/ha)	IMA (m^3/ha/año)	Edad (años)	Ensayo	Unidad Edafo-climática	Precip. (mm)	N° meses secos
E. camaldulensis	9,5	5,6	370	2,4			15	Fray Jorge	Coquimbo	115	>9
E. camaldulensis	15,3	11,2	266	5,3			15	Peralillo	Choapa	250	9
E. camaldulensis	15,2	9,7	962	18,7			15	Longotoma	Zapallar	330	7
E. camaldulensis	20,6	12,1	696	24,9			10	Peñuelas	Rapel-Talca	>500-700	6
E. camaldulensis	15,9	11,5	710	15,5			15	Santa Marta	Rapel-Talca	>500-700	6
E. cladocalyx	8,9	4,9	370	2,4			15	Fray Jorge	Coquimbo	115	>9
E. cladocalyx	10,5	8,0	281	2,2			15	Peralillo	Choapa	250	9
E. cladocalyx	20,6	14,1	60,7	17,9			15	Longotoma	Zapallar	330	7
E. cladocalyx	15,8	14,8	311	4,7			15	Colenguado	Rapel-Talca	350-500	6
E. delegatensis	22,0	30,0	1467		729	49	15	Leonera	Concepción	1500-2000	2 a 3
E. delegatensis	18,6	17,5	1700		445	30	15	Santa Ana	Concepción	700-1000	3 a 5
E. delegatensis	20,6	21,0	1950		749	50	15	Antiquina	Arauco	1200-2000	1 a 2
E. delegatensis	22,0	24,1	1700		760	51	15	San Antonio de Loncoche	Los Lagos	1500-2000	0

Especies Ensayadas	DAP (cm)	Altura (m)	Densidad (arb/ha)	AB (m^2/ha)	Volumen (m^3/ha)	IMA (m^3/ha/año)	Edad (años)	Ensayo	Unidad Edafo-climática	Precip. (mm)	N° meses secos
E. delegatensis	30,0	16,8	766		564	38	15	Llancacura	Valdivia	2000-2500	0
E. delegatensis	35,0	24,4	933		857	43	20	Trafún	Cordillera Sur	4000-5000	0
E. globulus* ssp *bicostata	16,1	9,1	118	2,5			15	Peralillo	Choapa	250	9
E. globulus* ssp *bicostata	19,4	12,2	636	20,8			15	Peñuelas	Rapel-Talca	>500-700	6
E. globulus* ssp *bicostata	12,2	11,2	755	9,4			10	Santa Marta	Rapel-Talca	>500-700	6
E. globulus* ssp *globulus	21,0	13,6	577	20,5			15	Longotoma	Zapallar	330	7
E. globulus* ssp *globulus	24,6	15,1	503	26,0			15	Peñuelas	Rapel-Talca	>500-700	6
E. globulus* ssp *globulus	16,1	16,4	821	17,6			15	Santa Marta	Rapel-Talca	>500-700	6
E. globulus* ssp *globulus	14,3	17,2	1933		208	13	16	San Antonio de Petrel	Paredones	>700	6 a 7
E. globulus* ssp *globulus	17,5	23,1	1533		310	19	16	Las Cañas	Constitución	1034	5
E. globulus* ssp *globulus	15,7	21,6	1900		414	28	15	Leonera	Concepción	1500-2000	2 a 3
E. globulus* ssp *globulus	17,3	15,3	1533		301	20	15	Santa Ana	Concepción	700-1000	3 a 5
E. globulus* ssp *globulus	20,5	21,3	2000		664	44	15	Antiquina	Arauco	1200-2000	1 a 2
E. globulus* ssp *globulus	21,0	20,6	967		341	23	15	San Antonio de Loncoche	Los Lagos	1500-2000	0
E. globulus* ssp *globulus	18,0	22,3	1297		363	28	16	Llancacura	Valdivia	2000-2500	0
E. nitens	19,3	18,4	2200		659	41,2	16	San Antonio de Petrel	Paredones	>700	6 a 7
E. nitens	25,0	23,5	1400		872	58	15	Leonera	Concepción	1500-2000	2 a 3
E. nitens	20,9	18,1	2133		767	51	15	Santa Ana	Concepción	700-1000	3 a 5
E. nitens	23,7	22,9	2166		1152	77	15	Antiquina	Arauco	1200-2000	1 a 2
E. regnans	19,3	20,0	1533		464	29	16	San Antonio de Petrel	Paredones	>700	6 a 7
E. regnans	19,3	25,2	1467		460	29	16	Las Cañas	Constitución	1034	5
E. regnans	23,4	32,9	1333		775	52	15	Leonera	Concepción	1500-2000	2 a 3
E. regnans	19,0	21,3	1533		393	26	15	Santa Ana	Concepción	700-1000	3 a 5
E. regnans	22,3	23,3	2200		940	63	15	Antiquina	Arauco	1200-2000	1 a 2
E. regnans	23,0	15,5	800		237	16	15	San Antonio de Loncoche	Los Lagos	1500-2000	0
E. regnans	18,0	19,9	1900		524	33	16	Llancacura	Valdivia	2000-2500	0
E. regnans	18,0	15,4	1233		277	18	15	Trafún	Cordillera Sur	4000-5000	0
E. sideroxylon	13,8	6,4	370	6,3			15	Longotoma	Zapallar	330	7
E. viminalis	15,0	15,7	1367		207	13	16	Llancacura	Valdivia	2000-2500	0

ASSESSMENT AND MONITORING OF VILLAGE FOREST RESOURCES IN BANGLADESH

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ABSTRACT

The area of village forest (0.27 million hectare) is very limited in comparison with government forest land (2.14 million hectare). But the village woodlot area contributes 85% of the total consumption and the remaining 15% is contributed by government forest land. Need for correct assessment and monitoring is discussed. The main objective of this paper is to recommend appropriate sampling design for correct assessment of village forest resources in Bangladesh. A case study was undertaken in the district of Chittagong located at the south-east corner of Bangladesh. A study population of 900 households was formed consisting of 14 rural thanas in the district. The seven parameters defined under five variables were calculated for complete enumeration. The parameters were estimated through Cluster Sampling, Two Stage Sampling and Stratified Two Stage Sampling (Self-Weighted) taking 250 sample households in each method. The enumerated values and the estimated values were computed for total homestead area, total area of compact tree gardens, total volume of trees, total volume of compact trees, total number of bamboos, volume of compact trees per hectare and number of households with bamboo plantations. The estimates were compared with the enumerated values on the basis of percentage standard error, percentage accuracy, percentage bias and 95% confidence interval. Stratified Two Stage Sampling (Self-Weighted) was found to be a suitable technique and was recommended to apply as field sampling design for correct assessment of village forest resources. A continuous monitoring system was also suggested.

INTRODUCTION

Bangladesh has 2.14 million ha land under Government forest and 0.27 million ha land under village forest. These two forest areas are about 16% of total land of the country. However, only 0.93 million ha (6.5%) is under tree cover (Anon 1989). The maximum village forest resources (75%) are in the northern and southern regions of the country (Davidson 1984). The village woodlot is normally a mixture of fruit trees, the smaller trees, the canes, the bamboos and the shrubs. The trees are not only planted for timber and fuelwood production, but also for food, fodder and other uses in the village communities.

It is known that the village woodlot area being about one-tenth of Government forest area, supplies bulk of sawn timber, firewood and bamboo to the nation. A village forest inventory was conducted and the contribution of sawlog, fuelwood and bamboo was estimated as 48%, 70-80% and 70-80% respectively (Hammermaster 1981). A Stratified Two Stage Sampling was followed for the purpose. Douglus (1982) estimated the contribution of the same resources as 85%, 90%, and 90% respectively using Stratified Three Stage (Self-Weighted) Sampling. Bangladesh Bureau of Statistics (BBS) (1990) obtained the contribution of village woodlot as 85%. BBS followed

Stratified Two Stage Systematic Sampling. It is clear that the requirement of wood and bamboo is largely met up from village forest resources.

Village woodlot plays a very important role in meeting up the country. It is necessary to get an idea on present stocking, species composition, cropping pattern, planting and harvesting rate and land use system, etc., of village woodlot before undertaking an extensive rural forestry sector planning. But no systematic and detailed investigation was made, except Village Forest Inventory conducted in 1981 on the resources. Most of the estimates were not supported by statistical accuracy and precision. The difference in estimation might have occurred mainly due to the choice of sampling method. The variation due to sampling method may be avoided and a search for appropriate sampling design is necessary for accurate and precise estimates. Without appropriate sampling method proper assessment and continuous monitoring of the resource are not possible. It is, therefore, decided to choose Cluster Sampling, Two Stage Sampling and Stratified Two Stage Sampling for field testing. It is intended to recommend a suitable sampling design out of these sampling designs as a field sampling technique in assessing and continuous monitoring of village forest resources in Bangladesh.

METHODS

The rural areas (14 rural thanas) of Chittagong district was considered as the study area. Chittagong district is one of 64 districts in Bangladesh. It has, however, almost similar type of homestead condition, household occupation, home garden with tree and bamboo plantation, etc. as in other rural areas in the country.

A target population was formed in the study area. A preliminary survey was conducted with a sample of 45 households. A field sheet containing homestead area, compact tree garden area, diameter at breast height, height measurement of trees in both compact and scattered areas, number of bamboos with culms, general information, economic status, etc., of a household was developed. A total of 11 major tree and 3 common bamboo species were selected for data collection. A number of many minor tree species was also grouped as others. Similarly a number of a few uncommon bamboo species was grouped as others.

A total of 7 parameters and 5 variables were considered for the study. The seven parameters of total homestead area (ha), total area (ha) of compact tree garden, total volume (m^3) of trees, total volume (m^3) of compact trees, total number of bamboos, volume (m^3) of compact trees per ha and number of households with bamboo plantation were considered. The five variables of area of compact tree garden (x_2), homestead area (x_4), volume of standing trees (y_2), volume of standing compact trees (y_3) and number of standing bamboos (y_4) of a household were also considered.

The target population of 900 households was estimated by a typical formula (Chacko 1955) on the basis of variable y_2 with 12% margin of error. Homestead area and area under compact tree garden of a household were measured by a long tape in ha and recorded in the field sheet. The diameter at breast height (dbh) measurement of all standing trees (dbh larger than 20 cm) except narikel (*Cocos nucifera*) and tal (*Borassus fiabellfer*) was taken by diameter tape. Volume of all trees were estimated by local volume tables (Aleem 1981; Islam 1984; Islam 1988). A total of 22081 trees and a total of 53229 bamboos of selected species were tallied and recorded in the field sheet. The summary of basic data of target population is presented in table 1.

The five variables are generated through computer. The complete enumeration is carried out and the seven parameters are calculated. Cluster Sampling, Two Stage Sampling and Stratified Two Stage Sampling (Self-Weighted) were chosen for field testing in order to recommend appropriate sampling design. The chosen sampling designs were applied on the target population for estimating the parameters. Stratification was done on the basis of location, land use system and homestead wood and bamboo resources so that each stratum was internally homogeneous. The 14 rural thanas were thus stratified as stratum-I (Mirsarai + Sitakunda), stratum-II (Sandwip), stratum-III (Hathazari + Fatikchari), stratum-IV (Rowzan + Rangunia), stratum-V (Anwara + Patiya + Boalkhali), stratum-VI (Satkania + Lohagora), stratum-VII (Banskhali + Chandonaish). The 22 villages and 900 households were distributed among the 7 strata. A sample of 250 households was considered to estimate the parameters by the chosen sampling designs. The population total and ratio were estimated by the formula of total estimate and ratio estimate (Obaidullah 1980). The population proportion was estimated by the formula of proportion estimate (Islam 1994). The study is to compare the estimates done by chosen sampling designs with the enumerated values of the parameters in respect of percentage standard error (%SE), percentage accuracy (%AC), percentage bias (%bias) and 95% confidence interval. The cost of the survey was not considered in the study. The percentage standard error of the estimate was estimated by (SE/estimate) 100. Similarly the percentage bias was estimated. The percentage accuracy was estimated by 100–{(population value – estimate)population value}100. The 95% confidence internal was estimated by usual formula. The sample of 14 villages (600 households) and 250 households selected randomly from seven strata were considered as first stage and second stage units respectively.

Table 1: *The summary of basic data of target population (area in ha.)*

Thana Name	House holds (No)	Agri-culture Area	Com pact Garden Area	Bam-boo Area	Home stead Area	Total Area	% Com act Are	All Trees (dbh> 20cm)	Bam-boo (No)	Clumps (NO)	Households % with Bamboo Plantation
1	2	3	4	5	6	7	8	9	10	11	12
Mirsarai & Sitakunda	143	83.905	9.693	0.599	19.929	114.126	8.49	3485	6046	134	45%
Sandwip	117	59.968	9.098	1.598	8.525	79.189	11.49	3000	15324	188	71%
Hathazari & Fatikchari	144	82.955	7.528	0.204	11.997	102.684	7.33	3876	3934	71	33%
Rangunia & Rawzan	128	86.509	5.793	0.168	10.174	102.644	5.64	2848	1750	56	29%
Anwara,Patiya&Boalkha	145	115.305	6.41	0.409	29.902	152.026	4.22	3734	6902	165	54%
Satkania & Lohagara	89	53.157	4.087	0.16	6.238	63.642	6.41	1680	2711	61	47%
Banshkhali & Chandanaish	134	96.093	6.405	0.334	10.041	112.873	5.67	3458	16562	91	38%
G. Total	900	577.892	49.014	3.472	96.806	727.184	7.04	22081	53229	766	45%

Table 2: *The results of complete enumeration*

Sl.No.	Parameter	Total	Mean	SD	CV
1.	Total area(ha) of compact tree garden (Σx_2)	97	0.05	0.07	1.33
2.	Total homestead area (ha) (Σx_4)	49	0.11	0.73	6.76
3.	Total volume (m^3) of trees (Σy_2)	9490	10.54	11.57	1.09
4.	Total volume (m^3) of compact trees (Σy_3)	8308	9.23	11.04	1.19
5.	Total number of bamboos (Σy_4)	53229	59.14	254.69	4.31
6.	Volume (m^3) of compact trees per ha ($R_1 = \Sigma y_3 / \Sigma x_2$)	170 *	-	-	-
7.	Number of households with bamboo plantation (NP=N_1)	407	-	-	-

* Indicates ratio.

RESULTS AND DISCUSSION

Complete enumeration was carried out and the mean, the standard deviation (SD) and the coefficient of variation (CV) of each of the variables were calculated for the target population (Table 2).

Average area of both compact tree garden (0.05 ha) and homestead land (0.11 ha) showed very small figure with high coefficients of variation (1.33 and 6.75). The averages for volume of standing trees (10.54 m^3) and number of bamboos (59) are reasonable with also high coefficients of variation (1.11 and 4.31). Here the standard deviations of all variables are larger than the means. It is an indication that the target population was heterogeneous and the stratification was justified. Total area (ha) of compact trees was about half of total homestead area (ha). It means that village people had limited areas for compact tree plantation. Volume(m^3) of compact trees per ha was not promising because of perhaps two reasons. One reason was that the smaller trees (less than 20 cm dbh) were not tallied. Another reason could be of dense spacing. Total number of bamboos and number of households with bamboo plantation were not encouraging. Only 407 households out of 900 were interested to plant bamboos. The village people had limited bamboo plantation in comparison with their daily demand. The target population was actually a variable population. Table 2. gives the present situation of wood and bamboo resources in Chittagong which shows an overall picture of village forest resources in Bangladesh.

The seven parameters were estimated on the basis of 250 sample households using Cluster Sampling, Two Stage Sampling and Stratified Two Stage Sampling (Self-Weighted). The total, ratio and proportion estimates of the parameters with corresponding percentage standard error, percentage accuracy and percentage bias are presented in Table 3.

Table 3: *Comparison of Cluster Sampling, Two Stage Sampling and Stratified Two Stage Sampling (Self-Weighted) with Complete Enumeration.*

Sl. No	Parameter	True value	Cluster			Two stage			Stratified Two stage		
			Est.	%Ac	%SE	Est.	%Ac	%SE	Est.	%Ac	%SE
1.	Σx_2	49	52.2	94	10	42.5	87	6	49.6	99	3
2.	Σx_4	97	167.3	27	34	63.4	65	8	78.4	81	2
3.	Σy_2	9490	8668.8	91	6	9076.5	96	6	9432.2	99	3
4.	Σy_3	8308	7614.1	92	6	7707.8	93	7	8182.5	98	3
5.	Σy_4	53229	59242.0	89	41	35261	16	17	53546.0	99	4
6.	R_1	170	179.3	1.5*	15	181.5	0.3*	6	164.9	0.3*	10
7.	NP	407	441.0	92	16	421.0	97	8	413.0	99	7

* Indicates % bias.

It is observed that the percentage accuracy of all estimates except estimate of R1 are increased in Stratified Two Stage Sampling (Self-Weighted) compared to Cluster Sampling and Two Stage Sampling. It indicates that the estimated values are very close to the tree values. The percentage bias of the estimate of R1 is also improved and negligible in the same sampling design. The percentage standard errors of all estimates are decreased in comparison with other two sampling designs except R1. The estimate of R1 has a standard error 10 which may be accepted in the present homestead condition of Chittagong. All population values (true values) lie within the intervals estimated at 95% confidence except the value of x_4. The value of x_4 does not lie between the estimated interval. It may lie between another 95% confidence internal estimated by a separate sample. In view of all these measures of reliability of the estimates Stratified Two Stage Sampling (Self-Weighted) yields reliable estimates.

After selecting the suitable sampling design, it is important to discuss about method of monitoring village forest resources. A continuous monitoring system is required for planning purposes. It needs remeasurement data about felling and growth of village forest at every certain period after first measurement is done by a suitable sampling design. The Double Sampling technique may be advantageously used to estimate growing stock at a subsequent period of 5 years or on two or more successive occasions after the first initial survey is done. It is possible to couple Double Sampling with selected Stratified Two Stage Sampling (Self-Weighted) for economy and enhancing the accuracy of the estimates. Two stage sample of villages and households may be taken for the estimation of the effective households having homestead tree resources and a sub-sample of households may be taken for estimating growing stock. In estimating the change in growing stock, it is suggested to take 10% sample of original samples at the second occasion at 5 years interval of time. In this way Stratified Two Stage Sampling (Self-Weighted) design may be used for both assessment and monitoring of present village forest resources.

ASSESSMENT AND MONITORING OF VILLAGE FOREST RESOURCES IN BANGLADESH

A HOUSEHOLD IS A GROUP OF FAMILY MEMBERS.
A PARA IS A GROUP OF HOUSEHOLDS.
A VILLAGE IS A GROUP OF PARAS.
AN UNION IS A GROUP OF VILLAGES.
A THANA IS A GROUP OF UNIONS.
A DISTRICT IS A GROUP OF THANAS.
A DIVISION IS A GROUP OF DISTRICTS.

CHITTAGONG DISTRICT STATISTICS:

	DISTRICT (NOS)	THANA (NOS)	UNION (NOS)	VILLAGE (NOS)	HOUSEHOLD (MILL NOS)	POPULATION (MILL NOS)	AREA (MILL HA)
CHITTAGONG	1	14	194	1290	0.58	5.29	0.52
BANGLADESH	64	460	4451	85650	17.60	108.80	14.39

ASSESSMENT AND MONITORING OF VILLAGE FOREST RESOURCES IN BANGLADESH

DISTRIBUTION OF SAMPLE VILLAGES AND SAMPLE HOUSEHOLDS AND SELF-WEIGHTING NATURE IN STRATIFIED TWO STAGE SAMPLING.

Stratum	Total Vills* (N_h)	Total HH* in N_h	Total Vills Selected n_h	fa $= \frac{n_h}{N_h}$	Total HH in n_h (M_h)	Total HH Selected (m_h)	fb $= \frac{m_h}{M_h}$	f=fa. Fb
I	3	143	2	0.6667	79	31	0.3924	0.2616
II	3	117	2	0.6667	87	35	0.4023	0.2682
III	3	144	2	0.6667	97	39	0.4021	0.2681
IV	3	128	2	0.6667	85	34	0.4000	0.2667
V	4	145	2	0.5000	86	45	0.5233	0.2616
VI	3	89	2	0.6667	72	29	0.4028	0.2685
VII	3	134	2	0.6667	94	37	0.3936	0.2624
TOTAL	22	900	14		600	250		

* **Vills and HH mean vilalges and households respectively**

The selected sampling design may be easily applied in the field. It will provide quick estimates with improved precision and accuracy as well as with reduced cost. It was tested with field data through computer. So, there was no scope of having non-sampling error. Sampling error was, however, obvious. The sampling units, frame, sampling intensity, stratification and self-weighting techniques may be easily used in present homestead situation depending on the cost and time factors. Therefore, Stratified Two Stage Sampling (Self-Weighted) may be recommended for the assessment and monitoring of village forest resources in Bangladesh.

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SPECIES DIVERSITY AND STAND DYNAMICS OF CATIVO (*PRIORIA COPAIFERA* GRISEB.) FORESTS IN DARIEN PROVINCE, PANAMA

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ABSTRACT

Early initial data from an applied International Tropical Timber Organization research project in eastern Panama show that cativo, a valuable timber tree for the domestic plywood industry, exhibits large variation in stand dynamics between sites. Cativo swamp forests can be categorized according to inundation regime, floristic diversity, and distance from tidal influence. Riverine cativales flooded by high spring tides show greatest *Prioria* dominance, up to 97% of all stems being cativo. Inland cativo forests can be subjected to continued inundation up to eight months of the year and show much slower growth and greater species diversity than all riverine sites. Two riverine cativo forests in different watersheds with similar species composition and flooding regime show markedly different stand dynamics. In one site we obtained an unrealistic time to maturity when we calculated lifetime growth from average growth rates. High mortality rates of young trees with low or no growth may have biased these growth projections. Such growth rate-dependent mortality probably should be incorporated into models of the stand dynamics of cativo.

INTRODUCTION

In 1996 the International Tropical Timber Organization funded a four year applied research project to study stand dynamics of *Prioria copaifera*, and to develop management plans as well as train local loggers in low impact logging techniques. The project also contains a non-timber forest product component that is studying the ecology and management of tagua (*Phytelephus seemanii*) and cocobolo (*Dalbergia retusa*), the seeds and wood of which respectively are carved by the Embera and Wounaan indigenous people, providing an additional source of income. The project is executed by the Panamanian Environment Ministry, Autoridad Nacional del Ambiente ANAM, in collaboration with the Smithsonian Tropical Research Institute.

Cativo (*Prioria copaifera*) is a large legume tree up to 40 m tall and 1.5 meters in diameter with clear straight boles of 12 to 15 meters. Cativo forms dense, monodominant stands and originally cativo forests covered 60,000 hectares in the easternmost Panamanian province of Darien. In February 1998 the SPOT 2 satellite acquired good images with little cloud cover of the entire province and we are currently trying to classify cativo and adjacent forest types with those images. Panamanian foresters estimate that less than 10,000 hectares of cativo forests remain however.

In the late 1950's the United States was importing 4 million cubic meters of sawn cativo annually. Today cativo is not exported but provides the raw material for 90% of the plywood manufactured in Panama. The harvesting of cativo also supports much of the economy in the buffer zone adjacent to Darien National Park, an area that has been included in the system of World Biosphere Reserves and World Heritage Sites. Besides the importance of the timber resource, cativo forests probably play an important role in erosion control along the many rivers of Darien, and also serve as wildlife refuges for many species including monkeys, rodents, crab, deer, and tapir.

GEOGRAPHY AND METHODOLOGY

The Pan American highway reaches the town of Yaviza, but the principle mode of travel in Darien province is by motorized dugout. Among the major rivers are the Chuncunaque, the Tuira, the Balsas, and the Sambu. The cativo component of the project has installed permanent plots for a demographic study of cativo at three sites, with temporary plots at an additional six sites. Other studies in progress are a reforestation trial, a vine-cutting experiment, and a thinning study. We are currently working with a mechanized logger on a low impact logging experiment, and with an Embera community in the development of a community forest management plan.

Three distinct types of cativo forests can be identified based on landscape position, flooding regime, and floristic diversity. The high tides of the Pacific ocean reach far up the major rivers of Darien. Cativo is first encountered in almost pure stands as a transition forest between mangrove forests and mixed-species cativales farther upriver. The project has permanent plots in this type of catival at two sites on the Balsas and Sambu rivers. (Table 1). Moving upriver more species are found mixed with cativo, including *Pentaclethra macroloba*, *Carapa guianensis*, *Pterocarpus officinalis*, and *Tabebuia rosea.* We have installed a thinning experiment in this type of cativo forest at a site called Guanacati, down river from El Real on the Tuira river. Inland cativo forests are flooded continually for the rainy season, up to eight months of the year. These cativales are found in a landscape position between wetter *Pterocarpus* swamps and mixed forest and the project has permanent plots as well as a low-impact logging experiment in this type of cativo forest near a stream called Naranzati, west of the town of Camoganti. In order to try to measure the range of variation in growth of cativo, six temporary plots were installed, three near the limit of the mangrove/cativo transition and three above tidal influence.

Table 1: *Site comparison*

Site	Landscape Position	Flooding Regime	Mgt. History
Balsas River	Riverine	periodic during wet season rains, spring tides	logged ~ 20 years ago, protected since
Sambu River	riverine	periodic during wet season rains, spring tides	logged recently
Guanacati	riverine	periodic during wet season rains	logged
Naranzati	inland	continuous during 8 month wet season	intact

In March to July of 1997 permanent plots were established, and were remeasured approximately one year later. The permanent plots are 40 x 40 meters where all trees greater than 10 cm dbh are measured. In one 20 x 20 quadrant of each plot, all trees between 1 and 10 cm are also measured. For the thinning study at the Guanacati site, six 50 x 50 m plots were installed and all stems greater than or equal to 4 cm were measured. Plot area at the Casarete site is 1 hectare, at the Sambu river site 0.8 hectare, at Naranzati 0.96 hectare and at Guanacati 1.5 hectares. At the temporary plot sites a population of around 150 cativo trees greater than 20 cm dbh are measured. We use five diameter classes for the demographic study: 1-3.9 cm, 4-9.9 cm, 10-29.9 cm, 30-59.9 cm, and greater than 60 cm.

Species Diversity

The two riverine sites flooded by high spring tides show a similar floristic diversity. At the Balsas river site, only *Carapa* and *Pterocarpus* are occasionally found sharing the overstory with *Prioria*. However, in wetter sites at bends in the river, pure stands of *Mora oleifera* are found. But in the catival, *Prioria* comprises well over 90% of all stems in all size classes (Table 3). At the Sambu river site, species composition is very similar, with a slightly higher percentage of *Pterocarpus* in the smaller size classes. *Prioria* still dominates the overstory, which is essentially nearly 100% cativo (Table 5).

Table 2: *Balsas River Species Composition Per Hectare*

Species	Diameter Class cm 1-3.9	4-9.9	10-29	30-59	>60	Total
Carapa guianensis	0	0	3	1	0	4
Ficus spp	0	0	1	0	0	1
Oenocarpus mapora	5	20	0	0	0	25
Prioria copaifera	1303	613	544	173	8	2640
Pterocarpus officinalis	33	18	15	7	0	72
others	0	0	2	0	0	2
Total	1340	650	565	181	8	2744

Table 3: *Balsas River Species Composition By Percentage*

Species	Diameter Class cm 1-3.9	4-9.9	10-29	30-59	>60	Overall Average
Carapa guianensis	0.0	0.0	0.5	0.6	0.0	0.3
Ficus spp	0.0	0.0	0.2	0.0	0.0	0.1
Oenocarpus mapora	0.4	3.1	0.0	0.0	0.0	0.6
Prioria copaifera	97.2	94.2	96.3	95.6	100.0	96.2
Pterocarpus officinalis	2.4	2.7	2.7	3.9	0.0	2.7
Others	0.0	0.0	0.4	0.0	0.0	0.1

Table 4: *Sambu River Species Composition Per Hectare*

Species	Diameter Class cm 1-3.9	4-9.9	10-29	30-59	>60	Total
Cecropia spp	0	0	1	0	0	1
Ficus spp	15	0	0	0	0	15
Mora oleifera	0	0	0	0	1	1
Prioria copaifera	2075	780	273	200	15	3343
Pterocarpus officinalis	55	100	10	5	0	170
Others	5	0	0	0	0	5
Total	2150	880	284	205	16	3535

Table 5: *Sambu River Species Composition By Percentage*

Species	Diameter Class cm 1-3.9	4-9.9	10-29	30-59	>60	Overall Average
Cecropia spp	0.0	0.0	0.4	0.0	0.0	0.1
Ficus spp	0.7	0.0	0.0	0.0	0.0	0.3
Mora oleifera	0.0	0.0	0.0	0.0	7.7	0.1
Prioria copaifera	96.5	88.6	96.0	97.6	92.3	95.1
Pterocarpus officinalis	2.6	11.4	3.5	2.4	0.0	4.3
Others	0.2	0.0	0.0	0.0	0.0	0.1

At the riverine Guanacati site near El Real, many more species are encountered. We will be collecting samples and identifying plants this year, but it is estimated that perhaps 35-50 woody species may be found. The overstory at Guanacati is dominated by large *Mora* and *Pterocarpus*, reflecting the easy accessibility of the forest to cativo loggers from El Real in the past decades (Table 6).

Table 6: *Guanacati (Tuira River) Species Composition Per Hecatare*

Species	Diameter Class cm 4-9.9	10-29	30-59	>60	Total
Astrocaryum standleyanum	0	17	0	0	17
Carapa guianensis	35	25	5	0	65
Gustavia spp.	29	5	0	0	34
Mora oleifera	1	0	0	14	15
Oenocarpus mapora	41	7	0	0	47
Pentaclethra macroloba	25	56	17	1	99
Prioria copaifera	225	162	45	3	435
Pterocarpus officinalis	36	25	15	9	85
Others	91	28	3	2	125
Total	483	324	84	29	920

Table 7: *Guanacati (Tuira River) Species Composition By Percentage*

Species	Diameter Class cm 4-9.9	10-29	30-59	>60	Overall Average
Astrocaryum standleyanum	0.0	5.1	0.0	0.0	1.8
Carapa guianensis	7.3	7.6	5.6	0.0	7.0
Gustavia spp.	5.9	1.6	0.0	0.0	3.7
Mora oleifera	0.1	0.0	0.0	48.8	1.6
Oenocarpus mapora	8.4	2.1	0.0	0.0	5.1
Pentaclethra macroloba	5.2	17.3	19.8	2.3	10.7
Prioria copaifera	46.6	50.0	53.2	9.3	47.2
Pterocarpus officinalis	7.4	7.6	17.5	32.6	9.2
Others	18.9	8.6	4.0	7.0	13.6

The inland site at Naranzati is also relatively floristically diverse. Here we expect to find 40 to 60 different woody species. The overstory, however, is still dominated by over 85% *Prioria*, along with the occasional *Anacardium*, *Pentaclethra*, and *Pterocarpus*. Because of the more difficult access presented by the inland location, these forests have only more recently begun to be subjected to logging, and at Naranzati we measured 51 *Prioria* stems per hectare greater than 60 cm dbh (Table 8). The 100% inventory for the low impact logging experiment showed that some areas contain over 70 cubic meters per hectare of *Prioria* wood in trees greater than 60 cm dbh, the legal cutting limit.

Cativo Diameter Distribution

Prioria diameter distribution is similar at the two tidally influenced riverine sites and reflect their respective management histories. Few trees greater than 60 cm are found at either site (Figure 1). The Balsas river site is on private land. Although it has been somewhat protected from logging for the last few years, it was probably logged heavily around fifteen to twenty years ago. The Sambu river catival is located on state land and has been subjected to less intensive but more frequent logging by small loggers who use no machinery to extract the logs. Instead, they cut smaller trees, 20 to 30 cm in diameter, and lay them end to end to serve as rails while the logs are hand-levered towards the river. The effect of this practice on stand structure can be seen in the low abundance of middle diameter class trees at Sambu relative to the Balsas River Site (Figure 1).

The freshwater cativo forests show distinct diameter distributions from the tidally influenced cativales. *Prioria* regeneration is not as abundant at either site. Virtually no large *Prioria* trees are found at Guanacati while the more difficult-to-access Naranzati still contains many large trees (Figure 2).

Table 8: *Naranzati Species Compostion Per Hectare*

Species	Diameter Class cm 1-3.9	4-9.9	10-29	30-59	>60	Total
Anacardium excelsum	0	0	0	1	4	5
Astrocaryum standleyanum	53	0	5	0	0	58
Brownea spp.	53	47	1	0	0	101
Carapa guianensis	0	0	6	0	0	6
Copaifera spp.	0	3	2	1	0	6
Eschweilera spp.	69	69	8	0	0	146
Gustavia spp.	69	25	5	0	0	99
Oenocarpus mapora	69	175	3	0	0	247
Pentaclethra macroloba	9	22	9	2	0	43
Prioria copaifera	625	400	147	43	51	1266
Pterocarpus officinalis	28	19	4	2	3	56
Others	453	147	35	0	1	636
Total	1428	906	227	49	59	2670

Table 9: *Naranzati Species Composition By Percentage*

Species	Diameter Class cm 1-3.9	4-9.9	10-29	30-59	>60	Overall Average
Anacardium excelsum	0.0	0.0	0.0	2.1	6.8	0.2
Astrocaryum standleyanum	3.7	0.0	2.3	0.0	0.0	2.2
Brownea spp.	3.7	[illegible]	[illegible]	0.0	0.0	3.8
Carapa guianensis	0.0	0.0	2.8	0.0	0.0	0.2
Copaifera spp.	[illegible]	[illegible]	[illegible]	[illegible]	0.0	0.2
Eschweilera spp.	4.8	7.6	3.7	0.0	0.0	5.5
Gustavia spp.	4.8	2.8	2.3	0.0	0.0	3.7
Oenocarpus mapora	4.8	19.3	1.4	0.0	0.0	9.2
Pentaclethra macroloba	[illegible]	[illegible]	[illegible]	[illegible]	0.0	1.6
Prioria copaifera	43.8	44.1	64.7	87.2	86.4	47.4
Pterocarpus officinalis	2.0	2.1	1.8	4.3	5.1	2.1
Others	31.7	16.2	15.6	0.0	1.7	23.8

Figure 1. Cativo Diameter Distribution - Río Balsas and Río Sambu sites 1998

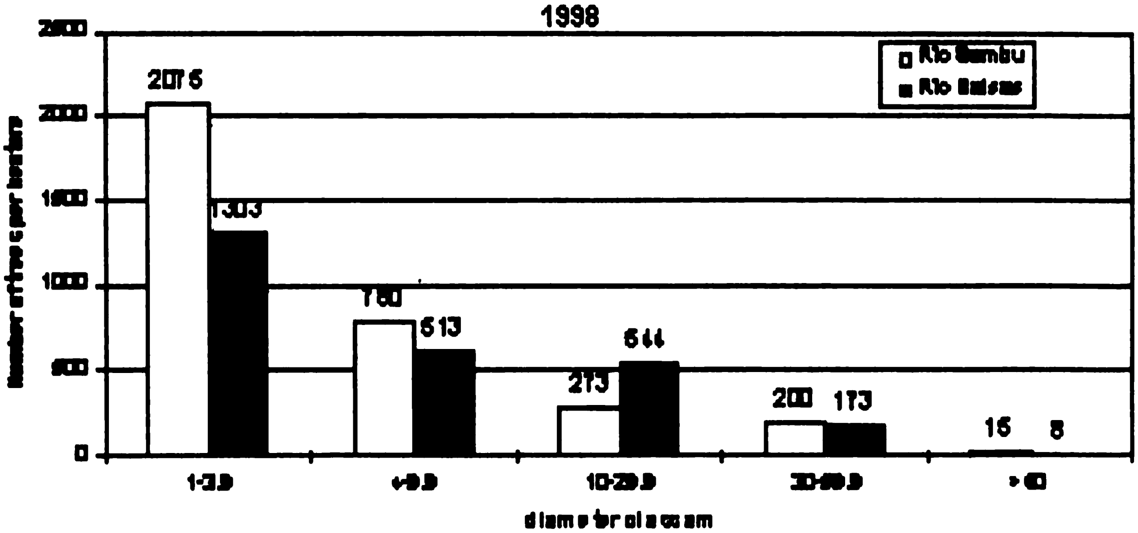


Figure 2. Cativo Diameter Distribution - Naranzati and Guanacati sites 1998

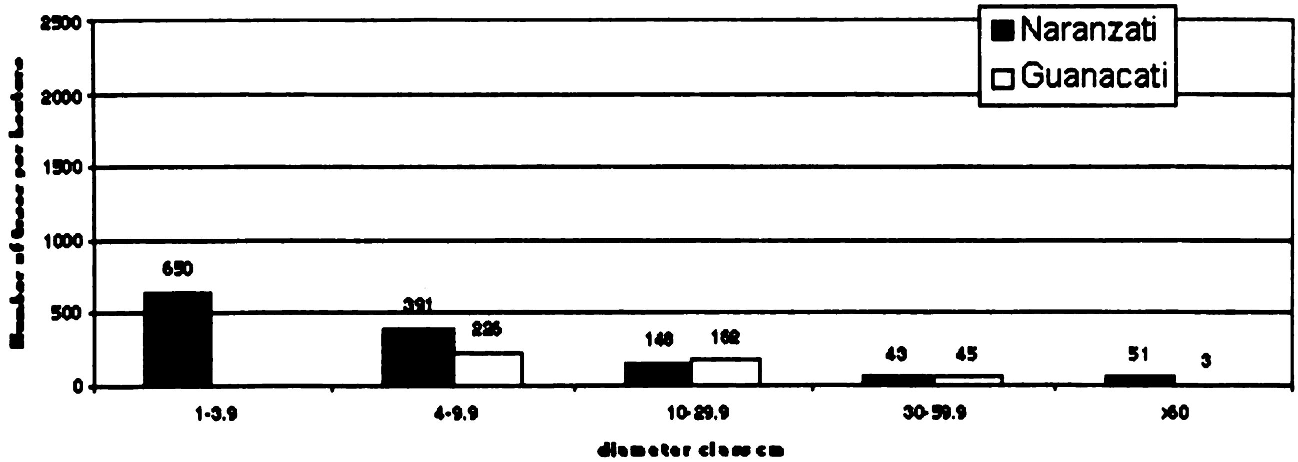


Figure 3. Rio Sambu projected cativo growth

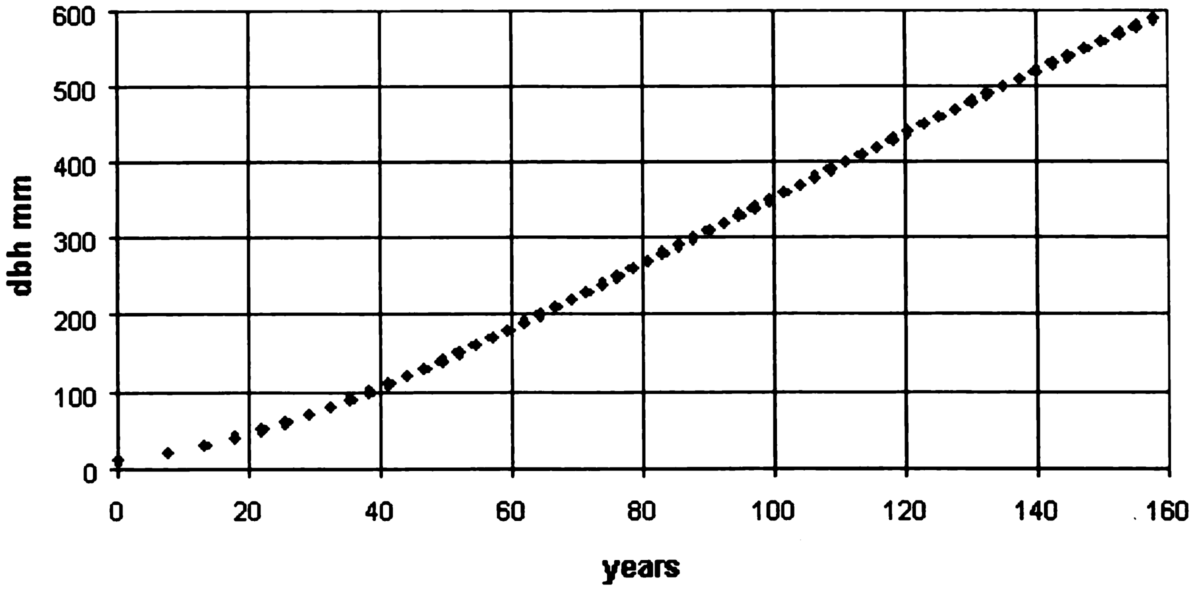


Table 10. *Comparative Stand Dynamics of Two Riverine Cativo Forests*

Site	DBH cm	# 1997	Mortality n	Mortality Annual %	Annual Growth n	Annual Growth Average	Annual Growth 95% CI	Recruitment n	Recruitment Annual %	# 1998
Río Balsas	1-3.9	571	57	8.7	468	0.01	0.01	8	1.2	519
Rio Sambu		404	8	1.9	379	0.15	0.03	35	8.3	416
Río Balsas	4-9.9	267	20	6.5	232	0.00	0.01	3	1.0	246
Rio Sambu		140	0	0	156	0.29	0.06	16	10.9	154
Río Balsas	10-29.9	555	8	1.3	526	0.15	0.03	3	0.5	545
Rio Sambu		220	1	0.4	207	0.48	0.06	6	2.6	220
Río Balsas	30-59.9	170	0	0	177	0.22	0.05	5	2.6	176
Rio Sambu		160	0	0	158	0.33	0.06	4	2.4	163
Río Balsas	>60	8	0	0	21	0.04	0.11	0	0.0	8
Rio Sambu		11	0	0	10	0.45	0.26	1	8.7	12

Figure 4. Río Balsas projected cativo growth

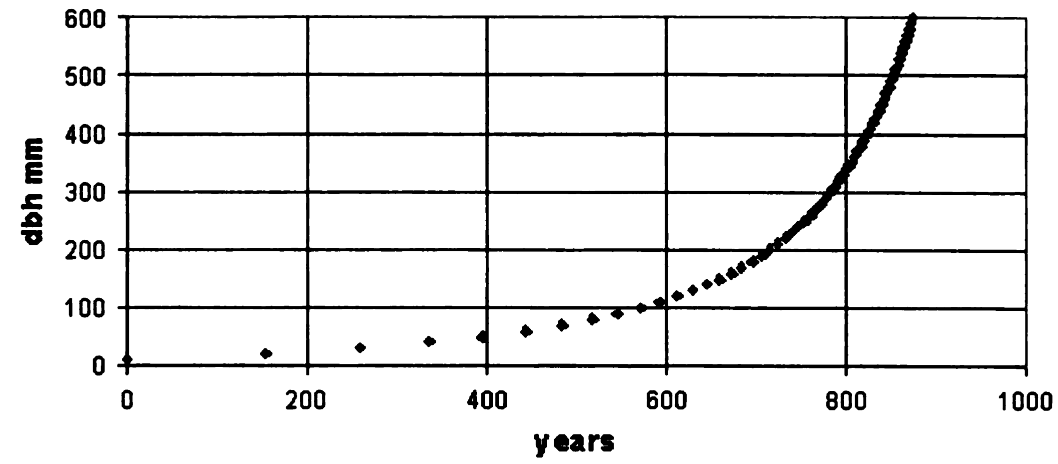
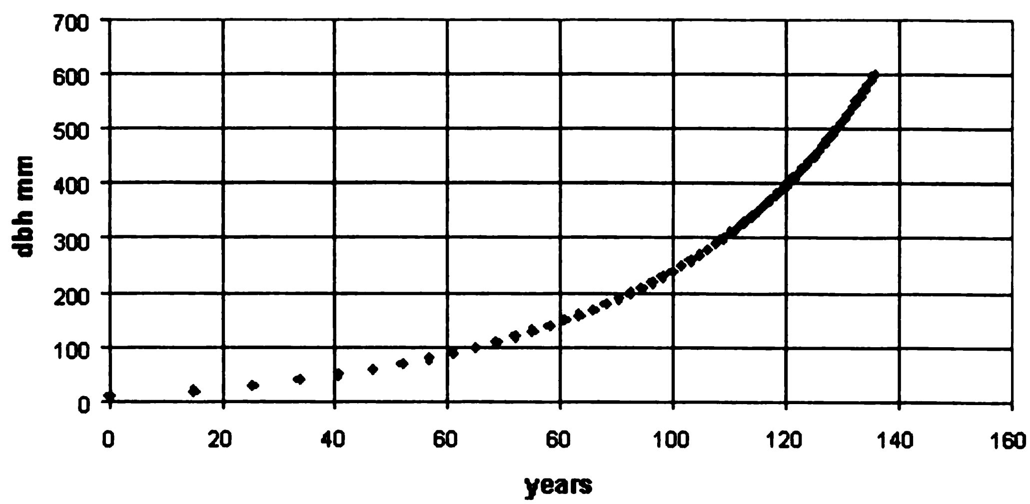


Figure 5. Río Balsas fastest 25% cativo



Stand Dynamics

Although the two riverine cativo forests on the Sambu and Balsas rivers are similar in floristic diversity, flooding regime, and somewhat similar in their management histories, they show markedly different stand dynamics. The Sambu river catival shows significantly faster growth in most size classes, much lower mortality rates, and higher recruitment rates than the Balsas river catival (Table 10). This can partially be explained by more light reaching the smaller trees at Sambu because of the more recent logging. But another project has permanent plots along the Balsas river near our plots on state land, and the area has an almost identical logging history as the Sambu river forest. Growth there is also extremely slow.

Because of some trees that were missed in the 1997 census but measured in 1998, some discrepancies are apparent in Table 10. These trees were not used in the mortality and recruitment analysis.

Growth Projections

We estimated lifetime growth projections by fitting polynomial regressions to instantaneous growth rates expressed as a function of log-transformed dbh. The solutions to the resulting differential equations give a function relating the dbh of a tree to its age (Condit et al. 1995). The method seems to give reasonable results with the Sambu river data, where it was estimated to require 160 years for a 1 cm stem to grow to a size of 60 cm (Figure 3). Using the Balsas river growth data, however, gives an unrealistic growth projection of over 800 years for the same growth range (Figure 4). This was caused by the large number of stems in the small size classes that showed little or no growth. Assuming that the vast majority of these stems will never reach 60 cm dbh, we arbitrarily chose the fastest 25% of the stems in the dataset and the results look more reasonable (Figure 5). With more data we will be able to determine a tree's probability of mortality based on its growth rate and use this information to more accurately model the growth of cativo.

SUMMARY

A management plan is being developed for an important timber tree, *Prioria copaifera*, that most commonly occurs in monodominant stands. In developing a management plan for a timber tree, quantifying growth rate, regeneration and mortality is essential. We anticipated that cativo would grow well in the sites where it is abundant. Instead, we have found substantial variation among stands in growth rates, with some sites having extremely slow average growth. Our analysis of the time required for trees to mature suggests that the application of average growth rates to such growth projections could lead to artifacts. Instead, the higher survivorship of the fast-growing plants should be included in the analysis. Cativo also occurs in both tidally influenced and non- tidal inundated sites. Hence, although the intrusion of salt water may be a factor in the establishment of some cativales, this is not the only factor responsible for cativo's monodominance. The variation in growth rate and in habitat types suggests that cativo dynamics may be controlled by a number of parameters, most of which remain to be identified.

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APROVECHAMIENTO DE RESIDUOS FORESTALES: UN APORTE AL DESARROLLO SOCIAL

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RESUMEN

El presente estudio tiene como objetivo establecer las condiciones para la transformación hidrolítica del aserrín en sustrato enriquecido en azúcares como alternativa para la alimentación animal. En el mismo se valoró el estado actual de los residuos de madera en la provincia de Pinar del Río y se evaluó la potencialidad de esta biomasa para diferentes usos. Se valoraron las características del aserrín de las especies *Pinus caribaea* var. caribaea y *Eucalyptus saligna*, como materia prima con fines hidrolíticos; se estudió el comportamiento de esta biomasa frente al tratamiento de prehidrólisis y se estableció el régimen óptimo para ambas especies, los cuales resultaron: 160 °C - 61 min para *Pinus caribaea* y 160 °C - 71 min para *Eucalyptus saligna*. Se comprobó que mediante este tratamiento a escala de banco se obtiene un producto denominado "masa de madera sacarificada", con un rendimiento entre 95 - 99 %, que es en sí lignocelulosa enriquecida en azúcares de fácil asimilación, lo que le confiere cualidades alimenticias; posee, además, elementos minerales y un valor de digestibilidad de 32 % y 49 % para *Pinus caribaea* y *Eucalyptus saligna*, respectivamente, los cuales se corresponden con las Normas Internacionales para suplemento alimenticio en las raciones para animales. Mediante la conversión del aserrín en alimento animal, se contribuye a la solución de un problema social y al saneamiento ambiental por la eliminación de residuos.

ABSTRACT

The present study has as an objective, to establish the conditions for the hydrolitic transformation of the sawdust in enriched sugar substrates as alternatives for the animal alimentation. The actual state of the wooden residuals were valued in the province of Pinar del Rio, and the potential of this biomass was evaluated for several uses. The characteristics of the sawdust of the species; *Pinus caribaea* var. *caribaea* and *Eucalyptus saligna*, were valued as primary material for hydrolitic products. The behavior of this biomass against the treatment of pre-hydrolisis was studied and a good regimen was established for both species, of which resulted: 160 ° C - 61 min for *Pinus caribaea* and 160 ° C - 71 min for *Eucalyptus saligna*. This treatment was proven at bank scale and the product obtained denominated "mass of wood enriched in sugars" with an efficiency between 95 - 99%, i.e lignocellulose enriched in sugars of simple assimilation, of which confers to alimentry qualities. This also possess some mineral elements and a digestive value of 32% and 49% for *Pinus caribaea* and *Eucalyptus saligna* respectively, of which corresponds with the International Norms for nourishing supplements in animal rations. The transformation of the sawdust to animal food, contributes to the solution of a social problem for the elimination of residuals and to the environmental sanitation.

INTRODUCCION

Un obstáculo para la sustentabilidad de los bosques y las industrias forestales lo constituye el nivel de desechos producidos, tanto en los bosques mismos, como en las plantas procesadoras de madera. La Comunidad Internacional reconoce que la situación de los residuos es un problema global que requiere una atención urgente. Muchas conferencias recientes de las Naciones Unidas, incluyendo la Conferencia de las Naciones Unidas sobre el Medio Ambiente (Río de Janeiro, 1992); la Conferencia Global sobre Desarrollo Sostenible de los Pequeños Estados Insulares en Desarrollo (Barbados, 1994) y la Conferencia Mundial sobre Reducción de desastres (Yokohama, 1994), han planteado la necesidad de crear mejores estrategias para reducir el volumen de los residuos. En 1990, bajo la dirección de la Organización Internacional de las Maderas Tropicales, se estableció un proyecto para evaluar el nivel de desechos y recomendar formas de reducirlos (Noack, 1995). Más reciente aún, en la Tercera Conferencia de las Partes, del Convenio Marco Climático de la ONU, se aprobaron una serie de resoluciones denominadas Protocolo de Kyoto, donde se prevé asistencia a los países en desarrollo, mediante el "Mecanismo de Desarrollo Limpio" para la fijación o reducción de las emisiones de dióxido de carbono (Ramos, 1998).

En la provincia de Pinar del Río se encuentran las mayores reservas forestales del país. La superficie cubierta de bosques representa el 38,6%, correspondiendo el primer lugar a las coníferas, las cuales representan el 30,7% del total de la superficie boscosa (Informe provincial al 2do Congreso Forestal de Cuba, 1998).

El interés industrial fundamental de estos bosques de coníferas es la obtención de madera en bolo para producir madera aserrada, la cual constituye su renglón económico principal. La industria de transformación de la madera genera altos volúmenes de residuos, los cuales en su mayoría se convierten en desechos sólidos o basura. Los volúmenes anuales que se acumulan de aserrín de pino en la provincia alcanzan entre 5 000 y 7 000 m3 y hasta el momento no se ha hecho un uso racional de esta biomasa, la cual al no ser evacuada con prontitud, en pocos días, puede obstaculizar el proceso productivo y por otro lado, su acumulación provoca efectos ambientales negativos.

La biomasa forestal que se origina en el proceso de aserrado de la madera, fundamentalmente aserrín y corteza, constituye un material lignocelulósico que por su naturaleza química (entre 60-70 % de polisacáridos) puede compararse con la del bagazo de caña y otros derivados de ésta, los cuales en nuestro país ya se utilizan industrialmente.

A partir de lo expuesto anteriormente, en el trabajo se abordarán las alternativas de aprovechamiento de esta biomasa partiendo del problema científico y las vías mediante las cuales puede ser resuelto, para ofrecer soluciones prácticas.

DESARROLLO

El Problema

No se aprovechan adecuadamente los residuos lignocelulósicos que se originan en las principales industrias forestales de Pinar del Río, los que provocan, además, la contaminación del entorno.

Solución del problema. Beneficio social.

Las utilidades serían:

Se conoce que una de los principales limitaciones en el desarrollo ganadero lo constituye el alimento. Es sabido que como país subdesarrollado del área tropical no estamos en condiciones de dedicarnos a producir cereales para la alimentación del ganado, como tampoco resulta económico su importación para este fin, debido a la demanda que de estos productos tiene nuestra población. La generación de Biomasa a partir de materiales lignocelulósicos tiene gran importancia para todos los países. Los residuos agrícolas y forestales constituyen una fuente importante de sustratos orgánicos para organismos que son capaces de degradar en la naturaleza la lignina y la celulosa. Dada la estructura altamente fibrosa de estos residuos se requiere de un tratamiento físico, químico o biológico para convertirlos en un producto asimilable por los animales. Se conoce que varios países como U.S.A., Finlandia, Australia y otros, realizan experimentos que demuestran la efectividad de la utilización de residuos de la industria de elaboración de la madera y el follaje en la obtención de alimento animal a partir de la tecnología química moderna y la biotecnología. En Canadá, la firma State Technology, LTD, comercializa un producto bajo la marca comercial "Procell" obtenida de los desechos del bosque descrito como un producto fibroso, de olor agradable, buen gusto y que eleva el apetito, el cual constituye un suplemento alimenticio en la dieta animal. En la antigua URSS se reportan diferentes experiencias en la obtención de suplementos carbohidratados y/o proteicos a partir de aserrín, astillas y corteza, empleando diferentes métodos (Utkin, 1984; Ladinskaya, 1987). Ensayos realizados por diferentes investigadores dan fe del valor nutritivo de tales suplementos. Ejemplos:

- Al suministrar suplemento carbohidratado obtenido a partir de astillas de madera a novillas y vacas lactantes, se comprobó que su valor nutritivo es elevado y equivale a 0,5-0,6 unidades alimenticias (Levanova, 1987).

- Se suplementó una dieta alimenticia para toros de ceba con masa sacarificada de madera, en dosis de 4 kg por cabeza al día y se observó un aumento en 32 % en peso de los animales con respecto al grupo de control(Strelsky, 1989).

En la agricultura son numerosos los reportes científicos acerca de la utilización del aserrín y la corteza de pino en la elaboración de compost para la fertilización orgánica y el mejoramiento de los suelos en diferentes países (Milbocker, 1991; Dangler, 1993). En Chile, un grupo de investigadores estudiaron el comportamiento de mezclas suelo-aserrín-ceniza y comprobaron la posibilidad de utilización de estos residuos como mejoradores de la fertilidad de los suelos, ya que las mezclas producen un incremento en el nivel de elementos nutritivos (Crez, 1990). En España se reporta la utilización con fines agrícolas, de corteza de pino, de la cual han sido extraídos los fenoles para la obtención de adhesivos, ya que por sus propiedades físicas y químicas impide el desarrollo de hierbas indeseables (López, 1993). Investigadores norteamericanos refieren efectos positivos de la corteza de pino pulverizada para el incremento de las poblaciones de hongos en el suelo (Kokalis-Burelle, 1994). En Portugal un grupo de investigadores demostró la efectividad de la corteza de pino y eucalipto como sustitutos de la zeolita en calidad de intercambiadores iónicos vegetales para la fertilización del suelo, compostada con otros compuestos (Guedes de Carvalho, 1994).

El aspecto ambiental del problema.

La comunidad mundial está muy preocupada por el uso sostenible de los recursos naturales por parte de las generaciones presentes y futuras, y por la calidad del medio ambiente. Tiende a crearse una ética ambiental; se habla, por ejemplo, cada vez más, de usar sin abusar, los recursos, de no forzarlos, de reutilizarlos, de hacer más con menos.

La agricultura, en su sentido más amplio, es una aplicación directa y práctica de la ecología, que aprovecha conocimientos para manejar diferentes componentes del ambiente, con el objeto de obtener bienes y productos para satisfacer los requerimientos del hombre. La agricultura es una parte primordial del conjunto de actividades socio-económicas que conforman la vida del hombre, y ese conjunto, unido a las características culturales y políticas de cada región, van a dar por resultado el grado de evolución de cada pueblo. Es por esta razón que en el futuro el desarrollo agrícola también tendrá que hacer hincapié en la necesidad de ser sostenible desde el punto de vista ambiental. Reorientando el saber científico en una dirección ambientalista, las ciencias pueden convertirse en un factor positivo para la solución de los problemas ecológicos actuales (Freyre, 1994). Entre las actividades susceptibles de degradar el ambiente se consideran las que propenden a la acumulación de residuos, basuras, desechos y desperdicios.

En el tema que nos ocupa, podemos señalar que la acumulación de los residuos en los aserraderos provoca:

- Que al descomponerse los mismos, se devuelva a la atmósfera el dióxido de carbono contenido en la materia orgánica.
- Que por la incidencia del sol y las altas temperaturas de nuestro país se provoca en las grandes montañas de aserrín una pirólisis a baja temperatura, producto de lo cual se emiten gases contaminantes al medio. Por otro lado, esta combustión aumenta la temperatura en la zona, provocando un efecto invernadero, lo cual ocurre fundamentalmente en la parte externa, por lo que estas partículas, al quedar con muy poco peso, son arrastradas por el aire.
- Estos residuos constituyen un medio ideal para la generación de plagas y enfermedades.

Por lo tanto, transformar estos desechos en productos de uso social se traduce también como aplicación de tecnología para el saneamiento ambiental.

Resultados experimentales.

Situación de los residuos madereros en la provincia de Pinar del Río.

Este estudio se basa en la obtención de información sobre el estado actual de los residuos madereros en la provincia de Pinar del Río. Para ello se estructuró una encuesta dirigida a las entidades procesadoras de madera, es decir, aserraderos y carpinterías (estatales y particulares). La encuesta se aplicó mediante un muestreo aleatorio simple en ocho de los catorce municipios de la provincia.

Por el estudio realizado se concluyó que son cinco los tipos de residuos madereros que se generan indistintamente en las entidades encuestadas. Ellos son: aserrín, costanera, corteza, viruta y leña.

En ninguno de los establecimientos estudiados existen áreas especializadas para el almacenamiento, ni se toman medidas para la protección de los residuos, es decir, estos permanecen a la intemperie. Este es un aspecto que conspira contra el uso posible de los residuos. No disponer de áreas para el almacenamiento de los residuos puede acarrear problemas relacionados con riesgos de incendios y dificultades en el desarrollo normal del trabajo. La costanera en algunos aserríos no se considera como residuo, pues constituye fuente de obtención de una producción secundaria, ya que se utiliza en la elaboración de módulos de envase. La leña y la costanera pudieran entrar en la misma clasificación por su demanda en las cocinas de las propias entidades y de la población, dada la escasez de combustible. Se observa en el análisis de las encuestas, que se reporta por algunos como leña lo que para otros es costanera, y está dado precisamente por el uso a que se destina. La corteza se bota en su totalidad. Esto demuestra el desconocimiento por parte de las Empresas del valor que posee este residuo y la falta de iniciativas para la búsqueda de soluciones encaminadas al aprovechamiento de los residuos. El aserrín es el que más variedad de uso presenta según estas categorías, si se tiene en cuenta, además, que es el residuo común a todas las entidades encuestadas. Los resultados se reflejan en las figuras 1 y 2. Este estudio ha permitido establecer un diagnóstico del estado actual de los residuos madereros en la provincia y se puede concluir que existe un potencial de recursos poco aprovechados, fundamentalmente aserrín y corteza, los cuales pueden encontrar utilización para diversos usos. Se necesita establecer una estrategia para hacer un uso racional de toda la biomasa residual de la industria de elaboración de la madera.

Estimado de volumen de aserrín de Pinus caribaea var. caribaea que se genera en el aserradero "Combate de la Tenería".

Los datos se tomaron de 120 trozas de Pinus caribaea (60 de 4 m y 60 de 3 m), de acuerdo a un muestreo aleatorio simple, en el interior del establecimiento. A las trozas se les midió el diámetro en el extremo y la longitud. Las mediciones de diámetro se realizaron con una forcípula de aluminio. Los cálculos se realizaron mediante las ecuaciones establecidas por Egas (1998) para la especie Pinus caribaea, en las condiciones de este aserrío. Los datos del experimento aparecen en las tablas 1,2 y 3.

Los porcentajes de aserrín generado fueron de 6,13 % y de 8,40 % para las líneas de cuatro y tres metros respectivamente. Mediante una media ponderada, se obtiene un porcentaje promedio, considerando las dos líneas, de 7,05 % de aserrín. Esto representa un volumen de aserrín de 3,86 m^3 en un turno de trabajo. Este valor expresado como masa, considerando la densidad de la madera de Pinus caribaea de 976 kg/m^3 (Guevara, 1998), equivale a 3,8 toneladas métricas en doce horas de trabajo.

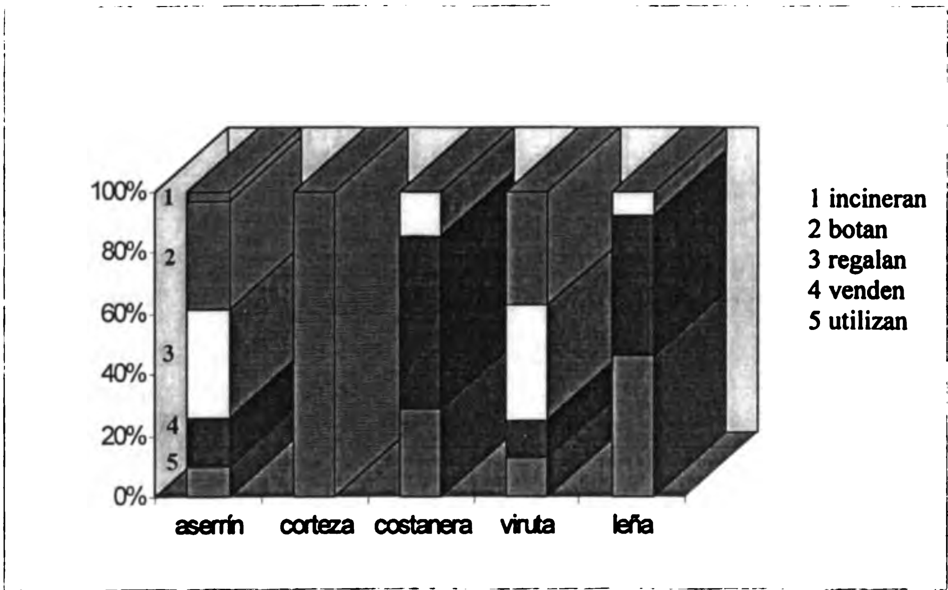

Figura 1. *Disposición de los residuos.*

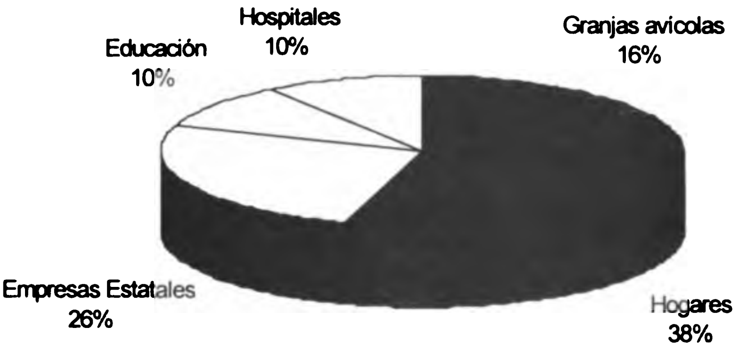

Figura 2. *Destino final de los residuos*

Tabla 1: *Estimación de volumen de aserrín para la línea de 4 m.*

Clase diamétrica (cm)	No. de trozas	V_{troza} (m^3)	% Aserrín	$V_{aserrín}$ (m^3)
20	12	0,0727	6,7554	0,0049
22	12	0,0883	6,5874	0,0058
24	10	0,1055	6,4034	0,0067
26	7	0,1244	6,2025	0,0077
28	6	0,1447	5,9874	0,0087
30	5	0,1666	5,7554	0,0096
34	7	0,2153	5,2434	0,0130
Promedio	-	0,1311	6,1335	0,0081

Tabla 2. *Estimación de volumen de aserrín para la línea de 3 m.*

Clase diamétrica (cm)	No. de trozas	V_{troza} (m^3)	Aserrín (%)	$V_{aserrín}$ (m^3)
14	6	0,0282	9,6048	0,2768
16	6	0,0370	8,9328	0,3305
17	7	0,0419	8,5632	0,3588
18	15	0,0471	8,1712	0,3849
19	10	0,0526	7,8368	0,4142
20	12	0,0585	7,3200	0,4285
Promedio	-	0,0442	8,4048	0,0036

Tabla 3. *Estimación de volumen de corteza.*

Clase Diamétrica (cm)	No. de bolos	Longitud (m)	V_{mcc} (m^3)	V_{msc} (m^3)	V_c (m^3)
23	6	14,01	0,2586	0,1900	0,0686
24	5	13,21	0,2815	0,2082	0,0733
25	6	13,80	0,3141	0,2359	0,0782
26	6	13,75	0,3518	0,2651	0,0867
27	4	13,26	0,3752	0,2850	0,0902
28	4	14,03	0,4225	0,3236	0,0989
29	5	14,02	0,4605	0,3532	0,1073
30	4	14,45	0,5093	0,3953	0,1140
31	4	14,01	0,5468	0,4238	0,1230
32	3	12,30	0,5501	0,4351	0,1150
33	3	13,65	0,6292	0,4996	0,1296
Promedio	-	13,68	0,4272	0,3286	0,0986

Composición química del aserrín y la corteza de Pinus caribaea var. caribaea generado en el aserradero "Combate de la Tenería".

Para la realización de este experimento se tomaron muestras de aserrín y corteza de *Pinus caribaea* var. caribaea obtenido como residuo en el aserradero de Macurijes. La toma de las muestras se realizó por el método del agotamiento en la pila, según se establece por el Control técnico-químico de las producciones hidrolíticas (Emilianova, 1979). La corteza se trituró en mortero de hierro y al igual que el aserrín, se tamizaron hasta partículas entre 0,4-0,6 mm según norma standard TAPPI y se envasaron en frascos de cristal para su posterior análisis. La caracterización química consistió en la determinación de los contenidos de celulosa, lignina, cenizas, sustancias solubles en agua a 95 °C y sustancias solubles en disolventes orgánicos (mezcla benceno-etanol), así como de la ceniza. La determinación de celulosa y lignina se realizó al material libre de extractivos, para lo cual se extrajo la muestra en equipo Soxhlet con mezcla benceno-etanol (2:1) durante ocho horas, cuatro horas con etanol y finalmente con agua durante una hora, en baño de agua hirviente. Se emplearon las normas standard TAPPI para el estudio de la composición química de madera y corteza (TAPPI, 1964). La composición química estudiada se expresa en las tablas 4 y 5.

Caracterización del aserrín con vistas a su transformación por la vía hidrolítica.

Se realizó una caracterización química de los materiales a utilizar para valorar su posible potencialidad con fines hidrolíticos. Esta consistió en la cuantificación de los polisacáridos fácilmente hidrolizables (PFH), polisacáridos difícilmente hidrolizables (PDH) y cenizas, resultados que aparecen en la tabla 6.

Tabla 4. *Composición química del aserrín de P. Caribaea y P. tropicalis (% ms).*

Componentes	P. caribaea	P. tropicalis
Celulosa	43,10 - 45,61	50,60 - 55,68
Lignina	28,41 - 31,27	30,06 - 30,93
Cenizas	0,48 - 0,68	0,22 - 0,45
Sustancias solubles en agua a 95 °C	2,79 - 3,90	3,84 - 5,10
Sustancias solubles en benceno-etanol	3,08 - 4,71	4,38 - 5,35

Tabla 5. *Composición química de la corteza de P. caribaea y P. tropicalis (% ms).*

Componentes	P. caribaea	P. tropicalis
Sustancias solubles en agua a 95 o C	6,25-7,39	8,70-11,96
Sustancias solubles en benceno-etanol	7,31-8,87	10,87-14,13
Cenizas	0,91-1,12	0,90-1,02

Se obtuvo el cuadro cinético de la prehidrólisis. Los parámetros que se determinaron con este fin fueron: hidromódulo, catalizador y régimen óptimo de temperatura y tiempo. Se seleccionó el valor de hidromódulo tres (HM=3) para realizar el tratamiento, por tratarse de una hidrólisis de bajo módulo, con el fin de que asegure, además, la humedad adecuada del producto final. Como catalizador se utilizó dihidrógenofosfato de calcio -Ca(H2PO4)2- (superfosfato de calcio de calidad forrajera), sustancia que posee actividad catalítica conocida (Morozov, 1988). Esta es una sal ácida, capaz de generar iones hidronio al hidrolizarse y a la vez, enriquece al hidrolizado con elementos minerales calcio y fósforo. Para el tratamiento de prehidrólisis se mezclaron 5 g de aserrín con 15 mL de agua (HM=3) y se adicionó el catalizador, superfosfato de calcio de calidad forrajera, en estado sólido, en cantidad suficiente para que su concentración alcance 4 % en base a masa seca de aserrín. La mezcla se agitó y se introdujo cuidadosamente en el autoclave, el cual se calentó en baño de glicerina, con regulador automático de temperatura. Se estudiaron los siguientes regímenes: Temperatura (150,160 y 170 o C), Tiempo (20, 40, 60, 80, 100 y 120 min). Transcurrido el tiempo de reacción, el autoclave se enfrió. Para cada tratamiento, al producto obtenido se le determinó el contenido como porcentaje, de sustancias reductoras totales, por el método ebullostático (Emilianova, 1969). Con los datos experimentales obtenidos, se obtuvo un modelo matemático, que permitió el establecimiento del régimen de prehidrólisis para esta especie con mayor precisión. El método que se utilizó fue un método matemático de Estimación no Lineal (método iterativo) del tipo quasi-Newton, con auxilio del paquete STATISTIC sobre Windows. El tiempo óptimo se seleccinó derivando el modelo para la temperatura escogida, con auxilio del paquete DERIVE sobre Windows. Los resultados se muestran en la tabla 6 y la figura 3.

Cualidades alimenticias de la masa sacarificada de madera de Pinus caribaea.

Se determinaron los indicadores organolépticos mediante examen visual (estado físico, olor, color). Se utilizó masa de madera sacarificada de *Pinus caribaea*, obtenida en condiciones de laboratorio, bajo el régimen óptimo que fue previamente establecidos: 160 oC - 61 min. Esta masa sacarificada, previo a los análisis fue neutralizada con amoníaco concentrado, ya que el pH del producto es bajo (< 4). La caracterización consistió en la determinación de humedad, sustancias reductoras libres (SRL) y totales (SRT), celulosa, fibra bruta, proteína bruta, extracto etéreo, sustancias solubles en agua, digestibilidad, cenizas, pH, furfural y ácidos orgánicos y los valores alcanzados se reflejan en la tabla 7.

Efecto del nivel de masa sacarificada de aserrín de pino en la alimentación de pollos de ceba en la finalización:

Se emplearon 200 pollos híbridos Plymouth Roch x Cornish para evaluar los niveles de 1; 6; 9 y 12 % de masa sacarificada en la alimentación de pollos de ceba durante la finalización (28 a 49 días de edad).La masa sacarificada sustituyó al maíz en los niveles señalados y las dietas se hicieron isoproteicas con 19,5% de proteína bruta, elevando el nivel de soya progresivamente según se incrementaba el nivel de sustitución. Se emplearon 4 réplicas/tratamiento con 10 pollos/réplica. Cada réplica consistió en una jaula con alimento y agua a voluntad. A los 49 días se pesaron 10 aves (5 machos y 5 hembras)por tratamiento y se sacrificaron para análisis de la canal. La composición de la dieta básica aparece en la tabla 8. Los resultados del experimento se presentan en la tabla 9.

Sólo murieron dos pollos (uno en 3 % y otro en 12%), por lo que puede considerarse como baja la mortalidad y no asociada a tratamientos. Con los niveles de 6 a 12 % se redujo la ganancia en peso vivo desde 41 a 111 g/ave, sin embargo se obtuvo reducción en la conversión de materias primas tradicionales (70 a 248 kg/t ganancia) y sin afectarse al nivel del 12 %. El peso de la canal no se afectó por los tratamientos y se observó una reducción en la cantidad de grasa excesiva, particularmente con los niveles de 9 y 12 % y el rendimiento se afectó poco.

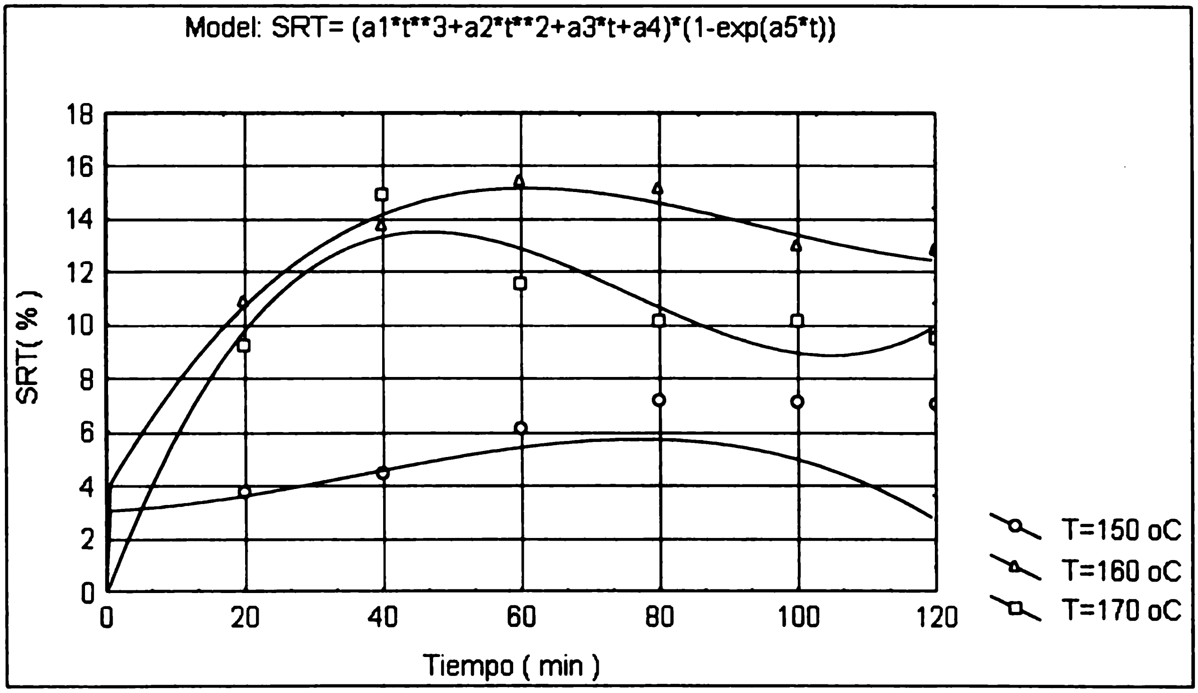

Figura 3. *Régimen de prehidrólisis para Pinus caribaea*

Tabla 7. *Indicadores de la masa sacarificada de P.caribaea.*

Indicadores	Contenido
Sustancias reductoras libres (%)	11,35
Sustancias reductoras totales (%)	16,15
Sustancias solubles en agua (%)	23,00
Extracto etéreo (%)	1,60
Proteína bruta (%)	3,90
Fibra bruta (%)	58,00
Digestibilidad (%)	32,00
Furfural (%)	0,017
Acido acético (%)	trazas
Cenizas (%)	3,88
pH	5-6

Podemos concluir que no existen diferencias significativas entre la utilización del maíz como dieta básica para la alimentación de los pollos en ceba desde 28-49 días y los niveles de sustitución de éste por masa sacarificada de aserrín de pino desde 3-9 % para los indicadores económicos más importantes. Además se comprobó superioridad para el contenido de grasa en la canal con los niveles de 9 y 12 %.

Por lo tanto la masa sacarificada de pino puede recomendarse como suplemento en la formulación de los piensos para aves.

Tabla 8. Composición de la dieta básica para pollos en la finalización.

Componentes	%
Harina de maíz	63,833
Harina se soya	32,593
Premezcla de vitaminas y minerales	0,300
Sal común	0,200
Fosfato dicálcico	1,500
Carbonato de calcio	1,474
DL – Metionina	0,100

Tabla 9. *Efecto del nivel de masa sacarificdrolizado en el comportamiento de las aves de 28-49 días.*

%	Peso inicial g/ave (28 días)	Peso final g/ave (49 días) machos hembras		Ganancia (g) g/ave (28-49 días)	Consumo g/ave	Conversión	Conversión MPT	Peso sacrificado g/ave	Peso canal g/ave	Vísceras + pescuezo g/ ave	Grasa excesiva g/ave	Rendimiento canal + vísceras (%)
0	446	1533	1344	929	2597	2,81	2,81	1377	815	66	9	64,0
3	436	1443	1438	929	2622	2,82	2,74	1374	794	70	14	63,0
6	456	1447	1319	888	2428	2,73	2,57	1396	798	66	6	62,0
9	437	1460	1393	876	2554	2,92	2,66	1398	800	64	3	62,0
12	449	1431	1343	818	2630	3,21	2,82	1392	800	67	2	62,3

MPT: Materias primas tradicionales

Evaluación comercial de la masa sacarificada.

La evaluación comercial de la masa sacarificada de madera obtenida a partir de aserrín de pino permitió determinar el valor total para la producción de una tonelada del producto, teniendo en cuenta los costos directos por concepto de materia prima (aserrín), reactivos (superfosfato de calcio, amoníaco) y energía (fuel oil). Este valor total equivale a $20,62 USD y $10,00 pesos cubanos. La masa de madera sacarificada como suplemento en la ración de aves puede sustituir al maíz, el cual constituye un renglón de importación en la provincia.

CONCLUSIONES Y RECOMENDACIONES

El volumen de aserrín que se genera en el aserrío más moderno de la provincia de Pinar del Río asciende a 3,8 toneladas métricas en un turno de doce horas de trabajo. Los indicadores que caracterizan a este aserrín, como materia prima en el aprovechamiento integral de la madera de *Pinus caribaea y Pinus tropicalis*, son los siguientes: 43,10-55,68 % de celulosa; 28,41-31-27 % de lignina; 0,22-0,68 % de cenizas; 2,79-5,10 % de sustancias solubles en agua a 95 oC y 3,08-5,35 % de sustancias solubles en benceno-etanol, en base a masa absolutamente seca, sin embargo, el 70 % del aserrín en la provincia de Pinar del Río, se desperdicia.

La corteza generada a partir de *Pinus caribaea y Pinus tropicalis* presenta entre 6,25-11,96 % de sustancias solubles en agua a 95 oC; 7,31-14,13 % de sustancias solubles en benceno-etanol y 0,90-1,12 % de cenizas y se desperdicia completamente.

El régimen óptimo de prehidrólisis de *Pinus caribaea* var. caribaea es 160 oC-61 min, y la masa sacarificada que por esta vía se obtiene, presenta las siguientes propiedades: 16,15 % de sustancias reductoras totales; 23,00 % de sustancias solubles en agua; 3,90 % de proteína bruta; 58,00 % de fibra bruta; 3, 80 % de elementos minerales y 32,00 % de digestibilidad, las cuales se corresponden con las normas internacionales establecidas para estos productos.

El procedimiento que permite la transformación hidrolítica de la madera de *Pinus caribaea* que crece en Pinar del Río, alcanza un rendimiento promedio de masa sacarificada entre 95 y 99 % y consta de las siguientes etapas:

Determinación de la composición química de esta fuente de biomasa.

Establecimiento del régimen óptimo de prehidrólisis.

Caracterización del producto obtenido mediante sus principales indicadores físico-químicos.

A partir de los resultados obtenidos experimentalmente y de los ejemplos reportados por la literatura mundial, las autoridades administrativas y políticas de esta industria deberán tomar sus propias decisiones y poner en práctica medidas encaminadas a dar un uso racional a sus residuos, los cuales constituyen una valiosa reserva de material orgánico. Los posibles usos van desde los energéticos hasta los agrícolas como enmendantes orgánicos o para la obtención de suplementos alimenticios.

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LONG TERM OBSERVATION AND RESEARCH IN FORESTRYWITH SPECIAL REFERENCE TO GROWTH AND YIELD STUDIES IN PENINSULAR MALAYSIA

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ABSTRACT

Long term observations and research in forestry is needed to generate reliable information on the growth response and development of both the natural and planted forests under management, due to their long gestation period or rotation cycle. In Peninsular Malaysia, long term observations and research in forestry on growth and yield was initiated to investigate the growth response and development of the selectively harvested natural forests managed under the Selective Management System (SMS). To date, a total of 12 such study areas had been established throughout the peninsula. In addition, a total of 95 growth plots and 46 Continuous Forest Inventory (CFI) plots were also established to study the regeneration status and potential yield of the logged-over forests, and to monitor forest changes that had occurred in between two national forest inventories, respectively. These are considered long term observations and research plots as they would be maintained and monitored through periodic remeasurements over a long period of time, for example in the case of the SMS, it would be over a duration of the rotation cycle of 25-30 years.

Extensive data are now made available through these long term observations and research plots. Some of the data collected have already been analyzed and various models developed, largely through post graduate work undertaken by the staff of the Forestry Department. This paper describes the efforts taken by the Forestry Department Peninsular Malaysia in establishing integrated growth and yield study areas, as well as other research plots aiming at generating reliable information on the growth response and development of the natural forest after harvesting. Some results of the studies and the status of computer model development for purposes of forest management planning and yield regulation are also presented.

INTRODUCTION

Forest management in Peninsular Malaysia has a long history that goes back to nearly a century ago when the first Forest Officer was appointed in 1901. Over time, forest management practices had been revised and/or new practices developed to keep in pace with the changing forest conditions, fluctuating timber supply and market demand, advancement made in industrial and harvesting technologies, as well as new information gathered from research studies. For example, prior to the Pacific War, forest management practices in Peninsular Malaysia were mainly concerned with the harvesting of durable heavy hardwood species and the forest management system in place then was the "Regeneration Improvement Felling (RIF)" which was designed to establish the regeneration of those heavy hardwood species that were selectively harvested.

However, after the Pacific War as more areas were opened up for harvesting due to the growing market for tropical hardwoods and a corresponding growth in sawmill operations, the RIF was found to be impractical and uneconomical and was replaced by the Malayan Uniform System (MUS). Basically, the MUS entails the removal of the mature tree crop in one single felling of all trees down to 45 cm diameter at breast height (dbh) and releasing the natural regeneration of mainly the light demanding medium and light hardwood species. Felling operations were followed by climber cutting and poison-girdling of defective relics and non-commercial species down to a minimum dbh of 5 cm (Wyatt Smith, 1963). The MUS was later modified (Modified MUS) to take a more conservative stance realizing that trees non-commercial today may be of economic value tomorrow. Subsequently, the dbh limit for poison-girdling was raised to 15 cm under the Modified MUS (Thang, 1987). Both the conventional and Modified MUS were found to be successful in regenerating substantial areas of the lowland dipterocarp forests (Shaharuddin, 1998).

As the country progressed and embarked on a large scale agricultural development scheme to eradicate rural poverty under the various Malaysia Plans, particularly in the 1970s, many of the rich lowland forests were logged and converted to agriculture plantations. This had inevitably resulted in a shift of forestry activities from the lowland to the hill forest. However, the MUS which was applied successfully in the lowland forest was found to be unsuccessful for the management of the hill dipterocarp forest. The primary reasons being the comparatively more difficult terrain, uneven stocking, lack of natural regeneration on the forest floor before logging, and uncertain seedling regeneration after logging due to irregular flowering of potential mother trees. In addition, the danger of soil erosion on steep slopes, the growth of *Eugeissona triste*, a palm species and other secondary growths also do not favour a drastic opening of the canopy as practiced under the MUS.

Consequently, the Selective Management System (SMS) was formulated for the management of the hill dipterocarp forest in 1978. The system is deemed to allow for more flexible timber harvesting regimes based on a pre-felling forest inventory and takes good advantage of the demands of the timber market. It emphasizes the retention of intermediate-sized trees (30-45 cm dbh) to form the next crop and discourages the poison-girdling of a lot of the presently non-commercial species which will not only conserve the wood but also the genetic resources available in the forests.

As SMS was a new management concept then and in view of the many difficulties envisaged in regenerating the hill dipterocarp forest, it was felt that the possibility of relying on the intermediate-sized trees to form the next crop warranted further investigation. This paper describes the efforts taken by the Forestry Department Peninsular Malaysia in establishing integrated growth and yield study areas, as well as other research plots aiming at generating reliable information on the growth response and development of the natural forest after harvesting. These are considered long term observations and research plots as they would be maintained and monitored through periodic remeasurements over the cutting cycle of the management system, which in the case of the SMS would be for 25-30 years.

BACKGROUND AND OBJECTIVE OF STUDY

In Peninsular Malaysia, the systematic establishment of growth and yield study areas by the Forestry Department was initiated by the Forestry and Forest Industries Development Project under the auspices of the United Nations Development Programme and the Food and Agriculture Organization of the United Nations (FAO, 1978). The Project proposed that growth and yield study areas be established as no reliable and quantitative growth information were available to assess the development of the forest stands managed under SMS. Hence the first of a series of growth and yield study areas was established in the state of Terengganu in 1974 to investigate the economic and silvicultural implications of forest management under various management regimes (diameter cutting limits) as advocated under the SMS. Subsequently, an additional 11 such study sites, based on the same or modified experimental designs had been established to cover the varying forest and stocking conditions of the peninsula. Two of the study areas were established with funding from the International Tropical Timber Organization (ITTO).

The main objective of growth and yield study is to generate reliable information on the growth and response of the forests under different forest management regimes (diameter cutting limits) after harvesting. Among the information to be generated include the following:-

(i) species composition and size class distribution of trees before harvesting;

(ii) effects of various forest management regimes on the residual stand and forest regeneration;

(iii) degree and extent of logging damage under different management regimes;

(iv) log outturn under different management regimes; and

(v) functional relationships between growth parameters and logging intensities.

The size of the study areas varies among the study sites depending on the number of treatments applied and its replications, ranging from 30 ha in Compartments 200 & 202, Kledang Saiong Forest Reserve, Perak to 638 ha in Compartments 142 and 144, Labis Forest Reserve, Johor. Prior to harvesting, a pre-felling forest inventory was conducted for each study site to determine its stocking for purposes of stratification and replication. Various combinations of cutting options (treatments) were applied. An example of the treatments applied for the study area at Gunung Tebu Forest Reserve, Terengganu is as shown in Table 1. They included flat and split cutting limits for the dipterocarp and non-dipterocarp species; ranging from low cutting limit of 38 cm dbh and larger to higher cutting limit of 61 cm dbh and larger for all species. All major treatments were replicated to ensure meaningful statistical analyses at later stages.

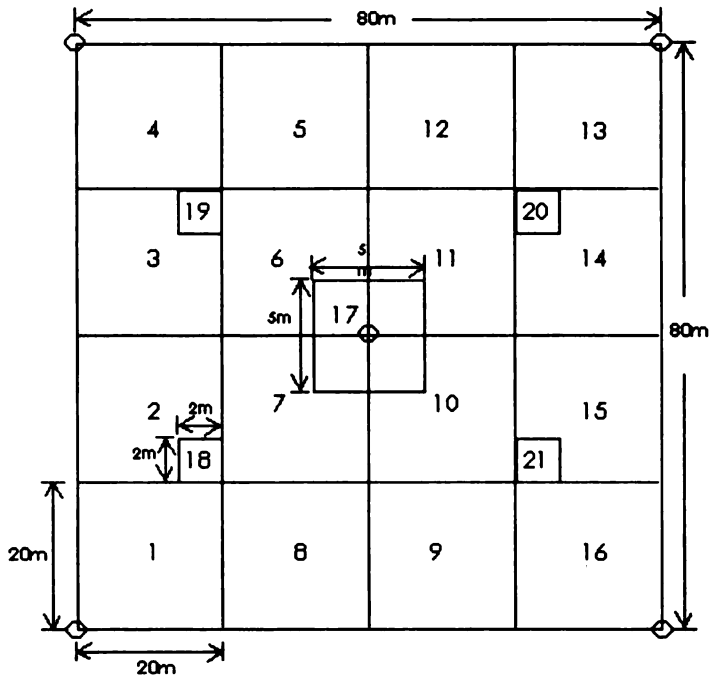
Table 1: *Application of Treatments*

Location	Type of Treatment (Cutting limits)		No. of Replications
Compt. 4,5 & 6, Gunung Tebu F. R. Besut, Terengganu.	A.	Cut all trees dbh 15" (38 cm) and above	3
	B.	Cut all non-meranti dbh 15" (38 cm) and above Cut all meranti dbh 18" (46 cm) and above	3
	C.	Cut all trees dbh 18" (46 cm) and above	3
	D.	Cut all non-meranti dbh 18" (46 cm and above Cut all meranti dbh 21" (53 cm) and above	3
	E.	Cut all trees dbh 21" (53 cm) and above	3
	F.	Cut all trees according to normal practices	3
	G.	Cut all trees dbh 12" (30 cm) and above	) Not replicated.
	H.	Cut all non-meranti dbh 12" (30 cm) and above Cut all meranti dbh 15" (38 cm) and above	) For) demonstration
	I.	Cut all trees dbh 24" (61 cm) and above	) purposes.

After the completion of timber harvesting based on the prescribed treatments, permanent sample plots (PSPs) were established within each study area to monitor the growth and development of the residual stand. Within each PSP, the trees are tagged and numbered, and enumerated on a periodical basis. The total number of PSPs established within each study site varies from 5 plots in Ulu Sat Forest Reserve to 32 plots in Sungai Lalang Forest Reserve, Selangor and Lesong Forest Reserve, Pahang. Information pertaining to the study area in terms of year of establishment, acreage, number and size of PSPs, as well as the number of enumerations carried out thus far appears as Appendix 1 while a typical experimental layout of the PSP is as shown in Figure 1.

Besides the Growth and Yield study areas, a total of 95 Growth Plots were also established in the logged-over forests of the permanent reserved forest (PRF) by States and Forest Districts in Peninsular Malaysia since 1992. The objective of the study is to investigate and evaluate the regeneration status and potential yield of the logged-over forest. This is considered to be of urgent priority as it is envisaged that the remaining virgin production forests of the PRF would be exhausted by the turn of the century. The future timber supply will have to come from the logged-over regenerated forests.

For this study, the logged-over forests were being stratified into different time-period classes, based on the number of years (10-year period) after harvesting. Special attention was made to ensure that the plots established cover as many time-period classes as possible for each State in Peninsular Malaysia.



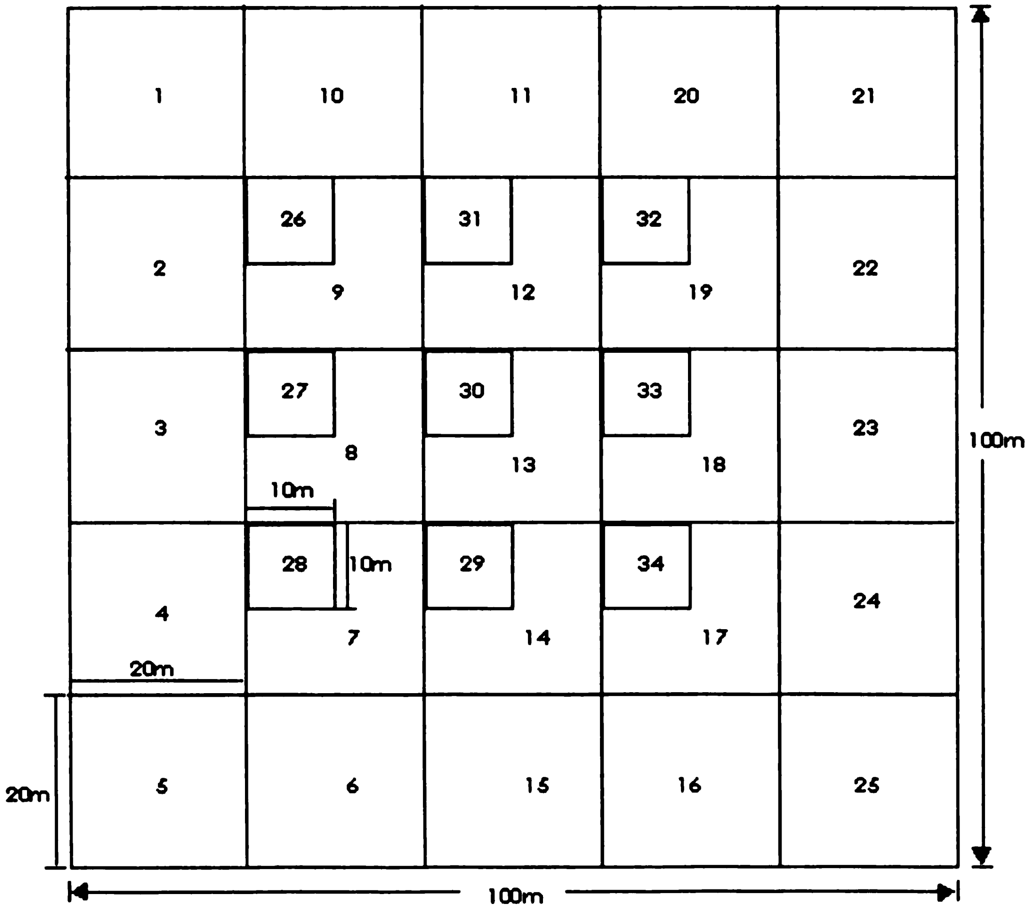
Measurement Specifications According To Plot Size

Plot Size	Plot No.	Measurement
20m x 20m	1, 2, 3, 4, 5, 8, 9, 12, 13, 14, 15 & 16	All trees 20cm dbh and above.
20m x 20m	6, 7, 10 & 11	All trees 5cm dbh and above. (+ 5 cm - 20cm)
5m x 5m	17	All trees 1.5m (5 feet) high to 5 cm (2 inches) dbh
2m x 2m	18, 19, 20 & 21	All saplings 5 inches high to 5 feet (1.5 m) high

Figure 1: *A Typical Experimental Layout For Growth And Yield Study*

Each plot measures 100 m by 100 m (1 ha) in size and is sub-divided into 25 quadrats to sample trees of different diameter sizes. A listing of the number of plots established by States in Peninsular Malaysia appears as Appendix 2 while the experimental layout of the growth plot is as shown in Figure 2.

Apart from the Growth Plots, a total of 46 Continuous Forest Inventory (CFI) plots were also established throughout Peninsular Malaysia since 1986. These plots were established to monitor changes in terms of forest area, stocking, as well as species composition that had occurred in between national forest inventories. In Peninsular Malaysia, the national forest inventory is being conducted once in every 10 years and the established CFI plots provide information pertaining to any changes and developments that had occurred within that ten-year period. To date, a total of three national forest inventories (NFI) had been conducted in Peninsular Malaysia, namely NFI-1 (1970-1972), NFI-2 (1981-1982) and NFI-3 (1990-1992). Most of the CFI plots established were former NFI plots, and they are being enumerated once in every two years. These plots would eventually cover all forest types found in Peninsular Malaysia through the Continuous Forest Resource Monitoring System (CONFORMS) established under the NFI-3. A list of the CFI plots established by States appears as Appendix 3 while a typical layout of the CFI plot is as shown in Figure 3.



Measurement Specifications According To Plot Size

Plot Size	Measurement
20m x 20m	All trees 10cm dbh and larger.
10m x 10m	All trees 5cm - 10 cm dbh.

Figure 2: *Experimental Layout Of Growth Plot*

Apart from the growth and yield study areas established by the Forestry Department, other growth and yield experimental plots have also been established by the various forestry related institutions within the country, notably by the Forest Research Institute, Malaysia (FRIM) and the Faculty of Forestry, Universiti Putra Malaysia (UPM). Most of these plots dealt mainly with short term objective such as planting trial and the determination of early growth response of residual trees (e.g. Abdul Rahman *et al.* 1992, Ashari Muktar *et al.* 1992, Ang *et al.* 1992, Dahia Toh 1994).

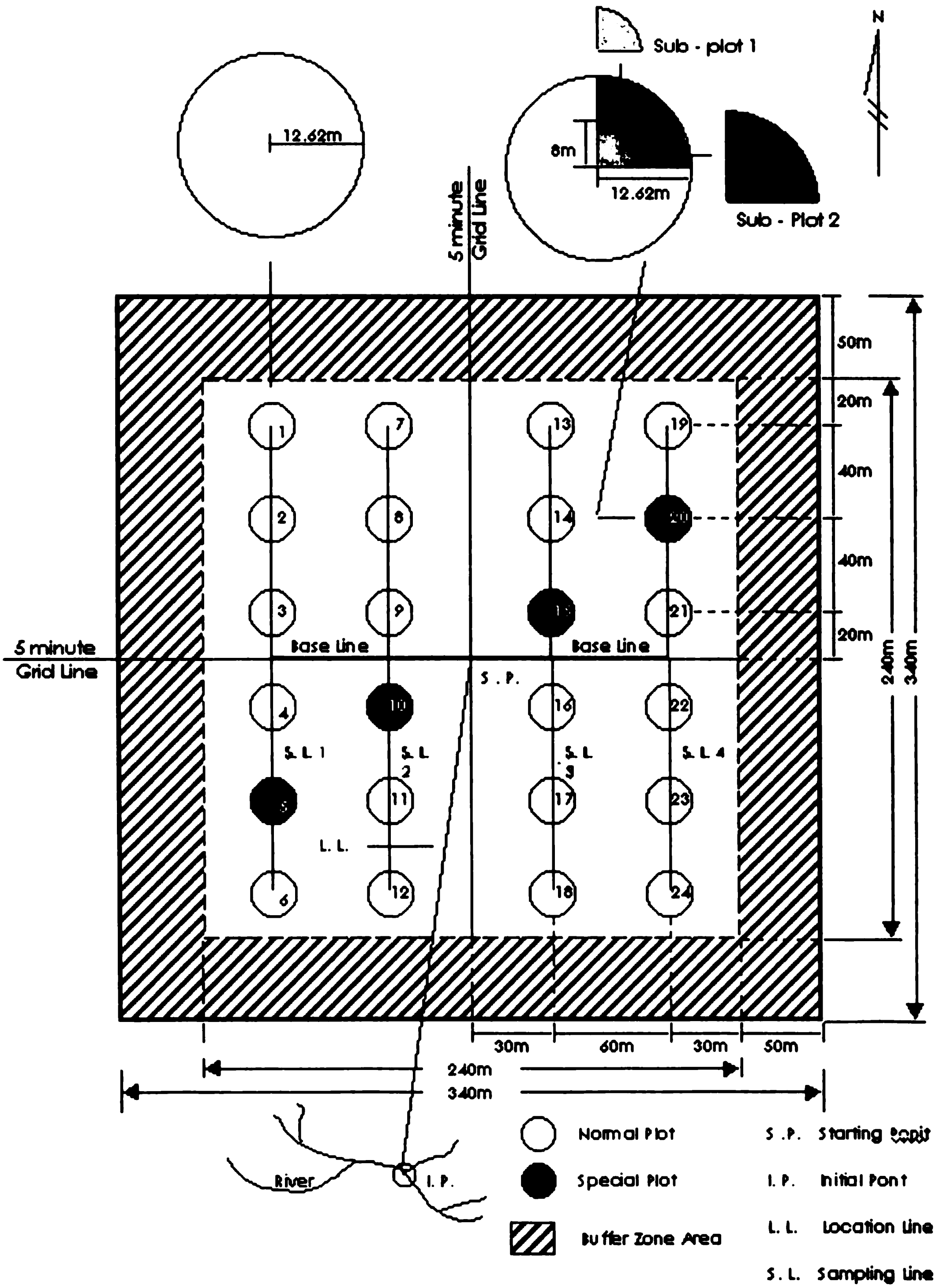


Figure 3. *Experimental Layout OFCFI Plot Based On The Third National Forest Inventory*

DATA ANALYSIS AND RESULTS

Of the 12 growth and yield study areas established, only data gathered from 6 of them had been analyzed, with almost all the analyses done through post-graduate work. Efforts are currently being undertaken by the Forestry Department Peninsular Malaysia, both through internal means and external assistance to analyze all the data collected from the growth and yield study areas, as well as other research plots established since the 1970s. In the wake of the call to sustainable forest management, it is of utmost urgency that these valuable data be analyzed so that they could be utilized for forest management planning and yield regulation. Among the data sets that had been analyzed to date were the study areas located in Gunung Tebu Forest Reserve, Terengganu (Tang 1976, Yong 1990, 1996), Labis Forest Reserve, Johor (Borhan 1985, FDPM 1998), Lebir Forest Reserve, Kelantan (Karkee 1993, FDPM 1998), Sungai Lalang Forest Reserve, Selangor and Lesong Forest Reserve, Pahang (Ashari, 1997), Tekam Forest Reserve, Pahang and Ulu Sat Forest Reserve, Kelantan (FDPM, 1998). Summary results of these studies, as well as results of other relevant studies conducted by FRIM, UPM and UNDP/FAO are given in Tables 1-9 of Appendix 4 (A.4).

In fact, the earliest growth and yield data analysed and subsequently widely used by the Forestry Department in formulating the SMS was done by FAO (1978). Data collected from a series of about one hundred continuous inventory sample plots of 0.4 ha and another hundred silvicultural treatment plots of size 4 ha were analyzed and the results are summarised as Table 1 of A. 4. Results of the studies indicated fast diameter growth rate of 1.05 cm/year for the dark/light red meranti species and an annual volume growth of 2.75 m^3/ha/year for all species combined and having diameter 30 cm and larger.

The results of Gunung Tebu Forest Reserve, Terengganu over the period 1974 - 1988 are summarized as Table 2 of A.4 (Yong 1990,1996). The study indicated the diameter growth of all trees 5 cm dbh and larger ranged from 0.19 cm/year for the non-dipterocarp miscellanous species to 0.44 cm/year for the dipterocarp merantis, with an overall growth rate of 0.39 cm/year. The mean basal area and gross volume increment of all trees 30 cm dbh and larger were 0.09 m^2/ha/year and 0.80 m^3/ha/year, respectively while the mean annual mortality and ingrowth of all trees into the 30 cm dbh limit were 2.75% and 3.35% respectively. The study also indicated that forest harvesting in general enhances forest regeneration, with most of the treatments achieving a higher number of stems per ha (5 cm dbh and larger) 14 years after harvest as compared to the stem stocking prior to harvest.

Study by Borhan (1985) for the Labis Forest Reserve recorded higher diameter increment rates for all species groups when compared to the results at Gunung Tebu Forest Reserve (Table 3 of A.4). The diameter increment of all trees 30 cm dbh and larger ranged from 0.59 cm/year for the non-dipterocarp heavy hardwoods species to 0.85 cm/year for the dipterocarp species, with an overall 0.69 cm/year for all species combined. Higher basal area and volume increment were also recorded for the study area, namely 0.59 m^2/ha/year and 2.15 m^3/ha/year, respectively. This could be attributed to the better site condition at Labis Forest Reserve (Yong 1990).

Karkee (1993) analysed the growth and yield data of Lebir Forest Reserve, Kelantan over the period 1978 to 1990 (Table 4 of A.4). He divided the plots into lowland and hill forest plots based on altitude. Trees located in the lowland plots recorded better growth performance than trees in the hill plots. The diameter growth rate of all trees 15 cm dbh and larger for dipterocarp merantis was 0.98 cm/year in the lowland forest and 0.81 cm/year in the hill forest.

Analyses on growth and yield data from two study areas, namely Lesong Forest Reserve, Pahang (Table 5 of A.4) and Sungai Lalang Forest Reserve, Selangor (Table 6 of A.4) were undertaken by Ashari (1997) while working on a consultancy report for a Joint Malaysia-ITTO project entitled

'Forest Management of Natural Forest in Malaysia'. Results of both study areas indicated high diameter growth rates for the dipterocarp merantis of more than 1 cm/year. The pioneer species also showed impressive diameter growth rates of more than 1 cm/year. The negative basal area and volume increments for all species over the 4 year period in Lesong Forest Reserve were attributed to poison-girdling of marked trees which were left unfelled during harvesting, after the first enumeration. As for the Selangor study site, the basal area and gross volume increments were recorded at 0.42 m^2/ha/year and 1.15 m^3/ha/year, respectively. In general, mortality rate was found to be high for both study areas, in excess of 5% per annum. Results of the latest analyses for the growth and yield study areas located at Labis Forest Reserve, Johor; Lebir and Ulu Sat Forest Reserves, Kelantan; and Tekam Forest Reserve (FDPM, 1998) as undertaken through the Malaysian-German Projected entitled "Sustainable Forest Management and Conservation in Peninsular Malaysia" appears as Table 7 of A.4.

Currently only preliminary data analyses for the Growth Plots established for the States of Pahang and Selangor had been conducted (Masran and Yong, 1994, Yong *et al.*, 1998a, Yong *et al.*, 1998b). Besides the analyses conducted on the growth and yield study areas established by the Forestry Departments, numerous data analyses were also carried out by researchers from other agencies. They included studies by Kamis and Ashari (1988), Ashari *et al.* (1992), Dahlia Toh (1994), Borhan and Abdul Rahman (1988), and Abdul Rahman *et al.* (1992). Results of analysis of Kamis and Ashari (1988) on the growth responses of logged-over hill forest in Peninsular Malaysia are summarized as Table 8 of A.4. Results of studies by other researchers mentioned above are summarized as Table 9 of A.4.

MODEL DEVELOPMENT

It is the ultimate dream and desire of all researchers that information gathered from long term research plots could be utilized to develop computer models that are robust and realistic to predict the future development of individual stands and the forest as a whole, given the present state of the stands and the forest and an anticipated sequence of management and silvicultural interventions.

In terms of model development, a survey of the existing growth and yield models developed in Peninsular Malaysia indicated that we are still at the infancy stage in the field of growth and yield modeling. This is not surprising though as tropical forests are composed of trees that differ markedly in terms of age, diameter, and species composition and hence developing modeling techniques for these forests are made more complex. It was aptly remarked by Vanclay (1994) that the most sophisticated growth models exist only for the most simple forest ecosystems (pure even-age plantations), and that models for the most complex of forests, the tropical forests, tend to be rather primitive and lacking. He attributed it to the limited resources and facilities that hamper the efforts of researchers in the tropics to gather reliable data and build robust models, and hence restrict their work to the simplest approaches.

The first attempt to develop a computer simulation model in Peninsular Malaysia was undertaken by Salleh (1977) who developed a preliminary forest stand management model (FORSTAM) to simulate the tropical forest stand under management. The model took into consideration the cutting regime, silvicultural system and logging system as part of management strategy alternatives and determined their impacts on the forest stand. The manager could evaluate the acceptability of the chosen alternatives by studying the output of the simulation, which consists basically of financial returns, the potential erosion and status of the residual stand. Iterative runs using different selective alternatives allowed the manager to decide on the most appropriate alternative to use.

In 1985, Borhan developed a linear regression model to predict the growth of a selectively cut dipterocarp forest in Labis Forest Reserve, Peninsular Malaysia. He found that the total standing basal area and volume of trees 10 cm dbh and larger, immediately after harvest, were the best independent variables to predict the standing basal area and volume yield four years after harvest.

Individual tree distance independent models were developed by Wan Razali (1986) to model the diameter increment and mortality of the mixed tropical moist forest of Peninsular Malaysia. Linear models and non-linear models were developed to model diameter increment and mortality, respectively.

Other models developed included that by Abdul Rahman (1989) and Yusuf (1990). Abdul Rahman developed a log production planning model for the state of Negeri Sembilan. The model reads the structure of the initial stand, simulates its harvest, project the development of the residual stand, and calculates its future yield based on existing available growth rates. Yusuf (1990) fitted inventory data into the model developed by Abdul Rahman to indicate how cutting cycles under the SMS could be determined, and subsequently applied it to plan the sustainability of timber production in Peninsular Malaysia.

Comprehensive growth and yield functions for the Growth and Yield study area at Gunung Tebu Forest Reserve, Terengganu was developed by Yong (1990). He developed growth functions by species groups and diameter limits for three stand variables, namely number of stems, basal area and gross volume and use these functions to predict the future yield of all trees having diameter 30 cm and larger.

Watts (1990) compared and evaluated five different modeling techniques in developing growth and yield functions for the mixed/moist tropical rainforest of Peninsular Malaysia. The five models considered were: (1) the Weibull probability density function to predict the future diameter distribution by species groups, (2) the logistic function to predict individual tree mortality and linear regression to predict dbh growth, (3) a stand class model to predict stand growth, (4) linear regression to predict mean annual increment over time by dbh class/limit and species group, and (5) linear regression to predict stand growth (stem, basal area, gross volume and net volume) by dbh class/limit and species group. He found model (5) to be most appropriate based on its: (i) statistical validity, (ii) accuracy in making predictions over the range of the data, and (iii) accuracy in making projections beyond the range of the data.

Based on a stand table projection model developed by Kofod (1982) for the selectively harvested mixed dipterocarp forest in Sarawak, Korsgaard (1989, 1995) had improved and adopted the model for use in Peninsular Malaysia. As the name implied, it is a stand table projection model that utilises mean time of passage and de Liocourts q value as a basis to determine the time and rates of growth and mortality to move from one dbh class to another. The projection is based on an initial stand table (stand inventory) and is projected over one or more periods and the effects of harvesting, damage and silvicultural treatments on growth simulated.

Currently, under the Malaysian-German Project on Sustainable Forest Management and Conservation in Peninsular Malaysia, work is in progress to modify the Dipterocarp Forest Growth Simulation Model (DIPSIM), which was originally developed for Sabah (Ong and Kleine, 1995) as a tool for decision making in growth and yield regulation in Peninsular Malaysia. Basically, DIPSIM is an individual tree based model and it allows for the simulation of:-

- the annual growth in terms of number of stems, basal area and volume;
- the stand dynamics for up to 60 years; and

- the effect of different harvesting prescriptions to provide support for decisions in yield regulation.

In developing the model, specific functions were developed for diameter increment, volume and height growth, mortality and recruitment. In addition, a harvesting component was also incorporated into the model to allow for forecasting of future timber yields over long periods. The harvesting model would permit: (i) the forecasting of the number of trees to be cut and their merchantable volume, and (ii) the estimation of the harvesting damage to the residual stand. The model simulation process consists of the following basic steps:

- simulation of harvesting effects;
- simulation of diameter growth;
- simulation of mortality; and
- simulation of recruitment.

FUTURE DIRECTIONS

Growth and yield is central to sustainable forest management and would therefore continue to dominate efforts in tropical forestry research and management. In Peninsular Malaysia, the utmost priority now is focused on the evaluation and analysis of all growth and yield data collected by the Forestry Department. This is a tedious task in view of the voluminous and extensive data collected. Besides analysis conducted under the Malaysian-German project, a substantial amount of data collected would also be analyzed by the Forest Research Institute, Malaysia (FRIM), through a special project funded under the Malaysian Timber Export Levy amounting to RM 250,000. The main purpose of the project is to collate and analyze existing research plots, including growth plots, ecological plots and yield plots in terms of growth and mortality rates, regeneration behaviour and the silvicultural treatments applied at the operational level.

Experiences gained from the establishment, maintenance of study areas and preliminary data analyses would further enhance future research efforts in evaluating the optimum size of the study area and design of the permanent sample plot, developing methodology to stratify the forest into homogenous units, ensuring adequacy and representativeness of the research plots, as well as in incorporating regeneration of seedlings and damage assessment into future growth and yield studies.

The ultimate aim of all growth and yield studies is to develop realistic growth models that would predict the future growth and yield of the forest for purposes of forest management planning and yield regulation. This is a daunting task for the tropical forest researchers in view of the complexity of the tropical forests. It is anticipated that the model to be developed should provide an efficient way to prepare resource forecasts and have the ability to explore management options and silvicultural alternatives and capable of addressing the following futuristic concerns: (i) different management needs, taken into account multiple-use forest management and the conservation of biological diversity; (ii) environmental changes over time; (iii) integration with other models, and (iv) simplicity and practicality of the model to be used by forest managers.

CONCLUSION

Extensive data are now made available through these long term observations and research plots. Some of the data collected have already been analyzed and various models developed, largely through post graduate work undertaken by the staff of the Forestry Department. In view of the importance of these information towards sustainable forest management, concerted efforts are currently being undertaken by the Forestry Department to analyze the remaining data collected, as well as to develop realistic growth models for purposes of forest management planning and yield regulation.

In the past decade, the call for the practice of sustainable forest management has further propelled growth and yield into the forefront of tropical forestry research and management. It is anticipated that forest growth and yield studies would continue to dominate tropical forestry research and management and the studies would be further intensified, to take into consideration the complex nature of the tropical forest and its multiple roles.

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Appendix 1
List of Growth and Yield Study Areas in Peninsular Malaysia

Study Area	Year Established	Area (ha)	No. of plots(size)	No. of Enumeration
1. Compt. 4,5 & 6, Gunong Tebu F.R., Besut, Terengganu.	1974	153.8	21 (80m x 80m)	12
2. Compt. 5, Ulu Sat F.R., Machang, Kelantan.	1974	189.4	5 (200m x 200m)	11
3. Compt.14 & 15, Tekam F.R., Jerantut, Pahang.	1975	161.9	21 (80m x 80m)	11
4. Compt. 142 &144, Labis F.R., Kluang, Johor	1977	637.7	9 (80m x 80m)	11
5. Compt. 71 & 72, Lebir F.R. Machang, Kelantan.	1977	145.8	21 (200m x 200m)	11
6. Compt. 147A, Piah F.R., K. Kangsar, Perak	1991	196.8	15 (100m x 100m)	6
7. Compt. 171 & 172 Lesong F.R., Rompin, Pahang*	1991	410	32 (100m x 100m)	6
8. Compt. 50, Sg. Lalang F.R., Ulu Langat, Selangor*.	1992	420	32 (100m x 100m)	5
9. Compt.10, Ulu Muda F.R., Baling, Kedah.	1994	200	15 (100m x 100m)	4
10.Compt 466 Labis F.R., Mersing, Johor.	1995	265.88	9 (100m x 100m)	3
11.Compt. 20 Jengai F.R., Dungun, Terengganu.	1995	147	8 (100m x 100m)	3
12. Compt. 200 & 202 Kledang Saiong F.R. Perak	1998	30	6 (100 m x 100m)	1

Note : * Joint Malaysia-ITTO project study areas.

Appendix 2
List of Growth Plots by States in Peninsular Malaysia

State	Year Established	No. of Plots	No. of Enumerations
1. Johor	1992	4	4
	1994	4	3
	1997	4	1
2. Kedah	1992	3	4
	1994	3	3
	1997	3	1
3. Kelantan	1992	3	4
	1994	3	3
	1997	3	1
4. Malacca	1992	1	3
	1994	1	2
	1997	1	1
5. Negeri Sembilan	1992	2	3
	1994	2	2
	1997	2	1
6. Pahang	1992	6	4
	1994	5	3
	1997	6	1
7. Perak	1992	5	4
	1994	5	3
	1997	5	1
8. Perlis	1992	1	4
	1994	1	3
	1997	1	1
9. Pulau Pinang	1992	1	4
	1994	1	3
	1997	1	1
10. Selangor	1992	3	3
	1994	3	2
	1997	3	1
11. Terengganu	1992	3	3
	1994	3	2
	1997	3	1

Appendix 3
List of CFI Plots by States in Peninsular Malaysia

State	Forest Type	No. of Plot		Year of Establishment	
		NFI 2	NFI 3	NFI 2	NFI 3
1. Johor	Logged-over forest (21 - 30 yrs)	1	1	1987	1994
	Logged-over peat swamp forest	-	1	-	1995
	Disturbed (soil erosion)	1	-	1990	-
	Peat Swamp Forest	-	1	-	1998
2. Kedah	Disturbed (soil erosion)	1	-	1990	-
	Logged-over forest (11 - 20 yrs)	1	-	1988	-
3. Kelantan	Virgin Forest (moderate stocking)	1	1	1987	1997
	Logged-over forest (1 - 5 yrs)	1	-	1987	-
	Shifting cultivation	1	1	1990	1997
	Disturbed (soil erosion)	1	1	1989	1997
	Virgin Forest (sup. stocking)	-	1	-	1995
	Virgin Forest (poor stocking)	1	-	1990	-
4. Negeri Sembilan	Virgin forest (sup. Stocking)	-	1	-	1996
	Logged-over forest (11 - 20 yrs)	1	-	1988	-
	Virgin Forest (good stocking)	-	1	-	1996
5. Pahang	Virgin Forest (sup. Stocking)	-	1	-	1996
	Logged-over forest (11 - 20 yrs)	1	1	1986	1993
	Logged-over peat swamp forest	1	-	1989	-
	Logged-over forest (21 - 30 yrs)	1	-	1988	-
	Virgin peat swamp forest	-	1	-	1995
6. Perak	Virgin forest (sup. Stocking)	-	1	-	1994
	Virgin forest (mod. Stocking)	1	-	1988	-
	Virgin forest (poor Stocking)	-	2	-	92/94
	Virgin Forest (montane)	1	1	1990	1996
	Disturbed (soil erosion)	1	-	1989	-
	Logged-over forest (11 - 20 yrs)	1	-	1988	-
	Shifting cultivation	-	1	-	1993
	Virgin Forest (good stocking)	-	1	-	1998
7. Selangor	Logged-over peat swamp forest (> 10 yrs)	1	1	1990	1997
	Logged-over forest (> 30 yrs)	-	1	-	1997
	Peat Swamp Forest	1	-	1990	-
8. Terengganu	Virgin forest (sup. Stocking)	-	1	-	1992
	Virgin forest (mod. Stocking)	-	1	-	1992
	Virgin forest (montane)	-	1	-	1992
	Virgin peat swamp forest	-	1	-	1995
	Logged-over forest (11 - 20 yrs)	-	1	-	1992
	Logged-over forest (21 - 30 yrs)	1	-	1988	
	Total	21	25		

Appendix 4

Table 1: *Summary of results from the UNDP/FAO plots of all trees 30 cm dbh and larger*

Species Group	Mean Annual Increment/Mortality			
	Diameter (cm/year)	Volume (m3/ha/yr)	Mortality (%)	Ingrowth (%)
All marketable spp	0.80	2.20	0.9	0.6
Dark/light red meranti	1.05	-	-	-
MHW-marketable	0.75	-	-	-
LHW non-meranti marketable spp	0.80	-	-	-
Non-marketable spp	0.75	-	-	-
All spp	-	2.75	-	-

Table 2: *Summary of results of growth and yield study in Gunung Tebu Forest Reserve, Terengganu (1974-1988)*

Species Group	Mean Annual Increment/Mortality/Ingrowth									
	Diameter (cm/year)		Basal Area (m^2/ha/yr)		Volume (m^3/ha/yr)		Mortality (%)		Ingrowth	
	5 cm+	30 cm +	5 cm+	30 cm +	5 cm+	30 cm +	5 cm+	30 cm +	5 cm+	30 cm +
Dipt. Meranti	0.44	0.56	0.01	-	0.01	0.01	2.58	3.36	3.74	3.38
Dipt. Non.Meranti	0.41	0.56	0.02	0.01	0.13	0.12	2.05	2.67	3.91	3.21
Non-dipt LHW	0.25	0.37	0.13	0.03	0.38	0.26	2.44	2.96	4.29	3.90
Non-dipt MHW	0.24	0.37	0.10	0.03	0.31	0.28	2.13	2.72	2.34	3.20
Non-dipt HHW	0.29	0.34	0.10	0.02	0.20	0.17	1.98	1.34	4.71	2.50
Non-dipt MISC	0.19	0.35	-0.02	-0.01	-0.08	-0.04	4.48	5.65	3.07	3.14
All Dipt	0.43	0.56	0.03	0.01	0.14	0.13	2.36	2.75	3.78	3.39
All Non-dipt	0.24	0.37	0.22	0.08	0.80	0.67	2.53	2.75	3.29	3.35
All species	0.25	0.39	0.25	0.09	0.94	0.80	2.50	2.73	3.30	3.35

Table 3: *Summary of results of growth and yield study in Labis Forest Reserve, Johor (1977-1981)*

Species Group	Mean Annual Increment			
	Diameter (cm/year)		Basal Area (m^2/ha/year)	Volume (m^3/ha/year)
	10 cm+	30 cm+	10 cm+	10 cm+
All dipt	0.85	0.85	0.09	-0.63
Non dipt	0.72	0.78	-	1.53
Non dipt MHW	0.65	0.72	-	0.70
Non dipt HHW	0.61	0.59	-	0.58
All Non dipt	0.67	0.71	0.50	2.78
All species	0.69	0.74	0.59	2.15

Table 4: *Summary of results of growth and yield study in Lebir Forest Reserve, Kelantan (1978-1990)*

Species Group	Mean Annual Increment/Mortality									
	Diameter (cm/yr)				Basal Area (m2/ha/yr)				Mortality (%)	
	Lowland Forest		Hill Forest		Lowland Forest		Hill Forest		Lowland & Hill forest combined	
	5 cm+	15 cm+	5 cm+	15 cm+	5 cm+	15 cm+	5 cm+	15 cm+	5 cm+	15 cm+
Dipt Meranti	0.75	0.98	0.54	0.81	0.12	0.07	0.13	0.09	1.56	2.43
Dipt Non Meranti	0.33	0.56	0.42	0.49	0.01	0.01	-0.01	-0.01	2.69	3.31
Non Dipt LHW	0.38	0.50	0.38	0.53	0.07	0.05	0.16	0.15	2.71	1.67
Non Dipt MHW	0.37	0.63	0.32	0.38	0.01	0.01	0.05	0.04	1.15	0.35
Non Dipt HHW	0.26	0.39	0.53	0.53	0.00	0.00	0.00	0.01	1.75	0.00

Table 5: *Summary of results of growth and yield study in Lesong Forest Reserve, Pahang for all trees 10 cm dbh and larger (1991-1994)*

Species Group	Mean Annual Increment/Mortality			
	Diameter (cm/year)	Basal Area (m2/ha/yr)	Volume (m3/ha/yr)	Mortality (%)
Dipt. Meranti	1.06	0.01	0.16	5.97
Dipt. Non. Meranti	0.67	-0.01	-0.17	3.86
Non-dipt LHW	0.49	-0.07	-0.97	6.05
Non-dipt MHW	0.59	-0.01	-0.52	5.81
Non-dipt HHW	0.50	-0.06	-0.52	8.17
Non-dipt MISC	0.42	-0.29	-2.79	6.83
Non-dipt non-commercial	0.31	-0.23	-1.81	6.53
Pioneer species	1.07	0.46	2.09	3.78
All species	0.58	-0.20	-3.67	6.17

Table 6: *Summary of results of growth and yield study in Sungai Lalang Forest Reserve, Selangor for all trees 10 cm dbh and larger (1992-1995)*

Species Group	Mean Annual Increment/Mortality			
	Diameter (cm/year)	Basal Area (m2/ha/yr)	Volume (m3/ha/yr)	Mortality (%)
Dipt. Meranti	1.01	-0.03	0.07	4.15
Dipt. Non. Meranti	0.79	-0.01	-0.03	5.25
Non-dipt LHW	0.61	0.03	-0.34	4.25
Non-dipt MHW	0.52	0.02	0.06	4.57
Non-dipt HHW	0.83	0.01	0.09	6.51
Non-dipt MISC	0.62	0.11	0.60	5.43
Non-dipt non-commercial	0.59	-0.22	-1.84	5.37
Pioneer species	1.08	0.49	2.55	7.24
All species	0.63	0.41	1.15	5.21

Table 7: *Summary Results From Various Studies Conducted Under the Malaysian-German Project on Sustainable Forest Management and Conservation in Peninsular Malaysia*

Location of Study Area	Tree size considered	Diameter increment (cm/yr)			All species
		Dipterocarp	*Non-dipterocarp*		
			Marketable	Non-mark.	
Labis Forest Reserve, Johor	≥10 cm dbh ≥30 cm dbh	0.77 0.75	0.61 0.59	0.55 0.48	0.62 0.61
Lebir Forest Reserve, Kelantan	≥10 cm dbh ≥30 cm dbh	0.80 0.87	0.51 0.65	0.46 0.68	0.53 0.68
Ulu Sat Forest Reserve, Kelantan	≥10 cm dbh ≥30 cm dbh	0.48 0.56	0.25 0.28	0.21 0.21	0.26 0.33
Tekam Forest Reserve, Pahang	≥10 cm dbh ≥30 cm dbh	0.65 0.63	0.42 0.43	0.39 0.52	0.44 0.48
Gunung Tebu Forest Reserve, Terengganu	≥10 cm dbh ≥30 cm dbh	0.56 0.55	0.35 0.36	0.30 0.34	0.36 0.39

Table 8: *Mean Annual Diameter Increments for Main Timber Species and Selected Hill Forests after Harvesting*

Location of Study Area	Altitude (m.a.s.l)	Year After Logging	Diameter increment (cm/yr)			All species
			Dipterocarp	Non-dipterocarp		
				Marketable	Non-mark.	
Sg. Lalang FR	230	6 months	1.24	0.95	1.06	1.04
Lesong FR	200	6 months	0.75	0.45	0.40	0.47
Lesong FR	200	4 years	0.56	0.42	0.39	0.43
Lesong FR (Kapur Forest)	150 - 300	2 years	0.79 - 0.91	0.51	0.58	0.54 - 0.61
Labis FR	100 - 500	5 years	0.85	0.67	0.67	0.69
Gunung Tebu FR	n.a.	1 year	0.51	0.36	0.43	0.41
Ulu Langat FR (Cpt 10a)		9 - 14 years 14 - 20 years	0.58 0.64	0.42 0.51	0.42 0.51	0.48 0.64
Ulu Langat FR (Cpt 10b)	n.a.	1 - 6 years 6 - 12 years	1.24 1.16	0.69 0.55	0.69 0.55	0.92 0.84
Ulu Gombak FR	n.a.	14 - 20 years	0.71	0.19	0.19	0.34

Table 9: *Results From Other Studies/Institutions*

Location of Study Area	Researcher	Tree size considered	Diameter increment (cm/yr)/Volume increment (m^3/ha/yr)		
			Dipterocarp	Non-dipterocarp	All species
Senaling Inas/ Angsi Forest Reserve, N. Sembilan (Hill Dipterocarp Forest).	Ashari *et al* (1992)	≥10 cm dbh	0.71 cm/yr	0.47 cm/yr	0.47 cm/yr
Tekam Forest Reserve, Pahang (Balau Hill Forest).	Dahlia Toh (1994)	≥10 cm dbh	0.81 cm/yr	0.58 cm/yr	0.60 cm/yr
FRIM's trial plots (planted *Dipterocarpus baudii)*	Borhan and Abdulahman (1988)	≥10 cm dbh	-	-	Av. = 0.8 cm/yr Max. = 1.2 cm/yr Vol =377 m3/ha (at 52 years)
Tekam Forest Reserve, Pahang (Hill Dipterocarp Forest). A= Highlead B= Tractor method.	Abdul Rahman *et al* (1992)	≥10 cm dbh	A = 4.24 m^3/ha/yr B = 2.10 m^3/ha/yr	A = 6.46 m^3/ha/yr B= 3.67 m^3/ha/yr	A = 0.39 cm/yr B= 0.30 cm/yr

TANNIN YIELD IN DIFFERENT SPACINGS OF BLACK WATTLE, *ACACIA MEARNSII* DE WILD

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ABSTRACT

The influence of initial spacing on the tannin yield in kilograms per tree and per hectare of *Acacia mearnsii* was studied. The experiment was conducted in randomized blocks with four repetitions and three treatments defined by spacing between plants of 2 X 1 m, 2 X 2 m and 2 X 3 m. The results indicate that the lower the spacing the higher the tannin yield in kilograms per hectare, with yields of 6216.5 kg/ha in the 2 X 1 m spacing, followed by 6094.5 kg/ha in the 2 X 2 m and 5661.3 kg/ha in the 2 X 3 m. However, the mean tannin yield per tree was higher in the wider spacings with 5.26 kg/tree in the 2 X 3 spacing, 3.91kg/tree in the 2 X 2 m and 2.49 kg/tree in the 2 X 1m.

Keywords: yield, tannin, spacing, *Acacia mearnsii.*

INTRODUCTION

Acacia mearnsii De Wild, commonly known as black wattle, is widely used in reforestation programs on the Central Depression, Lower Slopes of the Northeast and on the Southeastern Slopes, more precisely, in the vicinity of the bark processing centers of the counties of Montenegro and Estância Velha, Rio Grande do Sul. The profit of black wattle farms is superior to that of many other forest species, although the timber yield is lower. The higher profit is due to the commercialization of the bark, which is the main reason for the cultivation of this species, and of the wood that is sold for the production of pulp and paper, particle boards, and energy in the form of charcoal. Tannin, extracted from the bark is used in the pharmacy and leather industries, among others.

Brazil, used to be an importer of tannin vegetable extracts, became self sufficient in 1954. Today, Brazil exports the excess of the production, competing in the global market. Another important factor about the culture is the use of the agrosilvicultural system by the small farmers. Initially, when the trees are small and the canopy is not closed, the farmers plant corn, watermelon, or cassava, among several other crops. Later, when the canopy is closed, the area is used for cattle grazing.

Due to these factors, forest farming with black wattle, in Rio Grande do Sul, is a strong economic activity that, in the last forty six years has brought considerable benefits and prosperity to several counties in the state. This can be confirmed in the census in the Estatístico Brasileiro, which estimates that more than 25000 families, in some way, depend on the black wattle and its industrialization. There is no other example of a culture that has brought so much social and economical transformation to a region in such a short time (Ministério do Interior, 1980).

One of the major problems in the management and evaluation of black wattle forests is the difficulty to quantify the concentration, the tannin yield per hectare, and to project it over time. This component of the production of the forests should be considered in the evaluations and in the determination of the age of maximum income, which has not been done yet.

For this reason the present research was conducted, evaluating the influence of initial spacing on the average tannin yield per tree and per hectare.

LITERATURE REVIEW

Acacia mearnsii De Wild is a native tree from Australia. It is characterized by the dark green leaves, height of 10 to 30 meter, growth in any type of soil. The leaves are compost, bipenate, similar to *Acacia decurrens*, a species also widely used for reforestation, but the individual leaflets are narrower. *Acacia mearnsii* is found in the southeast of Continental Australia and also in Tasmania. In South Africa, it is widely planted for the extraction of tannin (Sherry, 1971).

Luckhoff *apud* Sherry (1971), made a landmark study about the concentration of tannin in the bark of *Acacia mearnsii* in different regions of South Africa and found significant differences among them.

Similar studies done by Sidey *apud* Sherry (1971), with materials identical to *Acacia mearnsii*, collected in different regions of South Africa, found tannin in all organs of the plant. The bark of some species, such as *Acacia australiana*, is among the ones with highest tannin content, with more than 30% of tannin on a dry matter basis. On the other hand, Maiden *apud* Sherry (1971), considers *Acacia mearnsii* as a better species in relation to the quantity of tannin produced and its quality and color.

Sherry (1971), studied the concentration of tannin of *Acacia mearnsii* at the DBH level, and found a negative correlation between the concentration and the local mean annual precipitation. In the same study, he concluded that the production of wood and bark per hectare is proportional to the density, age and site quality of the stand.

The concentration of tannin at the DBH level is positively correlated to the thickness of the bark at the DBH and negatively with the mean height and site quality. However, the tannin yield per hectare is positively correlated with the site, mean height, mean diameter, mean thickness of the bark, age, and density of the stand (Schoenau, 1969a).

Posenato (1977), studied the yield of bark and wood of *Acacia mearnsii* as a function of spacing, which varied from 3,38 to 10,0 m^2, and found, in a 7-year-old stand, that the lower the spacing the higher the yield of bark and wood per hectare, and that the average tannin yield per tree is directly proportional to the increase in the individual standing space. Significant differences on the bark yield were found, with an average difference between spacings of 1244 kg/ha.

The influence of the stand density on the increase in height, volume and bark of black wattle was studied by Schoenau (1969a) in an experiment on thinning intensity. The results showed that the density of the stand does not affect the increase in average and dominant heights, but affected the wood and bark production for, the higher the thinning intensity, the lower was the production of wood and bark. However, the stand density showed significant correlation with the bark yield, tannin content per hectare, and was not correlated with the incidence of gummosis.

The wood yield was influenced by the site, showing a positive correlation with environmental factors, such as annual precipitation, number of rainy days per year, soil depth, fertilization, latitude, slope, and stand density. The factors altitude and distance from the sea also contributed to explain the wood yield, however, the correlation was negative. Moreover, the wood yield was positively correlated with average height, average diameter, and site quality (Schoenau, 1969a), and negatively with the concentration of tannin (Schoenau, 1975).

Furthermore, in a study with *Acacia mearnsii* in South Africa, Schoenau (1969a) could show that the contents of tannin is highly correlated with the site quality, mean height and thickness of the bark. The proposed equation explained 53.3% of the overall variation in the tannin content. The thickness of the bark is also important on the experimental and economical points of view, for this is one of the major criteria for the determination of bark weight in several countries. Therefore, this is one of the major characteristics for selection in a black wattle forest.

Schoenau (1969b) defined a multiple regression equation to express the average tannin content in a stand (ATC) as a function of the tannin content of the average diameter tree (TCD) and average height (h) and another equation in which the dependent variable was only the TCD. These equations had a determination coefficient of 0.88 and 0.87, respectively.

Schoenau (1969a), also found that the tannin production can be estimated by a multiple equation expressed by the tannin yield per acre, average diameter, number of trees per acre, tannin content as a percentage of the average tree, average height, average thickness of the bark, and stand age. This equation explained 96,6% of the overall variation in the tannin yield.

Camillo (1997) determined that the tannin yield of *Acacia mearnsii* De Wild in the black wattle region in the state of Rio Grande do Sul can be obtained by the equation $\ln TY = -5{,}853512 + 1{,}53029074 \ln d + 0{,}38185298 \ln(d^2h)$, in which TY = tannin yield, in kilograms; d = diameter at breast height, in centimeters; h = total height, in meters.

MATERIAL AND METHODS

The species studied was *Acacia mearnsii* De Wild., commonly known as black wattle, and widely planted in the state of Rio Grande do Sul. The experiment was installed in the farm Horto Florestal Pinheiros, property of the Riocell S.A. Company. The area is located at 30° 20´S and 51° 31´W.

The climate of the region is "Cfa", subtropical humid, according to the climatic classification of Koeppen (Moreno, 1961). The average temperature of the coldest month is 9.2°C and of the hottest month does not exceed 24.6°C. The average annual precipitation is above 1000 mm. There is no drought in the region, and total precipitation in the driest month is above 80 mm. The altitude of the region is around 300 meters above sea level.

The soil of the experimental area is classified as belonging to the mapping unit of Pinheiro Machado. There, relief in general is strongly undulated, with rock outcrops. These soils are euthrophic leptosols (former lithosols) on granite substrate with average texture. The clay containing soils are poorly developed and not hydromorphic (Lemos *et al.*, 1973).

The soil was prepared to an average depth of 20 cm, with two crossed disk plowings. The seedlings were planted manually, receiving an initial fertilization in the furrow with 3-28-14 NPK, at the rate of 250 kg per hectare. And the maintenance of the stand was done with crowning of the seedlings, ant and weed control.

The experimental design was randomized blocks, with three treatments and four repetitions. The treatments were the initial spacings of 2 X 1; 2 X 2; 2X 3 m.

The plants were measured annually, with evaluations of diameter at breast height, total height, mortality and damages to the trees. Tannin yield per tree was estimated by the equation developed for the species and region by Camillo (1997):

$$\ln TY = -5{,}853512 + 1{,}53029074 \ln d + 0{,}38185298 \ln(d^2 h),$$

in which TY = tannin yield, in kilograms; d = diameter at breast height, in centimeters; h = total height, in meters.

The estimates for the tannin yield per hectare were obtained by the sum of the yield of each tree, adjusted for the hectare. The average yield per tree was estimated by the proportion of the yield per area and the number of trees of the sample.

The comparison of the averages of the treatments was done with the Duncan test, at the level of 95 % of probability. Statistical analysis was conducted with SAS, at Federal State University of Santa Maria, RS.

RESULTS AND DISCUSSION

The analysis of variance for the tannin yield, expressed in kilograms per hectare, in relation to the initial spacing of 2 X 1; 2 X 2; and 2 X 3 meters is shown in Table 1.

Table 1: *Analysis of variance of the tannin yield, in kilograms per hectare, in a 7-year-old stand of Acacia mearnsii De Wild.*

Source of Variation	DF	SS	MS	F	Prob.>F
Blocks	3	920208.3	306736.08	0.967	0.4671
Treatments	2	681189.5	340594.75	1.074	0.3993
Error	6	1902572.5	317095.42		
Total	11	3503970.1			

The analysis of variance for the tannin yield in the 7-year-old stand indicates that there were no significant differences among the treatments, at 5% probability (F = 0.3993). Nevertheless, the absolute values of yield were quite different, with differences of 122.0 and 555.3 kg/ha, between treatments with 2 X 3 m and with 2 X 2 m and 2 X 1 m, respectively.

The tannin yield in kilograms per hectare in each spacing is shown in Figure 1. Higher tannin yields in a 7-year-old stand were observed in the smaller spacings, with 5661.3; 6094.5 and 6216.5 kg/ha, respectively, in the spacing of 2 X 3, 2 X 2 and 2 x 1 m.

An analysis of variance was done to determine the influence of initial spacing on the average tannin yield, in kilograms per tree (Table 2). The results of the analysis showed a significant difference among the treatments, at a probability of 0.0088.

A comparison of the average tannin yield per tree by the Duncan test, indicated at the 5% probability level, that the spacing of 2 X 1 m produced on average 2.49 kg, statistically similar to the 2 X 2 m, with 3.91 kg, but lower than the 2 X 3 m, with 5.25 kg. However, the spacing of 2 X 2 m was not different form the 2 X 3 m either. The differences in the average tannin yield in kilograms per tree, for the three treatments evaluated are shown in Figure 2.

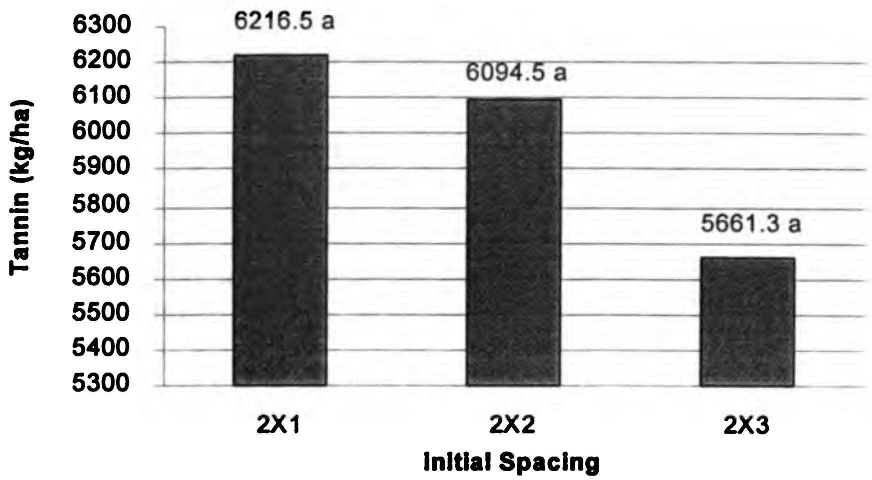

Figure 1: *Tannin yield in kilograms per hectare, in different spacings of a 7-year-old stand of Acacia mearnsii (Obs.: Treatments with one letter do not differ statistically and treatments with different letters differ statistically at the 1% probability level).*

Table 2: *Analysis of variance of the average tannin yield in a 7-year-old stand of Acacia mearnsii, de Wild.*

Source of Variation	DF	SS	MS	F	Prob.>F
Blocks	3	0.369340	0.1231132	0.187	0.9018
Treatments	2	15.251929	7.6259646	11.557	0.0088
Error	6	3.9593102	0.6598850		
Total	11	19.580579			

The observed results allow the inference that, although the tannin yield in kilogram per hectare is higher is denser stands, the average yield per tree is directly proportional to the vital average space available. This means that in larger spacings, the trees achieve higher diameters, more thickness of the bark and, consequently, higher tannin yield. However, when tannin yield is related to the hectare, the productivity is lower due to the lower number of trees per unit area.

As it can been seen in Figures 1 and 2, the average tannin yield per tree increased with the increase in the initial spacing, which was inverse to the tannin yield per hectare.

However, it should be noted that this is just an expression of the mass yield, and does not necessarily represent the most economical alternative for the production due to the other costs involved in the production system.

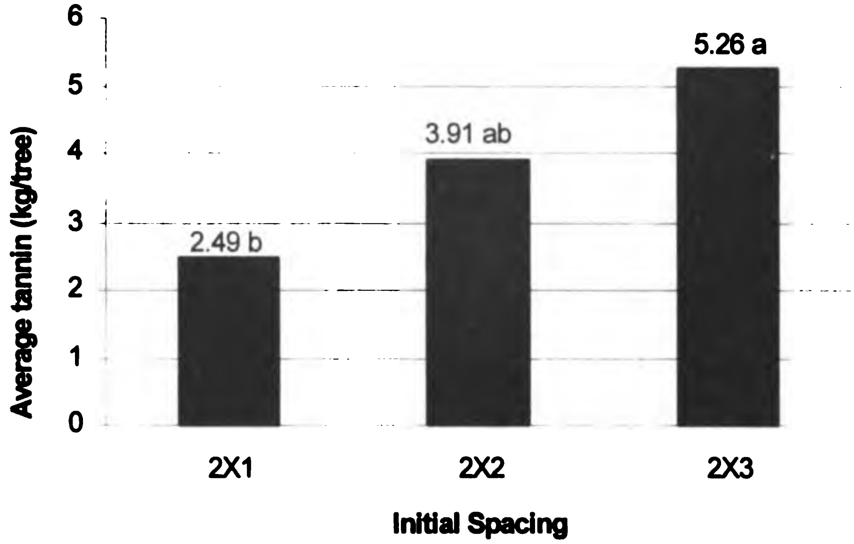

Figure 2: *Average tannin yield, in kilograms per tree, in different spacings of a 7-year-old stand of* Acacia mearnsii (*Obs.: Treatments with one letter do not differ statistically and treatments with different letters differ statistically at the 1% probability level).*

In order to determine the most adequate spacing, with the highest economical yield, the relations of harvest cost and average diameter, wood and bark production per spacing, age and site, among other factors should be studied. It is also important to note that initial cost of forest planting vary with each spacing. In the spacing of 2 X 1 m there are four times more seedlings than in the spacing of 2 X 3 m, a higher proportion of the soil is prepared, more fertilizers and labor are required on a per hectare basis. This may lead to higher costs of forming a forest stand in the spacing of 2 X 1 m than in the others.

CONCLUSIONS

Based on the results of this study, it is concluded that :

- although the tannin yield per hectare is not significantly affected by initial spacing, the amounts produced in the denser spacings deserve further analysis;
- a 555 kg/ha difference was observed between the narrowest and widest spacing, which may have an economic influence on the decision about which spacing to use;
- the average tannin yield per tree was significantly different among the treatments evaluated; a higher average yield was obtained in wider spacings, with 5.25 kg per tree.

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MORTALITY IN EVEN-AGED FORESTS ESTIMATED FROM ORGANIC GROWTH AND DIAMETRIC STRUCTURE

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ABSTRACT

It is shown in this paper that it is possible to determine in natural even-aged stands of trees that grow in spatially disperse patches, so much their instantaneous exponential mortality coefficient, $\lambda(t)$ as the instantaneous mortality $m(t)$, derived them mathematically from an organic growth model (von Bertalanffy) and from a population structure expressed as frequencies as a function of the quadratic diameter of the stands (Reineke). The method was applied to the tropical tree species *Campnosperma panamensis* (Sajo) found on the Colombian Pacific Littoral zone, it being found that $\lambda(t) = 0.04565$ and $m(t) = 0.04463$: the half-life ($t_{0.5}$) of this species being barely 15.2 years which represents 11.4 percent of its life span. This situation is attributed to the lumber exploitation.

Key words: mortality, *Campnosperma panamensis*, half-life, tropical trees, tropical rain forests, demography, even-aged forests, forested wetlands.

INTRODUCTION

In a previous paper (del Valle 1998) an indirect method had been proposed to determine the exponential mortality coefficient $\lambda(t)$ and the annual mortality $m(t)$, deducing them mathematically from an organic growth model (von Bertalanffy) which expresses the diametric growth at breast height (D) of the trees, as a function of the age (t), and of a population structure model for diametric class sizes (diametric structure) based on a variation of the De Licourt & Meyer model which characterizes population structures in inverted J shape and, consequently, uneven-aged; this being, populations in which a close mixture of trees of different sizes and ages are presented. An example of this method was made with tropical tree species *Otoba gracilipes* (A. L. Smith) Gentry, native to the southern Pacific Colombian littoral zone. The objective of the present paper is to determine functions of mortality, or survival, as much as in the base in $\lambda(t)$ as in $m(t)$, from the organic growth and from the population structure made up by natural cohorts of spatially disperse even-aged trees stands (practically monospecifics stands); this is the regeneration of heliophytic tree species that establish themselves in large clearings within the forest (generally produced by anthropic causes) in different periods. Thus, the forest contains differently aged patches stands with regeneration of one species but with trees virtually even-aged within these patches, conforming that which Oliver & Larson (1990) have called multiple-cohort populations.

The theoretical development that is illustrated here concerns the case of *Campnosperma panamensis* Standl., a tropical American tree, common in the fresh water forested wetlands of the southern Colombian Pacific littoral, but whose distribution spans from the north of Ecuador to Costa Rica (del Valle 1972; Morales 1996). *Campnosperma panamensis* grows in practically monospecifics associations in even-aged stands (del Valle 1993; 1997c); in large clearings which have been produced by the lumber exploitation over the last forty years. At this point this species accounts for 83 percent of timber yielding volume exploited (del Valle 1997a). *Campnosperma panamensis* is a heliophytic species (Moreno 1997), but it is not a pioneer following the criteria of Martinez-Ramos (1985), it could be considered more to be an anthropic pioneer (Kageyama 1994). According to Galeano (1997) only 0.0034 percent of the existing *Campnosperma panamensis* forests in the area where the information is taken, have been interpreted as primary forests by color photographs at the scale 1:10,000, the rest are patches in different successional stages.

METHODS

Model for population structure

In order to represent the population structure by size classes of even-aged monospecie cohorts, the model proposed by Reineke (1933) was employed.

$$\ln N = \alpha + \beta \ln \bar{D}q \,, \tag{1}$$

where: N = number of trees per hectare,

Dq = quadratic mean diameter, cm,

ln = natural logarithms,

α, β = parameters estimated by regression.

In eqn 1 β, the slope, is negative; so the model shows the self-thinning effect, or the reduction in the size of the population in proportion to the increase in Dq.

One must keep in mind that $\bar{D}q$ is the measurement of the central tendency of the trees most widely employed in forestry, therefore it coincides with the diameter of the tree of mean basal area (g), this figure multiplied by the number of trees per hectare gives the basal area (G) in m^2/ha, perhaps the best criterion for the spatial occupation of a community of trees (Prodan 1968; Assman 1970; Clutter *et al.* 1983). Eqn 1 thus can be expressed in terms of $(\bar{g})$ resulting in:

$$\ln N = \alpha + (\beta/2) \ln[(4/\pi)g]. \tag{2}$$

Growth model

The von Bertalanffy model (1968), one of the most widely utilized in epidometry (Rawat & Franz 1974; van Laar & Bredenkamp 1979; Sweda & Koide 1981; Ito & Osumi 1984; del Valle 1986; 1997b; Somers & Farrar 1991; González 1994; Vanclay 1994; 1995) will be employed for the organic growth. Zeide (1993) showed that a large number of commonly used growth models are special cases of either von Bertalanffy or Lavakovic I model. In this case the von Bertalanffy differential equation will be expressed in terms of the growth rate of the tree of mean basal area as: dg/dt

$$d\bar{g}/dt = \eta g^m - \gamma g \,, \tag{3}$$

where η, m and γ, are parameters that must be estimated by nonlinear regression. In this equation g represents the mark class of each lapse of measuring in cm^2; this is $(g_{inicial} + g_{final})/2$, recommended proceeding by Vanclay (1995). The integration of eqn 3 gives

$$g = g_{max}\left(1 - be^{-k(t-t_0)}\right)^{1/(1-m)}, \tag{4}$$

where:

g_{max} = $(\eta/\gamma)^{1/(1-m)}$ is the asymptote of the tree basal area, cm^2,

K = $(1-m)\gamma$, intrinsic growth rate,

b = $1-(g_0/g_{max})^{1-m}$,

t $\geq$ 0 age (years), associated with each, $\bar{g}$,

t_0 = age on $\bar{g}_0$,

$\bar{g}_0$ = mark of the smallest class, cm^2,

M $\neq$ 1,

is the growth equation of the mean basal area tree.

Exponential mortality coefficient (λ)

Is one of the most commonly used expressions of mortality (Silvertown 1982; Krebs 1984; Lieberman *et al.* 1990; Condit *et al.* 1993; Manokaran & Swaine 1994; Phillips & Gentry 1994; Phillips *et al.* 1994) and it is derived from the exponential function

$$N_2 = N_1 e^{-\lambda(t_2-t_1)}, \tag{5}$$

where:

N_1 = number of trees at age t_1,

N_2 = number of trees existing in t_1 at age t_2,

e = base of the naperian logarithms,

then

$$\lambda(t) = \ln(N_1/N_2)/(t_2 - t_1) \tag{6}$$

Solving eqn 2 for g and replacing in eqn 4, one arrives at

$$\ln N = C_1 + C_2 \ln\left(1 - be^{-kt}\right), \tag{7}$$

where: $C_1 = \alpha + (\beta/2)\ln[(4/\pi)g_{max}]$,

$C_2 = (\beta/2)/(1-m)$.

Eqn 7 is a model of survival in as much as it represents the declining of the population as a function of time t or age.

It is possible to calculate the $\lambda(t)$ instantaneously by deriving with respect to t in eqn 7 and deriving in eqn 5 with respect to t and inserting it in the previous derivative. One arrives at the expression

$$\lambda(t) = -C_2 bke^{-kt}\left(1 - be^{-kt}\right)^{-1}. \tag{8}$$

Annual mortality(M)

Some researchers prefer to calculate the annual mortality (Shugart 1984; Primack *et al.* 1985; Botkin 1993; Korning & Balslev 1994; Sheil *et al.* 1995; Alder 1995), whose expression is equivalent to the calculation of a compound negative interest rate. The formula is expressed through

$$m(t) = 1 - (N_2/N_1)^{1/t}. \quad \textbf{(9)}$$

Sheil *et al.* (1995) consider that the correct way to calculate the mortality is eqn 9 and not eqn 6. They demonstrate, as well, that the discrepancies between the formulas can be significantly greater in m versus λ when the mortality rates are high. Sheil *et al.* (1995) also demostrated that

$$m(t) = 1 - e^{-\lambda(t)}, \quad \textbf{(10)}$$

then

$$m(t) = 1 - \exp\left[C_2 bk e^{-kt}\left(1 - b e^{-kt}\right)^{-1}\right], \quad \textbf{(11)}$$

which expresses the instantaneous mortality at any time or age.

What remains evident then is that as is seen in the case of the uneven-aged communities (del Valle 1998), it is also possible to determine in spatially disperse even-aged cohorts of trees stands such variables as the exponential mortality coefficient $\lambda(t)$ and the annual mortality $m(t)$, from an organic growth model and a population size structure. The developed models permit determining continuous functions for $\lambda(t)$ and $m(t)$.

Half life $T_{0,5}$

The half-life has been defined as the required time for a population to reduce itself by half assuming a constant mortality (Batschelet 1978; Silvertown 1982; Lieberman *et al.* 1985; Korning & Balslev 1994; Sheil *et al.* 1995). The calculation of the half-life in species that form even-aged multiple-cohort stands that are spatially disperse requires a long process of monitoring of permanent plots. In the revised literature the author found not one previous study of the mean life in tropical forest trees in several even-aged cohorts of one species. But, the correct equation in the context of the present document, implies the employment of λ and $\overline{m}$ in the interval of time t_1 and t_2, that is so

$$t_{0.5} = -\ln(0.5)/\lambda_{t_1,t_2} \quad \textbf{(12)}$$

$$t_{0.5} = \ln(0.5)/m_{t_1,t_2} \quad \textbf{(13)}$$

where $t_{0.5}$ = half life, years,

λ_{t_1,t_2} = average exponential mortality coefficient between times or ages t_1 and t_2,

m_{t_1,t_2} = average annual mortality between times or ages t_1 and t_2.

$\lambda(t)$ and $m(t)$ can also be calculated exactly by applying the mean value of a function (Batschelet 1978) because it is possible to determine the instant when $\lambda(t) = \lambda_{t_1,t_2}$ and $m(t) = m_{t_1,t_2}$ by the following equation

$$y = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} f(t)dt, \quad \textbf{(14)}$$

if $y = \lambda(t)$, $f(t)$ is from eqn 8; if $y = m(t)$, $f(t)$ is from eqn 11.

APPLICATION

For population structures by size class 133 plots were measured in *Campnosperma panamensis* forests on the Patía river delta as such: the diameters of all trees with $D > 1$ cm were measured in 22 of 374 m^2 circular plots. All of these plots correspond with new regenerations with $\bar{D}q < 13$ cm; all of the trees with $D > 5$ cm in plots whose $\bar{D}q$ was found to be between 17 and 23 cm were in 45 circular plots that were 314.16 m^2; 44 sample plots in *Campnosperma panamensis* stands gathered by way of employing point sampling and prisms of different basal area factor (Burkhart *et al.* 1984; Lema 1995) in stands who Dq varied between 8 and 28 centimeters; seven 5,000 m^2 plots where the trees were measured with $D > 5$cm. It was found that in all of these plots 84.2 percent ± 15.7 percent (± the standard deviation) of the trees measured were *Campnosperma panamensis*, an amount that guarantees a high level of specific homogeneity in these populations. Based on these data it was determined the estimators of the parameters in eqn 1, resulting in:

$$\ln N = 12.97322 - 1.92139 \ln(\bar{D}q) \tag{15}$$

(R^2 adjusted = 0.9318; $F = 1807$; $P << 0.0001$; 132 degrees of freedom; $S_{xy} = 0.2443$).

It is shown in Fig. 1 the previous regression with its correspondent confidence belts at 95 percent. Reineke (1933), as well as other researchers (Clutter *et al.* 1984; Oliver & Larson 1990), state that in even-aged monospecie stands full-occupied $\beta \cong -1.6$. In the regression found here a greater negative slope was obtained, perhaps because of the human exploiting of timber yielding trees in these forests (del Valle 1993), which reduced the stock in the stands of trees of greater dimensions causing the greater negative slope. The fact that *Campnosperma panamensis* stands were not completely monospecific could also affect the negative slope. In terms of $\bar{g}$ eqn 15 would remain

$$\ln N = 12.97322 - 0.9607 \ln[(4/\pi)\bar{g}]. \tag{16}$$

Del Valle & Lema (1998) have estimated by nonlinear regression the parameters of eqn 3 for even-aged stands of *Campnosperma panamensis* resulting in

$$d\bar{g}/dt = -0.00021(\bar{g})^{1.79953} + 0.09250(\bar{g}) \tag{17}$$

where: $dg/dt =$ growth rate of the mean basal area tree, cm^2/year,

$g =$ mean basal area tree, cm^2,

(R^2 adjusted by 77 degrees of freedom = 0.7475; $F = 300$; $P << 0.001$; $S_{xy} = 41.540$)

whose integration is the growth curve of *Campnosperma panamensis* (Fig. 2)

$$g = 2{,}012.2\left(1 + 156.8e^{-0.07396t}\right)^{-1.25073}. \tag{18}$$

Replacing the estimate parameters of eqns 16, 17 and 18 in 8 for $\lambda(t)$ and in 11 for $m(t)$, respectively, the following results are given

$$\lambda(t) = 13.9356e^{-0.07396t}\left(1 + 156.8e^{-0.07396t}\right)^{-1}, \tag{19}$$

and

$$m(t) = 1 - \exp\left[-13.9356e^{-0.07396t}\left(1 + 156.8e^{-0.07396t}\right)^{-1}\right] \tag{20}$$

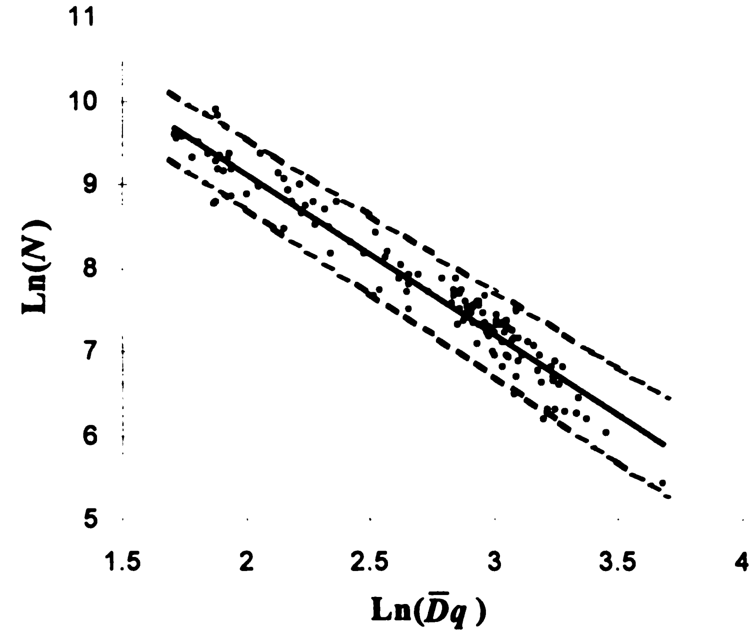

Figure 1: *Diameter structure of Campnosperma panamensis forests expressed as the logarithm of the number of trees by hectare (ln N) as a function of the logarithm of the quadratic mean diameter* ($\ln \bar{D}q$) *in cm, according to Reineke model (1933). Points are 133 plots; continuous line is the regression (eqn 15) discontinuous lines are 95 percent confidence belts.*

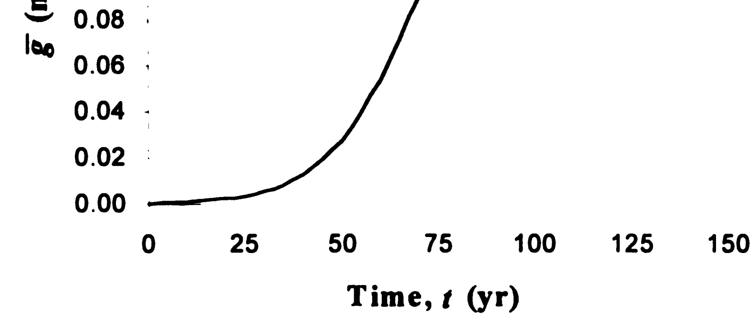

Figure 2: *Growth curves of the mean basal area tree* ($\bar{g}$) *for* Campnosperma panamensis, *(eqn 18).*

and are represented in Figs 3 and 4 up to 133 years, the life span of *Campnosperma panamensis*, estimated as the time required for this species to reach 99 percent of its asymptotic diameter. In the previous figures are also represented $\bar{\lambda}_{0,133}$ and $\bar{m}_{0,133}$, according to eqn 14.

Both trajectories, $\bar{\lambda}(t)$ and $\bar{m}(t)$ are very similar rotates sigmoid curves in shape and numerically next identical.

According to 14:

$\bar{\lambda}_{0,133} =$ 0.046, ($\bar{\lambda}_{0,133} = \lambda_t$) and is represented at $t \cong 69$ years, then from eqn 12

$t_{0.5} =$ 15.2 years, and

$\bar{m}_{0,133} =$ 0.045 ($\bar{m}_{0,133} = m_t$) at $t \cong 68$ years, so

$t_{0.5} =$ 15.2 years.

The difference between λ and $\bar{m}$ are minimal, and apparently without practical value.

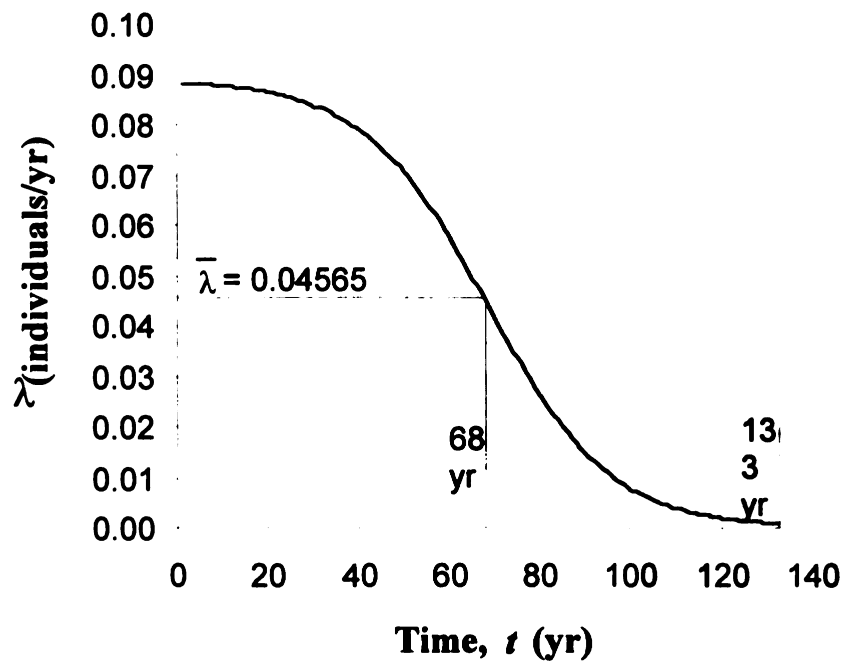

Figure 3: *Mortality curve of Campnosperma panamensis trees population according to the exponential mortality coefficient λ(t) (eqn 19). It is shown the mean exponential mortality coefficient, the age when it is equal to its instantaneous rate and the life span of this species.*

A mortality of nearly 4.6 percent is almost three times the average obtained (1.6%) in the 38 sample areas reported by Philips & Gentry (1994) in their study on trees in tropical rain forests. In addition the mortality in these *Campnosperma panamensis* forests here surpassed the highest levels gathered by these authors: 3.27 percent in the forests of Sumatra. The half life calculated with the average pantropical (43.3 years) is almost three times of *Campnosperma panamensis* obtained here and is only comparable with that registered for *Otoba gracilipes* (del Valle 1998) in these same forests ($\bar{\lambda} = 0.052$; $t_{0.5} = 13$ years).

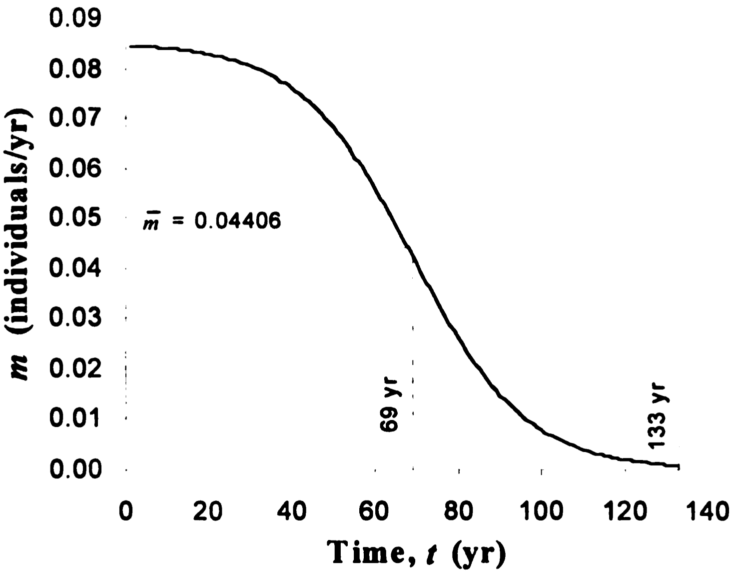

Figure 4: *Mortality curve of Campnosperma panamensis trees population according to mortality m(t) (eqn 20). It is shown the mean mortality, the age when it is equal to its instantaneous rate and the life span gof this species*

For both species, the timber exploitation exercised by the local population of these two species over the last four or five decades (del Valle 1993), is the principal cause for the high rates of mortality and its consequent short half life (equivalent in *Campnosperma panamensis* as being only 11.4 percent of its life span). Fig. 3 indicates the age in that the exponential mean mortality coefficient for 133 years is equal to the instantaneous which occurs at approximately 69 years. In terms of *m*, the mean mortality is leveled approximately to 68 years (Fig. 4). These amounts correspond to being about 22 to 27 years greater than those found for the *Otoba gracilipes* (del Valle 1998). This is owed to the fact that the curves of $\lambda(t)$ y $\bar{m}(t)$ of the species studied here have sigmoid rotated shape with relatively low rates of mortality during the first 40 years; as opposed to, in the referred species, both curves revealing forms of inverted *J* shape and, therefore, greater initial rates of mortality.

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SESSION II

”Modeling”

THE SILVICULTURAL EXPERIMENTAL PLOTS OF PARACOU IN FRENCH GUIANA: EXAMPLE OF USE AND LIMITS OF THE AVAILABLE DATA FOR DEVELOPPING INDIVIDUAL GROWTH MODELS

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ABSTRACT

Long-term monitoring of the rainforest dynamics, according to various kinds of disturbance, has been undertaken in French Guiana since 1984, on the Paracou site, 50 km north-west from the spatial center of Kourou. The great amount of detailed and spatialised data gathered on twelve plots, 9 ha each, and dealing with more than 46 000 trees, allowed us to build models of forest dynamics. One of them is an individual-based spatially explicit model, the development of which led us to describe as precisely as possible the different components of the dynamics : growth, mortality and ingrowth, at an individual scale, before including them inside a simulator. The object of the paper is to present the results obtained with the growth component. It has been developped using the " potential x modifier " philosophy, but adapted to take into account the rainforest conditions. It presently predicts the mean annual diameter growth of trees, according to their diameter, local environment described through competition indexes, and species they belong to. Trials to take into account pedological and topographical information remained unsuccessful due to the lack of accuracy of the available data. Problems encountered and remaining to improve this model are discussed.

INTRODUCTION Since the beginning of the 1970's, the forest department of CIRAD (ex " CTFT") settled or took part to the settlement of large size experimental plots in natural and/or disturbed tropical moist forests around the world, in order to gather data and elaborate knowledge about their dynamics and functioning (Maître, 1990, Favrichon *et al.*, 1998). The Paracou experimental design, located in the north-eastern part of the amazonian region in French Guiana, is the last but one of them. Installed in 1984, it is particularly interesting because it made profit from the successes, failures and inadequacies of the preceding experiments and the following issues, for example, were particularly addressed:

- delimitation and survey of big surfaces (more than 1 ha), to take into account the biological and physical heterogeneity of the environment,
- delimitation of plots in previously undisturbed stands and repeated survey before any silvicultural treatment, so that each plot can be its own control,
- survey of all trees more than 10 cm dbh, whatever the species (potentially commercial or not) they belong to,
- following of all identifiable types of mortality, natural or consecutive to silvicultural treatments. For natural mortality, three categories are concerned: standing death, primary windthrow, secondary windthrow,
- coupling with a systematic survey of regeneration.

Since 1984, a lot of informations have been collected which are definitely useful to the lowland evergreen rainforests managers, notably for the definition of felling cycles in the management units of the coastal part of French Guiana. Results from Paracou helped to imagine " ideal " silvicultural scenarios, which are currently tested in real scale in managed forests (Gourlet-Fleury, 1992a).

In 1993, in addition to this costly field experimentation, CIRAD-forêt started a modelling program in order to: (*i*) make profit from the huge amount of data gathered on the experimental plots, were they demographical or physical, to describe and predict the growth of stands according to various silvicultural scenarios; (*ii*) thus identify gaps in our knowledge and modify consequently the current surveys; (*iii*) try, through the synthesis of current knowledge and the analysis of the model functioning, to better understand the underlying mechanisms of tropical rain forest dynamics. Up today, a density-dependent matrix model was built by Favrichon (1995, 1998), as well as a first version of a single-tree, distance dependent model (Gourlet-Fleury, 1997, 1999) implemented in a simulator called SELVA (Caruso, 1994). Another approach, derived from the gap models, is still under completion (see Vanclay, 1994, for more details on forest dynamics models).

In this paper, we will focus on the single-tree model and more precisely on the possible improvement of its growth component. In a previous work (Gourlet-Fleury, 1997, Gourlet-Fleury and Houllier, 1999) we put forward a model linking diameter growth increment with diameter at the beginning of the growth period, competition indices rendering the local environmental pressure, and taking into accout species information. Here, our specific objectives will be:

- to study and discuss the remaining plot effect on the residuals of the growth model,
- to examine the physical data allowable on those plots (dealing with soil on some of the plots, and topography on all of them) and their potential ability to improve the efficiency of the growth model,
- to discuss, in the light of the growth model behaviour, some of the main weaknesses of the Paracou design.

MATERIALS

Paracou was settled in 1984 in a previously undisturbed forest area of the coast, about 50 km WNW from Kourou, near Sinnamary. 12 plots, 9 ha each, were delimited on a globally homogeneous substrate qualified as " Sols à drainage principalement superficiel " (soils with mainly superficial drainage), which represent the most commonly encountered soil conditions in the area (Boulet et Brunet, 1983). Those soils are developped on schists (" Série de Bonidoro ") and mainly consist of clay and sandy-clay.

On each plot, all trees more than 10 cm of dbh are localized by their cartesian coordinates inside a core of 6.25 ha (the core is surrounded by a buffer zone 25 m wide), and their girth (gbh) is measured each year since 1984. Recruitment and mortality are monitored as well. The trees have been botanically identified when possible: 200 so-called species (*ie* several appellations contain more than one species) are distinguished. The identification by means of Herbarium collection is still ongoing. Physical information allowable on the stands are:

- data from soil profiles sampled in the 3 control plots (Barthès, 1991). 6 variables were examined (see table 1): depth of usefull soil (" drainage "), hydromorphy at the top of the soil profile (" hydromorphy "), presence of layers with coarse sand (" coarse sand "), presence of layers with ferruginous nodules (" nodules "), pH of water (" pH ") and carbon content (" carbon ") between 5 and 20 cm of depth;
- topography, by the way of a digital elevation model, elaborated for the 12 plots from 5 meters contour lines.

Between 1986 and 1988, 3 types of silvicultural treatments were applied on 9 of the plots (each treatment repeated 3 times), the last 3 remaining control plots (T0). The treatments were the following: (T1) traditional selective felling of commercial species, representing about 10 trees more than 50 to 60 cm dbh per hectare; (T2) selective felling plus thinning by poison-girdling of all non-commercial species (NCS) more than 40 cm dbh; (T3) selective felling plus logging of NCS between 40 and 50 cm dbh (for fuel wood), followed by poison-girdling of all NCS more than 50 cm dbh (Schmitt, 1989). Table 2 summarizes for each treatment the evolution of the number of trees and the total basal area between 1984 and 1994.

To adjust the components of the single-tree / distance dependent model, we focused on 8 of the 12 plots (2 plots per treatement), in order to keep an independent data set for a validation work. In each plot, to calculate diameter increment, we considered trees as far as: (*i*) they did not present any measurement anomaly and (*ii*) they were located more than 30 m from the border line, to authorize the calculation of competition indices. This left us with 10 745 trees and 173 species (or so-called). We worked on a three-years time step basis.

Table 1: *Soil variables and notations used in the analysis. The classes are described according to Barthès (1991).*

Variables	Classes	Notations
Drainage	Bottomland, greyish sandy profile, moistened to humid from bottom to top	*drain1*
	Moistened profile with a depth more than 100 cm	*drain2*
	Moistened profile with a depth between 80 and 100 cm	*drain3*
	Moistened profile with a depth between 60 and 80 cm	*drain4*
	Moistened profile with a depth less than 60 cm	*drain5*
Hydromorphy	No trace	*hydro0*
	Clear signs at the top of the profile	*hydro1*
	No sandy layers	*sable0*
Coarse sand	Presence of a layer with coarse sand, thickness more than 30 cm	*sable1*
PH (water between 5 and 20 cm of depth)	$pH \leq 4.6$	*pH1*
	$4.6 \leq pH < 5$	*pH2*
	$pH \geq 5$	*pH3*
Carbon (carbon content between 5 and 20 cm of depth)	Content < 1%	*carbo1*
	Content between 1 and 3 %	*carbo2*
	Content ≥ 3%	*carbo3*
Nodules	No trace	*nod0*
	Presence of a layer with ferruginous nodules, thickness more than 30 cm	*nod1*

Table 2: *Number of trees more than 10 cm dbh (N) and total basal area per hectare (G) for each treatment (3 plots per treatment) at the Paracou site. Timber felling took place from Oct. 1986 to May 1987, and thinning from Dec. 1987 to Jan. 1988. After Prothery (1995).*

Years	Control plots		Treatment 1		Treatment 2		Treatment 3	
	N	G (m^2)	N	G (m^2)	N	G (m^2)	N	G (m^2)
1984	625	30.9	603	30.6	623	31.9	628	32.1
1985	626	30.9	606	30.7	626	32.0	626	32.0
1986	626	31.0	606	30.7	626	32.1	625	32.1
1987	622	30.8	512	25.0	523	25.5	442	21.3
1988	618	30.7	506	24.9	496	20.4	425	17.6
1989	615	30.7	508	25.0	488	19.3	423	17.1
1990	614	30.7	509	25.1	489	19.2	431	17.2
1991	616	30.8	521	25.4	504	19.4	449	17.3
1992	614	30.9	530	25.6	513	19.7	470	17.7
1993	611	30.9	533	25.8	525	20.1	487	18.1
1994	607	30.9	531	25.9	527	20.3	490	18.5

METHODS

The growth model consists of 15 submodels, each one fitted to a particular group of species. It was built according to the " potential x modifier " philosophy (see, for example, Monserud, 1975, Hahn and Leary, 1979, Leary and Holdaway, 1979, Shugart, 1984, Fairweather, 1988, Parresol, 1995, Murphy and Shelton, 1996 and, for a more systematic review, Gourlet-Fleury, 1997): in this class of model, growth is considered to be the product of " potential growth ", the maximum possible growth when there is no competition, and a " modifier component ", usually a function of more or less empirical competition indices (Dreyfus, 1988, Biging and Dobbertin, 1992, 1995, Gourlet-Fleury, 1992b, 1998) which represent the environmental pressure on the tree. The calibration was done by ordinary least square regression after log-transformation of the dependent variable, diameter increment.

A one-way analysis of variance (ANOVA) was used to study the plot effect on residuals (hypothesis of ANOVA were checked). In order to explain this plot effect, we investigated the informations brought by soil and topographical data (namely altitude and slope, extracted from the digital elevation model), taking into account the fact that the only way to extrapolate pedological information (availability restricted to control plots) was to rely on topographical ones.

First, we studied the relationships between soil variables (all discrete). The association was tested by means of the Pearson chi--square test of independence for a pairwise study of the variables. Since they do not have the same number of classes, the tests do not have the same number of degrees of freedom. Therefore it is not possible to compare directly the Pearson chi--square values obtained for the different variables. For this purpose, the coefficient phi is a better statistic (see Bishop *et al.*, 1975). It varies between 0 and 1 and any test is associated with this coefficient. A value near zero indicates a weak association and a value near 1 indicates a strong association. A multiple correspondance analysis (MCA, Lebart *et al.*, 1984) was performed to precise the nature of the associations.

To quantify the relationships between topographical and pedological variables, while taking into account the relationships between altitude and slope, we performed a multivariate analysis of variance where those variables were the response variables and the soil variables were the factors.

We finally realized a canonical correlation analysis. Given two sets of variables X and Y (here, the topographical and soil variables respectively), this type of analysis find linear combinations of X and Y (called the canonical variables) such that the correlation between the two sets of variables is maximized. Canonical correlation analysis has certain maximal properties similar to those of multiple correspondance analysis. However, whereas MCA considers interrelationships within a set of variables, the focus of canonical correlation is on the relationship between the two groups of variables. Simple and multiple correlation are special cases of canonical correlation in which one or both sets contain a single variable (see Mardia *et al.*, 1979). This analysis provided us with canonical variables and we studied the interest of the first of them to improve our growth model.

All computations were performed by using procedures of SAS (SAS, 1990).

RESULTS

The growth model

The 15 submodels use the following expressions:

$$Log(\Delta D + 0.287) = Log(potential) + Log(modifier) + \varepsilon,$$

with, in all cases,

$Log(potential) = Log(a) + Log(D) + Log[Log(K) - Log(D)]$ that is to say the Gompertz model and, according to the species groups:

- $Log(modifier) = bNBD^{1/2} + c\Delta NBD + d\Delta NBD^2 + e$ [6]
- $Log(modifier) = bNBD^{1/2} + c\Delta NBD + d\Delta NBT^2 + e$ [7]
- $Log(modifier) = bLog(NBD + 1) + c\Delta NBD + d\Delta NBT^2 + e$ [8]
- $Log(modifier) = bNBD + c\Delta NBD + d\Delta NBD^2 + e$ [9]
- $Log(modifier) = c\Delta NBD + d\Delta NBD^2 + e$ [10]
- $Log(modifier) = c\Delta NBD + d\Delta NBT^2 + e$ [11]
- $Log(modifier) = c\Delta NBD + e.$ [12]

D is the diameter at breast height (cm) in 1988, immediatly after the completion of silvicultural treatments, D*D* the annual diameter increment of the tree, smoothed over the period 1988-1991 (cm/yr). *NBD*, D*NBD* and D*NBT* are competition indices:

- *NBD* (resp. *NBT*) is the total number of neighbours with a dbh greater than or equal to the subject one in 1988 (resp. total number of neighbours ≥ 10 cm of dbh) and located less than 30 m from it;

- D*NBD (resp.* D*NBT)* is the variation of the *NBD* (resp. *NBT*) index during the 3 years period preceding the current period of growth, *ie* from 1985 to 1988: negative values of Δ*NBD* render a decreasing environmental pressure on the subject tree, either because it grew faster than its neighbours or because death — natural, logging or poison-girdling — occured; positive values, on the contrary, result from a better growth of the neighbours and render an increase in competition. D*NBD* is particularly efficient in rendering the effect of silvicultural treatments.

a and *K* (cm) are the parameters of the Gompertz model: *a* is the inverse of a time constant and *K* is the maximum value *D* can reach. *b*, *c* and *d* are the other regression parameters. Their values, all significantly differing from zero, are shown on table 3. Details about the species grouping and the method followed to build the submodels will be found in Gourlet-Fleury (1997, p.119-133).

The global efficiency of the growth model can be roughly characterized by the pseudo-R^2:

$pseudo - R^2 = 1 - \left[SSR/_{CSS} \right] = 0.42$ with *SSR* (sum of squared residuals) = 995 and *CSS* (centered sum of squares) = 1715. Residual distributions are norl (Shapiro-Wilk tests) for all but two species groups (g1.2 and g3.1). However, the deviation was not judged sufficiently important to invalidate the following analysis.

Table 3: *Values of the parameters of the 15 submodels (the line titled " sub-model fitted " refers to equations given in the main text). The 15 species groups are allocated among 5 super-groups corresponding to size criteria and susceptibility to social position. Inside each of them, species groups are characterized by an increasing mean of diameter growth. Note that group g1.3 gathers non identified species belonging mainly to Chrysobalanaceae (" gaulettes "). NB. See Gourlet-Fleury (1997, p.119-133) for more details.*

Table 3(a) Super-group 1: small size species with no obvious susceptibility to social position.

Species group	Group g1.1	Group g1.2	Group g1.3	Group g1.4
Mean diameter increment on the control plots (cm/yr)	0.05	0.05	0.11	0.07
Typical species	*Catostemma fragrans* Bentham Bombacaceae	*Iryanthera sagotiana* (Bentham) Warburg Myristicaceae	—	*Sloanea cf. guianensis* (Aublet) Bentham Elaeagnaceae
Sub-model fitted	[6]	[6]	[6]	[6]
Parameters	Estimate *(s)*	Estimate *(s)*	Estimate *(s)*	Estimate *(s)*
a'[a]	-4.29 *(0.04)*	-4.28 *(0.05)*	-4.39 *(0.06)*	-4.29 *(0.05)*
K (cm)	71.68 *(3.88)*	77.13 *(6.07)*	93.81 *(7.59)*	87.27 *(7.62)*
b (*10^{-3})	0.00	0.00	0.00	0.00
c (*10^{-3})	-9.97 *(0.84)*	-12.66 *(1.02)*	-15.70 *(1.37)*	-11.40 *(0.89)*
d (*10^{-3})	-0.050 *(0.009)*	-0.070 *(0.011)*	-0.053 *(0.014)*	-0.053 *(0.010)*

[a]: see bottom of table 4(d).

Table 3(b): *Super-group 2: average to big size species showing no obvious susceptibility to social position.*

Species group	Group g2.1	Group g2.2	Group g2.3	Group g2.4
Mean diameter increment on the control plots (cm/yr)	0.06	0.09	0.12	0.17
Typical species	*Bocoa prouacensis* Aublet Caesalpinia-ceae	*Lecythis poiteauii* Berg Lecythidaceae	*Licania cf. micrantha* Miq Chrysobala-naceae	*Eperua falcata* Aublet Caesalpinia-ceae
Sub-model fitted	[6]	[5]	[5]	[5]
Parameters	Estimate *(s)*	Estimate *(s)*	Estimate *(s)*	Estimate *(s)*
a'[a]	-4.38 *(0.06)*	-4.52 *(0.03)*	-4.45 *(0.03)*	-4.50 *(0.05)*
K (cm)	81.66 *(5.40)*	94.21 *(2.76)*	96.78 *(2.26)*	112.85 *(4.57)*
b ($*10^{-3}$)	0.00	0.00	0.00	0.00
c ($*10^{-3}$)	-13.72 *(1.84)*	-22.47 *(1.55)*	-20.91 *(1.62)*	-30.64 *(2.76)*
D ($*10^{-3}$)	-0.044 *(0.014)*	-0.174 *(0.027)*	-0.153 *(0.029)*	-0.278 *(0.045)*

[a]: see bottom of table 4(d).

Table 3(c): *Super-group 3: large size species with obvious susceptibility to social position. Super-group 4: average to large size species with obvious susceptibility to social position.*

Species group	Group g3.1	Group g3.2	Group g4.1	Group g4.2
Mean diameter increment on the control plots (cm/yr)	0.27	0.50	0.16	0.31
Typical species	*Qualea rosea* Aublet Vochysiaceae	*Sclerolobium melinonii* Harms Caesalpinia-ceae	*Recordoxylon speciosum* (R, Ben) Norm. et Marq Caesalpinia-ceae	*Symphonia globulifera* Linnaeus f. Clusiaceae
Sub-model fitted	[4]	[7]	[1]	[1]
Parameters	Estimate *(s)*	Estimate *(s)*	Estimate *(s)*	Estimate *(s)*
a'[a]	-4.38 *(0.08)*	-4.36 *(0.28)*	-3.73 *(0.15)*	-4.05 *(0.17)*
K (cm)	131.53 *(8.80)*	196.34 *(83.99)*	69.98 *(4.60)*	99.71 *(12.65)*
b ($*10^{-3}$)	-1.19 *(0.47)*	0.00	-47.25 *(10.45)*	-27.28 *(10.49)*
c ($*10^{-3}$)	-28.82 *(3.22)*	-19.03 *(4.32)*	-24.15 *(2.72)*	-29.89 *(2.60)*
d ($*10^{-3}$)	-0.257 *(0.056)*	0.00	-0.125 *(0.044)*	-0.192 *(0.042)*

[a]: see bottom of table 4(d).

Table 3(d): *Super-group 5 : small size species with obvious to great susceptibility to social position.*

Species group	Group g5.1	Group g5.2	Group g5.3
Mean diameter increment on the control plots (cm/yr)	0.09	0.18	0.25
Typical species	*Drypetes variabilis* Uittien Euphorbiaceae	*Couepia cf. caryophylloïdes* R, Ben Chrysobalanaceae	*Inga cayennensis* Sagot ex Bentham Mimosaceae
Sub-model fitted	[3]	[3]	[2]
Parameters	Estimation *(s)*	Estimation *(s)*	Estimation *(s)*
a'a	-2.96 *(0.28)*	-3.14 *(0.16)*	-3.76 *(0.35)*
K (cm)	56.62 *(4.39)*	74.70 *(3.70)*	94.83 *(29.04)*
b ($*10^{-3}$)	-234.94 *(48.31)*	-223.95 *(30.02)*	-47.73 *(18.58)*
c ($*10^{-3}$)	-17.33 *(1.18)*	-17.72 *(1.16)*	-21.93 *(1.88)*
d ($*10^{-3}$)	-0.069 *(0.014)*	-0.055 *(0.011)*	-0.107 *(0.021)*

[a] The constant e in the modifier components cannot be estimated separately from the parameter a of the Gompertz model (potential component). The parameter estimated then is a'=Log(a)+e.

Soil and landfacets effects

A significative plot effect remains on the residuals and a Bonferroni test (multiple comparison of means) separates three groups (table 4): (*i*) plot 10 (treatment 2), with diameter increments definitely underestimated by the growth model, (*ii*) plots 1 and 6 (control plots) with only a slight underestimate and (*iii*) plots 4, 5, 7, 9, 12 (all treatments) where diameter increments are slightly overestimated. This plot effect is not due to a treatment effect, as was confirmed by a hierarchical analysis of variance " Plot (Treatment) " of the residuals (Gourlet-Fleury, 1997, appendix 6, table a11). Among the remaining factors which can play a part, physical ones are worth being investigated: as a matter of fact, table 3 shows that, before the implementation of silvicultural treatments, mean increments were highest on the control plots than on the others despite similar densities of trees more than 10 cm dbh. This could be due to site effects, at least for the group of plots with negative residual means.

Table 5 shows the relationships between the 6 soil variables collected on plot 1 and 6. All the chi-square tests are significant at the 0.1 % level, indicating redundancy information among them. The phi coefficient ranges from 0.1 to 0.7 for all but three pairs, and show that " drainage ", " hydromorphy ", " coarse sand " and " carbon " are well linked together, " drainage " being associated to " nodules " as well. As can be seen on the two first factorial axes of the MCA (fig.1) for the best described classes, signs of hydromorphy, bottomlands, presence of sandy layers, low carbon content and absence of ferruginous nodules are linked. There is evidence, from Barthès maps and explanations, that those variables are more or less dependent from the toposequence. This can be quickly checked on fig.1, where we projected (as an additional variable) on the first factorial plan the classes of a variable defined from " altitude " and " slope " as follows: bottomlands (altitude ≤ 5 m and slope ≤ 5°), hillsides (slope > 5°, whatever the altitude) and summits (altitude > 5 m and slope = 0).

Table 4: *Ranking of the plots (resp. of the silvicultural treatments) by decreasing values of the growth model residuals (last column). A Bonferroni test (multiple comparison of means) allows a distinction between three groups of plots, according to the mean values of this variable: they are respectively represented with italic, normal and bold type in the last column. (A total of 10745 trees are concerned by the study).*

Plot (treatment)	Number of trees studied	Mean (standard deviation) diameter increment before treatment: 1984-1986 (cm/yr)	Mean (standard deviation[a]) diameter increment after treatment: 1988-1991 (cm/yr)	Mean (standard deviation) of the residuals (Log(cm))
10 (T_2)	1177|	0.117 (0.439)	0.325 (0.090)	*0.100 (0.336)*
1 (T_0)	1596	0.217 (0.599)	0.142 (0.033)	0.021 (0.280)
6 (T_0)	1561	0.267 (0.790)	0.127 (0.029)	0.013 (0.279)
12 (T_3)	1250	0.159 (0.543)	0.252 (0.052)	**-0.017 (0.298)**
9 (T_1)	1344	0.121 (0.384)	0.202 (0.046)	**-0.018 (0.303)**
5 (T_2)	1449	0.124 (0.419)	0.232 (0.064)	**-0.023 (0.311)**
7 (T_1)	1376	0.157 (0.539)	0.188 (0.042)	**-0.027 (0.289)**
4 (T_3)	992	0.143 (0.499)	0.282 (0.065)	**-0.038 (0.333)**
Treatment				
T_2	3157	0.242 (0.700)	0.274 (0.078)	0.032 (0.329)
T_0	2626	0.139 (0.469)	0.135 (0.031)	0.017 (0.279)
T_1	2720	0.121 (0.428)	0.195 (0.044)	-0.023 (0.296)
T_3	2242	0.152 (0.524)	0.266 (0.058)	-0.026 (0.314)

[a] NB. In this column, diameter increment is equal to the slope of a straight line fitted to 4 consecutive measures of diameter, resp. in 1988, 1989, 1990 and 1991. In the previous column, diameter increment is calculated as an arithmetic mean of two values (increment between 1984 and 1985, and increment between 1985 and 1986). Hence, standard deviations are not comparable between the two columns.

Table 5: *Relationships between the different categorical soil variables, as tested by chi-square tests and measured by the phi coefficient: in bold type in the table (Bishop et al., 1975). The analysis are realized on 3157 trees located on the control plots 1 and 6.*

Chi-square (df) **Phi coef-ficient**	Drainage	Hydromor-phy	Coarse sand	pH	Carbon	Nodules
Drainage	-					
Hydromor-phy	1044 (4) **0.575**	-				
Coarse sand	1523 (4) **0.695**	1042 (1) **0.574**	-			
pH	286 (8) **0.301**	394 (2) **0.353**	41 (2) **0.114**	-		
Carbon	1212 (8) **0.620**	541 (2) **0.414**	563 (2) **0.422**	257 (4) **0.285**	-	
Nodules	1032 (4) **0.572**	124 (1) -0.198[a]	49 (1) -0.124[a]	147 (2) **0.216**	164 (2) **0.228**	-

[a] It has to be noted that for 2X2 table, SAS is using a formula which allows negative values.

The class " bottomlands " is by far the best represented on the plan, and strongly linked with the class *drain1* of " drainage " and the corresponding classes of " hydropmorphy ", " coarse sand " and " carbon ". The class " hillsides " is also well represented but in a more neutral position given the great heterogeneity of the soil profiles encountered in that position. The class " summits " is not well represented. Those observations are enforced by the results of the MANOVA (table 6), which show a strong effect of all the pedological variables on the topographic ones except for " hydromorphy " and " coarse sand " which are redundant with " drainage " and are then the less informative.

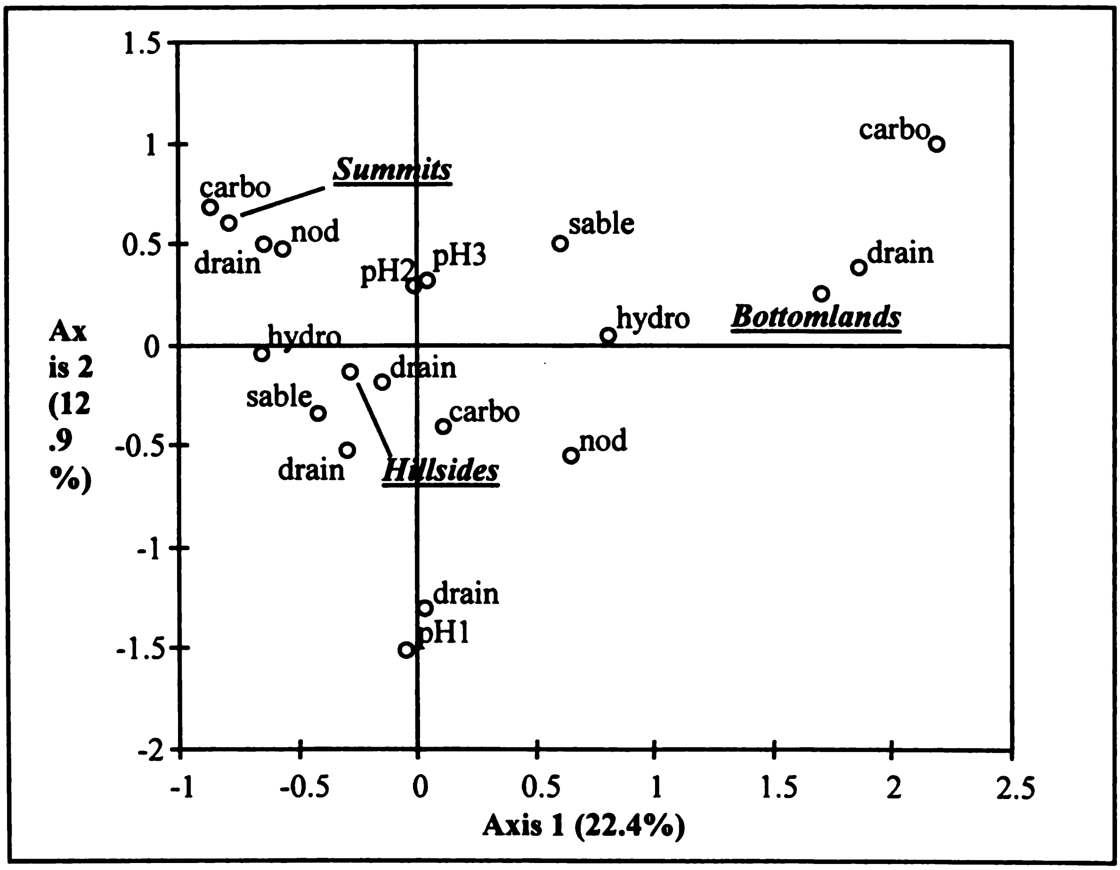

Figure 1: *Projection of the classes of each soil variable (see table 1) on the first factorial plan of a multiple correspondance analysis. The topographical variable (with 3 classes) is treated as an additional variable. This analysis was performed using the three control plots (5182 trees used).*

Table 6: *Results of a MANOVA on the topographical and pedological variables.*

	Wilk's	F	num. df	den. df	P
Drainage	0.97	11.43	8	6210	<0.0001
pH	0.98	18.12	4	6210	<0.0001
Carbon	0.99	7.14	4	6210	<0.0001
Nodules	0.99	22.71	2	3105	<0.0001
Coarse sand	≈ 1	0.41	2	3105	0.66

Building of a synthetic topographical variable

The landfacets are interesting mainly because they can be calculated on all the plots, and it can be checked that they have a significative effect on diameter increment as well as on the growth model residuals (table 7. F=9.64, df=2, P<0.001 for the residuals). However, the classes " hillsides " and " summits " are pedologically heterogeneous and we decided to look for a more optimal use of the overall information brought by the soil variables, while using the fact that " altitude " and " slope " are continuous variables. This is why we performed the canonical correlation analysis.

It appears from it that the correlation is not very high between " altitude " and " slope " (r = 0.21). The first canonical variable, which equation is:

$$var1 = 0.82 * altitude + 0.43 * slope,$$

is from far the most important and explain 92% of the correlation between the topographical variables and the pedological ones. The equation of the second canonical variable is: $var2 = -0.61 * altitude + 0.93 * slope$. Its contribution is well smaller than the first one, but the effect is still significant. Var1 mostly represents the toposequence, with minimum values obtained in bottomlands and maximum values on the top of the hillsides (see fig.2), while var2 characterizes the hillsides. The canonical redundancy analysis shows that var1 is a good overall predictor of the pedological variables with an explained proportion of variance of 42%. Var2 does not strongly improve the model.

The residuals of the growth model are plotted against var1 on figure 3. It can be seen that the correlation between the two variables is weak, but it differs significantly from zero (r = -0.08). A simple linear model can be fitted to those data:

$$\varepsilon = a_1 * var1 + a_2 + \varepsilon_t$$

with ε: residuals of the growth model, ε_t residuals of the linear model (*ie* residuals of the growth model once the topographical variable has been taken into account) and coefficients a_1 and a_2 significantly differing from zero (table 8). The resulting *SSR* (989), compared to that initially obtained with the growth model (995: see above) shows that the potential improvement with topography is negligible: it is finally quite comparable to the improvement that can be obtained by directly using a plot factor (*SSR* = 979, but with 7 more parameters instead of 2).

DISCUSSION AND PERSPECTIVES

Information available in the data base of Paracou allowed us to build an individual, spatialised tree growth model which we developped following several steps. The first step consisted in linking diameter increment with diameter of the tree at the beginning of the growth period, and competition indices describing the environment. This resulted in a model working whatever the species, which pseudo-R^2 was equal to 0.23 (Gourlet-Fleury, 1997, p.109). A definite improvement came from the building and taking into account of 15 species groups, defined according to size, mean growth and susceptibility to social position. They allowed to almost double the efficiency of the model.

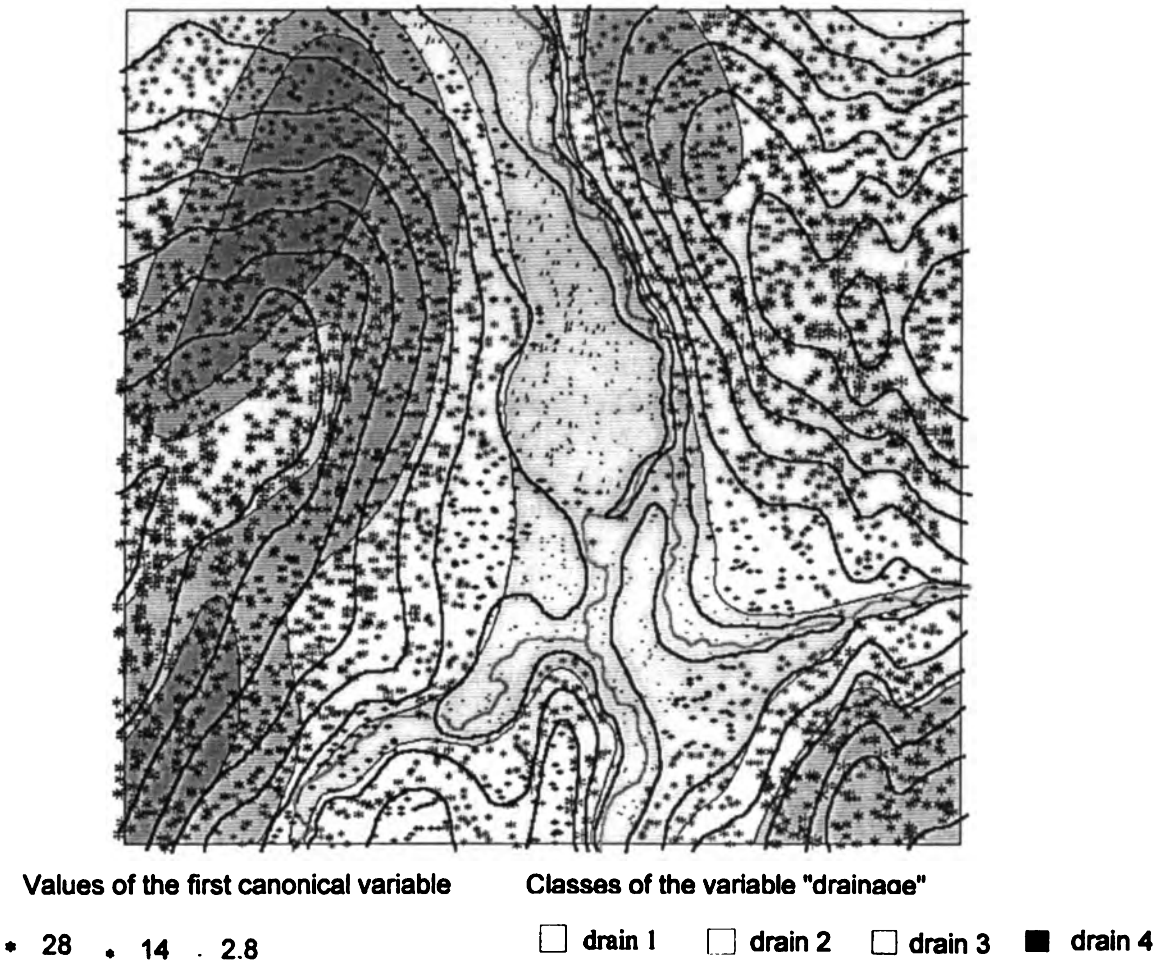

Figure 2: *Map of plot 6, showing the different classes of the variable " drainage ", the 5 m contour lines and the synthetic topographical variable (ie the first canonical variable) obtained through the canonical correlation analysis.*

Table 8: *Results of the fitting of a simple linear model linking the residuals of the growth model to the first canonical variable (10745 trees used for the analysis).*

Source	df	Sum of squares	Mean square	F
Model	1	6.15	6.15	66.75 (P<0.001)
Error	10743	989.15	0.09	
C. total	10744	995.29		
		Parameter estimates		
	df	Estimate	Standard error	
Var1 (a1)	1	-0.0037	0.00046	
Intercept (a2)	1	0.056	0.0073	

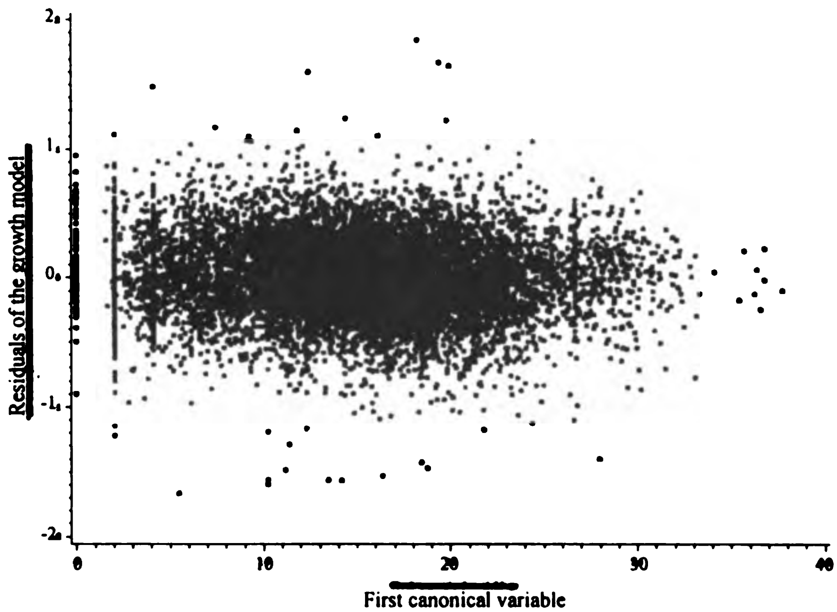

Figure 3: *Link between the residuals of the growth model and the synthetic topographical variable built with the canonical correspondance analysis (10745 trees used).*

Among the soil variables available on the control plots, three deal with the hydrological functioning of the soils (" drainage ", " hydromorphy " and " coarse sand "). Now, it is well known that availability of water along the year is a very important factor which can be critical for a lot of species in those stands; it has an influence on spatial and structural patterns as well as on the overall dynamics (see Barthès, 1990, for a synthesis on the subject in the Guianan forests, and Collinet, 1997), especially growth: trees grow faster in bottomlands. This is well verified at Paracou: see table 7, especially the results obtained with residuals as they allow to get free from such confusing effects as size (trees tend to be smaller in badly drained soils), environment (density tends to be higher in bottomlands) and possibly species. If other soil variables seem to have an effect on growth, like for example " Nodules " (on the control plots, the absence of ferruginous nodules goes with higher increments), this is mainly due to a confusing effect of bottomlands (where nodules are absent). The variable pH does not really bring a useful information and the pattern of its variations on the plots is confused (Barthès, 1991). As far as " carbon " is concerned, the information brought is redundant with " altitude " but in a quite surprising way: contents are smaller in the bottomlands, medium on the hillsides and higher on the summits when the inverse situation would be expected (Ferry, *pers. comm.*). Increments being higher in the bottomlands, a negative link with the carbon content appears.

Those analysis show that the real important information to take into account is the presence of a bottomland, and this makes the potential interest of the topographical variables altitude and slope. The first canonical variable built is strongly linked to " altitude " and reveals to be negatively correlated with the residuals of the growth model: for low values of var1, increment observations tend to be underestimated by the model, while for high values of var1, they tend to be overestimated. This is coherent with what was precedently said. However, the link between var1 and the residuals is too loose to bring any significative improvement to the prediction of growth, and does not prove more efficient than a mere " plot factor ".

In fact, the sampling design made by Barthès to analyse the pedological cover (29 , 39 and 59 soil profiles realized resp. on plot 1, 6 and 11) was very loose, while the author recognized himself (Barthès, 1988) that very contrasted local situations could be encountered on the plots, with important changes occuring on a few meters (eg. changes in soil depth, presence of sand pockets ...). A recently and precise study of the bottomlands on one of the control plots led Ferry to completely reconsider the limits of the very important class " *drain1* " of the variable " drainage ", and to question the real interest of variables like carbon content (Ferry, *pers. comm.*). Important progresses must be made in this field at Paracou.

Table 7: *Effect of landfacets on diameter increment, as measured on the trees of our calibration data set (10745 trees are taken into account).*

Landfacets	Number of trees	Mean annual diameter increment		Residuals of the growth model	
		Mean (cm)	Variance (cm^2)	Mean (Log(cm))	Variance ($(Log(cm)^2)$)
Bottomlands	751	0.224	0.066	0.040	0.104
Hillsides	9225	0.212	0.054	0.001	0.091
Summits	769	0.192	0.049	-0.028	0.098

Nevertheless, the plot effect remaining on the residuals of our growth model cannot be entirely attributed to topographical and physical effects, as proven by the opposite behaviour of plot 4 and 10. On those plots, mean diameter increments and densities were similar before the treatments, increments being slightly more important on plot 4 (see table 4). The silvicultural treatment applied to plot 4 was particularly heavy (T3), with resulting increments smaller than those observed on plot 10 less heavily touched (T2), a phenomena that the growth model failed to predict. Among the possible explanations, a physiological stress due to a severely modified micro-environment could be put forward (as shown by Colin, 1989, with *Goupia glabra*), but remains to be proved.

We focused here more specifically on plot effects to lighten the information still lacking at Paracou. But other problems remain to be solved, which could lead to significantly increase the efficiency of our model. Botanical determination is one of them, as the relevance of our species groups greatly depend on it. At least as important is the problem of the measurement of large trees. In our calibration data set, those trees are under-represented, because they frequently are buttressed or warped and diameter increments are not reliable. This causes the *K* parameters of the growth models to be estimated with a low accuracy, with important consequences when they are implemented in a simulator of forest dynamics. Our trials (Caruso, 1994, Gourlet-Fleury, 1997, 1999 — to be published —) showed that the *K* parameters play an important part in the under- or over- accumulation of large trees in simulated stands and hence on basal area and global as well as local competition, thus finally on the general behaviour of the system. A method to correctly estimate the dbh of those individuals, and to re-introduce them in the data set, is currently under study.

We finally can mention that other sources of informations also are quite usefull for modelling the growth. Thanks to the availability of now long time series, we could calculate and introduce autocorrelation between successive predicted increments, leading to a definite improvement of the simulator behaviour. There also is a possibility to take climate effects into account, as we could show, for example, a link between peaks in annual rainfalls and high diameter increments two years after. This could be interesting for the simulation of long term scenarios.

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CIRAD is a French scientific organisation specialized in development-oriented agricultural research for the tropics and subtropics (Centre for International Cooperation in Agricultural Research for Development).

MODELLING PENTACLETHRA FOREST – AN IMPORTANT CENTRAL AMERICAN LOWLAND RAIN FOREST TYPE – FOR TIMBER PRODUCTION

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ABSTRACT

Pentaclethra forest is a major component of the Central American Atlantic Moist Forest Ecoregion (CAAMFE). It covers most of the Costa Rican Atlantic Lowland region and parts of Panama and Nicaragua. Although soils are poor, deforestation in this forest type, for pastureland or permanent crops such as citrus, has been extensive during recent decades. The remaining forest stands, are small fragments in protected areas or on privately owned land, of which, the latter is one of the main sources of timber in the countries mentioned. The traditional log-and-leave methods are recognized to be obsolete and a relatively good biophysical information base for the management of Pentaclethra forests has been built up by CATIE and other institutions. This information is appropriate for the development of computer models of stand dynamics in managed forests. In this paper we present a synthesis of studies in Pentaclethra forest aiming to demonstrate the feasibility of silvicultural interventions to promote sound management practices in these forests. A model framework is presented.

INTRODUCTION

Pentaclethra forest (Finegan and Camacho 1999) is a major component of the Central American Atlantic Moist Forest Ecoregion (CAAMFE). Dinerstein et al. (1995) defined the CAAMFE among other Latin American ecoregions, and according to its importance to ecological processes, conservation status, and priority, they classified it as bioregionally outstanding, vulnerable and moderate priority at regional scale respectively. CAAMFE covers an area of about 155,020 Km^2 extending from Guatemala down to Panama. In the Southern region of this area, from Panama through Costa Rica to Southern Nicaragua this ecoregion is dominated by *Pentaclethra macroloba*, a legume tree species with dominance of about 14-25 % of the IVI and 18-44 % of total basal area for trees with dbh ≥ 10 cm.

These forests have been severely devastated for banana plantations, cattle breeding, and unplanned logging leaving the area with small to medium size fragments of forests. Most of the remaining forest fragments are under total protection or in privately owned farms, subject to conversion to other more attractive land use forms. Forest management practices that promote ecologically sound timber harvesting as alternative to logging and abandon, and total protection include silvicultural treatments to improve the economic value of the forest while maintaining ecological processes of the natural forest system. CATIE is a leading institution among those that investigate forest management principles and practical issues within CAAMFE and in Pentaclethra forest in particular. Long-term research areas have been established since 1988 in four areas, two in Northern Costa Rica and two in Southern Nicaragua to monitor forest interventions and response of the forest to these interventions.

Modelling these ecosystems is now undergoing with perspective to produce general tendencies using the information derived along the one decade of observations. Preliminary results on logging and silvicultural effects on species composition, growth trends, regeneration and mortality patterns have been reported elsewhere (Sitoe 1992, Castillo 1997, Finegan and Camacho 1999, Finegan et al. 1999). A general framework for a patch model (based on gap-modelling principles) has been adopted for the site conditions and data available at hand (Sitoe 1998). The model is expected to be able to test hypotheses regarding forest management interventions in relation to the ecosystem integrity in terms of species composition, growth of remnant forest stand, regeneration and mortality as well as give insights of the forest dynamic processes.

Our purpose with this paper is to present *(a)* a review of the long-term research activities in Pentaclethra forest by CATIE's Natural Forest Management Unit; *(b)* a summary of preliminary results; and *(c)* the modelling strategy and framework adopted.

HISTORY OF LONG TERM RESEARCH

Five research sites were established by CATIE in the three countries covered by CAAMPFE. These sites were established with the objective to (a) monitor forest dynamics and biodiversity of primary forests with different intervention (logging and silvicultural treatment) intensities, (b) evaluation of ecologically and economically sound logging operations, and (c) cost-benefit analysis of the activities in a) and b). The following paragraphs are a brief description of the history of the sites. More detailed description of ecological and silvicultural conditions of the sites can be found elsewhere (Finegan and Camacho 1999, Finegan *et al.* and Castillo, 1997). For all sites the permanent sample plots (PSP) followed Synnot (1979) procedures, with quadrangular form, measuring 100 x 100 m and bordered by 40m stripe each side, except for Changuinola.

Los Laureles de Corinto Research Site is located in a private property in Northern Costa Rica at an altitude of about 250 m.a.s.l. It covers an area of 150 ha with primary and secondary forests. Nine (PSP) were established between 1987 and 1990 within the primary forest area. Commercial logging operation was planned and implemented in 1992 in 30 ha, which also included six of the PSP. A liberation silvicultural treatment was applied in three of the logged plots four years after logging.

La Tirimbina Research Site is also in a privately owned land in Northern Costa Rica, about 50 Km north of Laureles de Corinto, in an altitude of about 200 m.a.s.l. La Tirimbina covers an area of about 80 ha with primary and secondary forests. Nine PSP were established between 1988 and 1990 in within the primary forest area. Between 1989 and 1990 all the plots were commercially logged followed (in 1991 and 1993) by silvicultural treatments (liberation, refinement and shelterwood).

Changuinola Research Site is located in Northern Panama in a private land of about 78 ha of which one half are primary forest. Eight 80x80 m plots were established in 1990. These plots have been selectively logged by the landowner in a yearly basis. Liberation silvicultural treatment was applied in 1992 in two plots.

La Lupe and Los Filos Research Sites are located in Southern Nicaragua and presently are being managed by UCA (Universidad Centroamericana). Six PSP were established in La Lupe in 1990 and a liberation silvicultural treatment was applied between 1992 and 1995. In Los Filos, eight PSP were established in 1992 followed by improved logging operation.

RESULTS FROM 1988-1998

Early results from the research sites have been reported in a variety of forms, from thesis dissertations to scientific papers. In this section, we present some of the most relevant results reported from the Southern Nicaragua (La Lupe and Los Filos) and Northern Costa Rica (Laureles de Corinto and La Tirimbina) sites.

All the sites are dominated by *Pentaclethra macroloba* with IVI varying from 14 to 26% and a relative abundance of about 18-44%. The total number of species identified is between 161 and 272. Table 1 presents the general characteristics of the CATIE research sites in Pentaclethra forest. The Costa Rican sites seem to be denser and diverse than the Nicaraguans.

Table 1: *General characteristics of the Pentaclethra forest. IVI – importance value index; BA – basal area ($m^2.ha^{-1}$).*

Site	Area* (ha)	Total species	Species per ha	#Stem per ha	Pentaclethra macroloba		
					IVI %	% stems	%BA
Corinto(1)	9	272	103	435	25.9	24.9	44.3
Tirimbina(2)	9	259	103	504	15.6	14.0	32.0
La Lupe(3)	6	161	94	499	14.2	10.5	17.8
Los Filos(3)	8	180	101	436	14.7	11.0	18.7

* Effective area of the plots.
(1) Brenes, H. Natural Forest Management Unit Data base administrator. Unpublished data
(2) Camacho and Finegan 1999, Finegan et al. 1999
(3) Castillo, 1997

Of the total species identified in the each site, there is an average of fifty commercial (timber) species. These are considered more in detail in silvicultural studies.

The diameter distribution structure conforms the reverse-J, with most of the trees not exceeding 30 cm dbh. This large group of small trees includes juveniles of canopy species, adults of understorey species and palms. The analysis of the vertical structure of the forest shows that trees (dbh≥10cm) grow in a variety of canopy closure conditions with relatively few trees growing in completely open conditions and also few in completely shaded conditions. This means that the majority of the trees receive a certain amount of sunlight either directly or through sunflakes during the daytime.

Diameter to height equations were developed based on literature information. Llerena and Malleux (1984), experimented with several equations while Botkin (1993) used a quadratic function and Lieberman *et al.* 1995 used a power function. The power and quadratic functions were used to test the best fit to the data of Corinto Research Site. Analyses were divided in adult size (Zamora *et al.* 1997) because Finegan and Camacho et al found final adult as influencing the stem diameter growth pattern.

From the regression and the residual analysis for the diameter-to-height function we found that the quadratic function performed well for all adult size species groups except the understorey species that exhibited a linear relation. Note that understorey species have stem diameters up to 30 cm. One equation was developed for each adult size and the coefficients are presented in Table 2. The residuals for all the models were checked and were found to be randomly distributed with mean zero and homogeneous variance as required by regression assumptions. The coefficients of determination (R^2) ranged from 0.32 to 0.81. Figure 1 shows the scater plot with the fitted lines for each adult size species group.

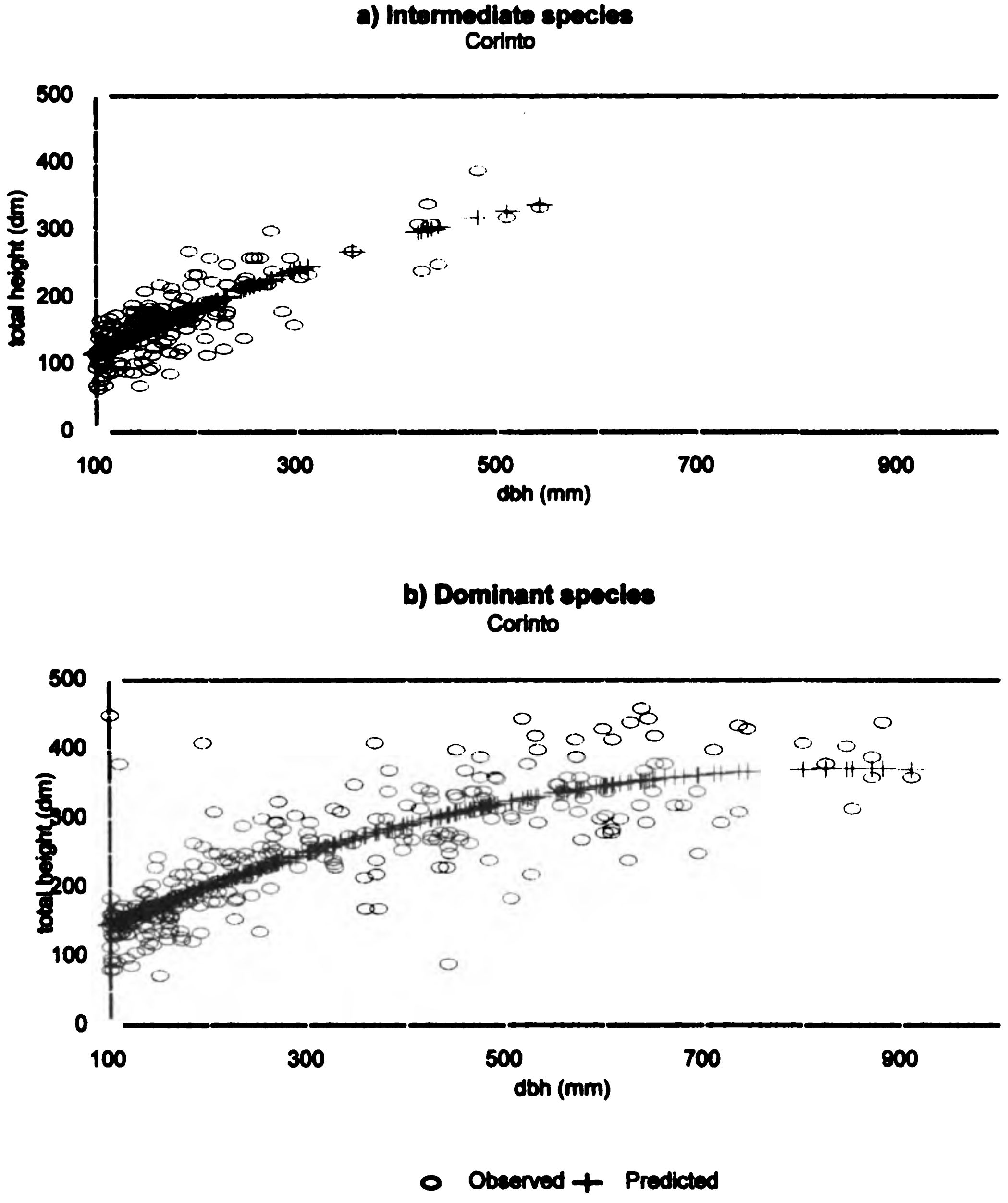

Figure 1: *Scatter plot of the observed and predicted total stem height for Corinto (data from plots 1,2,3 and 4). Statistics of regressions used to estimate predicted heights are presented in Table 2. Figure 2.a was manually set to a different scale (x-axis) to evidence the trend.*

Table 2: *Regression coefficients for the quadratic function of height on dbh. N – number of stems; a – intercept; b_1 and b_2 are linear and quadratic coefficients respectively; R^2 is the model coefficient of determination. All models are highly significative ($P<0.0001$).*

Adult size	N	*a*	b_1	b_2	R^2
Understorey	54	43.62	0.704	-	0.32
Intermediate	165	38.19	0.828	-0.000503	0.65
Sub-canopy	136	-11.98	1.129	-0.000739	0.50
Dominant	280	81.94	0.687	-0.000405	0.66
Unknown	84	25.22	0.875	-0.000501	0.81

MODELLING FRAMEWORK AND STRATEGY

The ultimate purpose of long-term data collection is to empower the researcher through the data set with new knowledge. Specific objectives include finding general trends and patterns of the reaction of the tree species when logging and silvicultural treatments are applied in a forest stand. If trends and generalizations could be made, then they can be formally stated in form of a simulation model. The final goal of the modelling process as stated by the Forest Management Unit is to "*broaden and deepen our understanding of the forest dynamic processes...*" (CATIE 1995, Campos et al. 1997). The defined modelling objective suggests a model to give insights of the forest dynamic processes rather than predictions. A process-based model would be the ideal tool for the stated purpose. However, the development of a process-based model requires costly data not collected traditionally in forestry sciences, where "pragmatic data" are the most important. On the other hand, the empirical models that have been traditionally used in forestry, despite their relative simplicity and accuracy, do not fit well in this objective. Empirical models have been reported as neglecting the ecological aspects while fitting well the observed data to statistical equations (Amateis 1994). This is expected when considering the Levins tricotomy of biological models, in which to gain in accuracy, one should sacrifice one of the other two aspects, generality and realism (Levins 1966, 1993).

Taking into account the objectives stated and the data available, an intermediate term was to be found between empirical and process-based models. The gap-based models offered one of these viable alternatives (Botkin 1993, Shugart 1998). The gap-based models use most of the data traditionally collected in permanent sample plots in forest sciences and offer an acceptable alternative of expressing ecological relations within a forest ecosystem that could be interpreted for forest management purposes. We do recognize the difficulties existing to depart from empirical to process-based models. Recent gap-models use non-traditional input data, and biological processes are better represented in these models. Thus, the model framework we are proposing here has an important goal: to provide a research framework, highlight data requirements and areas for further research.

Figure 2 presents the general model framework adopted based on this approach, and will be used to develop the first modelling approach for our research sites (Sitoe, 1998). The species ecological groups developed by Finegan et al.1999 will be used together with the commercial value of the species to develop the species list. Output from other relevant models could be used to provide input for our model when data could not be collected (e.g. Maximum age could be estimated using the growth simulation technique - Lieberman and Lieberman, 1987). Allometric functions of correlated tree characteristics (e.g. dbh-to-height) will be developed. Topography and soil type will act as micro-site factors within the site while logging and silvicultural treatments will be simulated according to the established rules for forest management. The global model will be composed of the traditional growth, mortality, regeneration and silvicultural sub-models. The model resolution will be at individual tree level simulated in function of species, relative size to the neighbours, initial conditions of the tree and micro site characteristics.

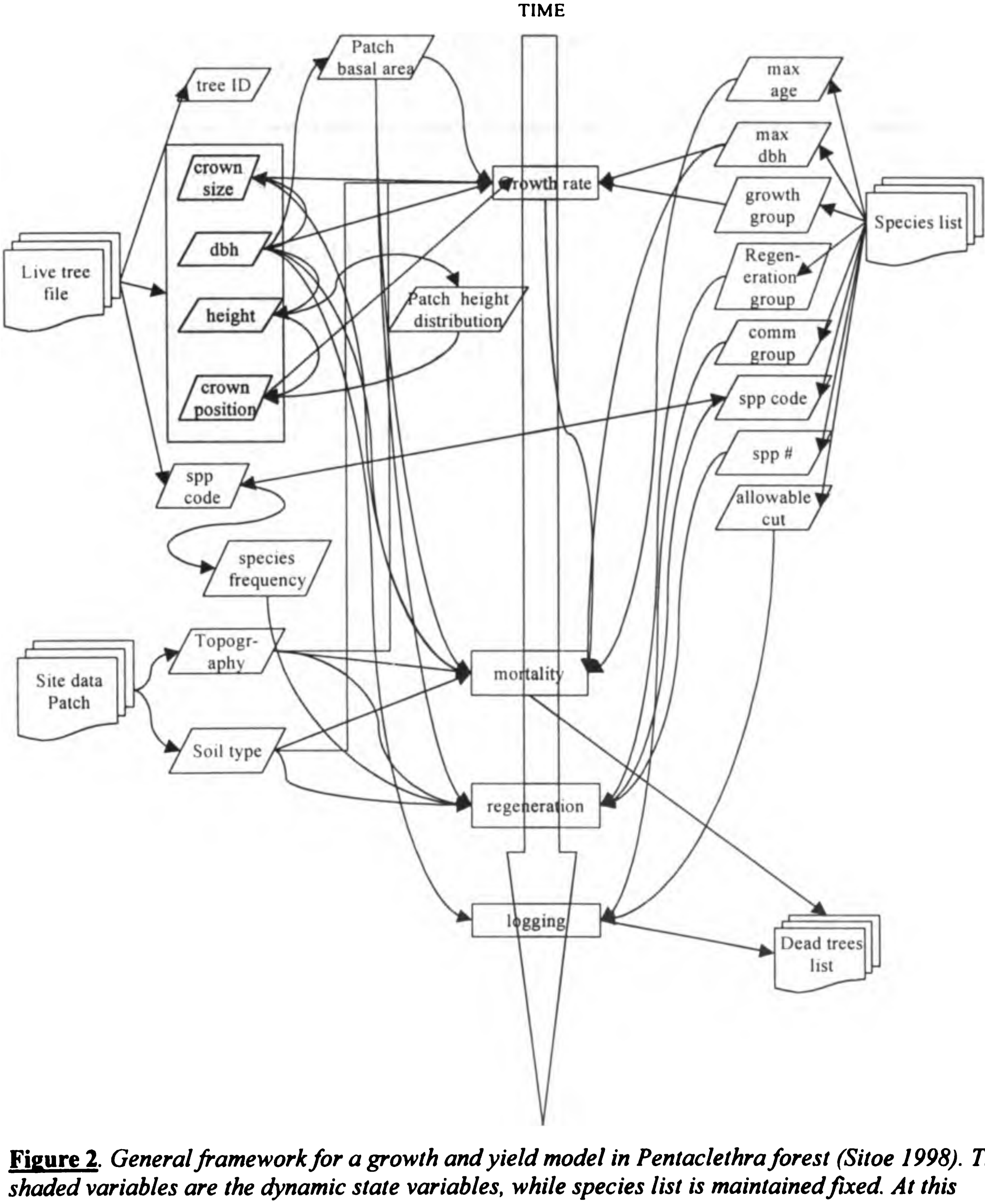

Figure 2. *General framework for a growth and yield model in Pentaclethra forest (Sitoe 1998). The shaded variables are the dynamic state variables, while species list is maintained fixed. At this stage, site characteristics will also be considered fixed. The large downward arrow represents the time and rectangles on it, the "processes" to be modeled.*

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MODELAMIENTO EN BOSQUES NATURALES EN CHILE

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ABSTRACT

The Universidad Austral de Chile is actually developing a project titled "Software of Planning of Activities in Second Growth Forests of Roble - Raulí - Coigue in the IX and X Region". This Roble - Raulí – Coigue's "renovales" (from the genus Nothofagus) correspond to pure or mixed natural second growth forests that have a relatively regular age; they are originated after anthropic interventions or environmental catastrophes of magnitude. The project before mentioned considers the following modules:

A. GROWTH projection of the species under study.

· To gather, depure and analyze the available information of companies and institutions.

· To obtain information from temporary plots.

· To design and implement a National Net of Permanent Trails.

· To design a Data and Information Administrative System.

· To fit Yield and Growth Models and implement them in a simulation software.

B. Determination of internal QUALITY of the commercially susceptible logs and projection of the qualities spread.

· To select and measure sampling plots, to make a trees stratification and a measurement of them.

· To select a sub-sample for laboratory analysis of wood defects.

· To determine log models between the external attributes and the internal quality.

C. Generation of ECONOMIC EVALUATIONS for several options, scenarios and products.

· To analyze the methodology of Economic Evaluation and to obtain indicators of Profitability.

· To develop and to implement a system of Economic Analysis.

The first great challenge is the seeking of enough base information, due to restrictions in time it has been tried to gather all the experience that other work groups (as universities, state organisms and companies) have generated in this topic. This has been a very interesting experience due to the fact that the information coming from inventories was complemented with silvicultural experiences, with the problems that this brings as: variables definition, codes, protocols, absence of some variables, bad or lack of documentation, etc. however, their recovery has allowed to save between to 2 - 3 years in time and savings close to 30% of the original project cost.

Another important element refers to the experience of sharing protocols and procedures for the installation of new experimental units with different institutions as a way to converge to a common technical language that allows to improve the use of the information and it produces savings in the generation of this.

In respect to the above-mentioned facts, a Data Administrative system has been generated in which we have the information purified of previous experiences, and all the new one generated by mensurations within this project or others that are related will be picked up and put inside the system.

This Project is been developed with the participation of forest companies, and institutions of relevance in natural resources researches of the country. The project counts with founding from FONDEF (Scientific and Technological Development Foment) - CONICYT (National Commission of Scientific and Technological Research).

The present work is presented with the sponsor of the Research and Development of the Universidad Austral de Chile.

INTRODUCCIÓN

Los bosques naturales o nativos ocupan un importante espacio en Chile, tanto por su superficie (13.443.316 ha) como por su alto valor de protección, escénico, albergue de flora y fauna y aspectos de biodiversidad. Dentro de estos bosques, los renovales alcanzan aproximadamente un 25%, definiéndose como "bosques naturales de segundo crecimiento, puros o mixtos, de una edad relativamente regular desarrollados luego de intervenciones antrópicas o ambientales de magnitud".

Por su parte, el género Nothofagus presenta un interesante potencial econó-mico al producir madera de alta calidad y con interesantes perspectivas en el mercado tanto nacional como internacional.

Dado este escenario, la Universidad Austral de Chile, tradicionalmente líder en investigación de recursos naturales, se encuentra desarrollando un proyecto titulado "Software de Planificación de Actividades en Renovales de Roble-Raulí -Coigue en la IX y X Región".

De acuerdo al "Catastro de Recursos Nativos de Chile" (CONAF 1997), la superficie bajo el concepto de Renoval de las especies antes mencionadas corresponde a un total de 1.044.367 hectáreas en tres regiones de la zona sur del país. De este total, la población de interés de estudio se acotó según el grado de intervención (bajo) y cobertura de copas (> 75%), con lo cual se redujo a 309.537 ha.

El proyecto en referencia generará diversas herramientas como son:

- Simulador de rendimiento y crecimiento
- Metodologías de determinación de calidad internas de las trozas
- Descuentos según el producto objetivo
- Sistema administrador de datos
- Consolidación de la investigación en torno al tema
- Procedimientos estandarizados de toma de datos y de su respaldo

Dado que el proyecto tiene una duración de sólo 30 meses, se determinó que parte importante del esfuerzo se concentraría en la recuperación de información histórica de estudios silviculturales, lo que motivó una serie de contactos y visitas a terreno para seleccionar aquellas experiencias que aportasen a los objetivos del proyecto. Por otra parte, se determinó que una vez hecho el primer análisis de ensayos históricos, se volvería a medir aquellos que se encontraran en buenas condiciones en terreno, de tal forma de incrementar la serie de crecimiento después de la intervención.

Una vez obtenida la información histórica, con otros elementos de muestreo se completará la base mínima para efectos de modelamiento. Por otra parte, se ha preparado un prototipo muy simple del simulador, en que se han incluido algunas funciones de bibliografía para su funcionamiento.

RECOPILACIÓN DE INFORMACIÓN

Uno de los objetivos principales del proyecto, está referido a la creación de una base única, a nivel nacional, que incorpore toda la información histórica que se ha generado en las especies bajo estudio, así como toda las nuevas remediciones de los ensayos antiguos y las mediciones de parcelas semipermanentes instaladas en este período. Esta base estará disponible para cualquier investigador en el tema y será administrada por la Universidad Austral de Chile, además de que sería transferida a siete (7) empresas e insti-tuciones participantes del proyecto.

Por esta razón se ha generado un Sistema Administrador de Datos e Infor-mación con una estructura amplia y flexible que permita acoger a tan diversas fuentes de información. La Universidad Austral de Chile ha generado la "Guía de Ensayos Permanentes en Bosques Nativos de Chile" (Lara *et al*, 1996) en la cual se han incluido todas las experiencias en el ámbito silvicultural en los bosques naturales y con atributos tales como localización, institución o empresa ejecutante, especie, objetivo del ensayo, oportunidad de mediciones, tratamientos silviculturales y otros. Esta Guía permitió seleccionar aquellas experiencias realizadas en las especies de interés y dentro de las Regiones en estudio. La selección dejó un total de 25 experiencias, de las cuales sólo se pudieron recuperar nueve (9).

La etapa de recuperación fue lenta y en un gran porcentaje, hubo que digitar los datos puesto que sólo se obtuvieron los formularios de campo. Una vez recopilada esta información, se clasifica en lo siguiente:

Cuadro 1: *Descripción de datos recuperados*

Tipo estudio	**Nº parcelas**
Parcelas permanentes	75 parc.
Parcelas temporales	124 parc.
Análisis de tallo	308 árb.
Tarugos de crecimiento	55 tarugos
Otros estudios de crecimiento (1)	10 parc., 74 árb. volteados
(2)	12 parc., 81 árb. volteados
(3)	3 parc.
(4)	39 parc.

La instalación de las parcelas (excluidas las temporales), por año, se distribuyen de la siguiente manera:

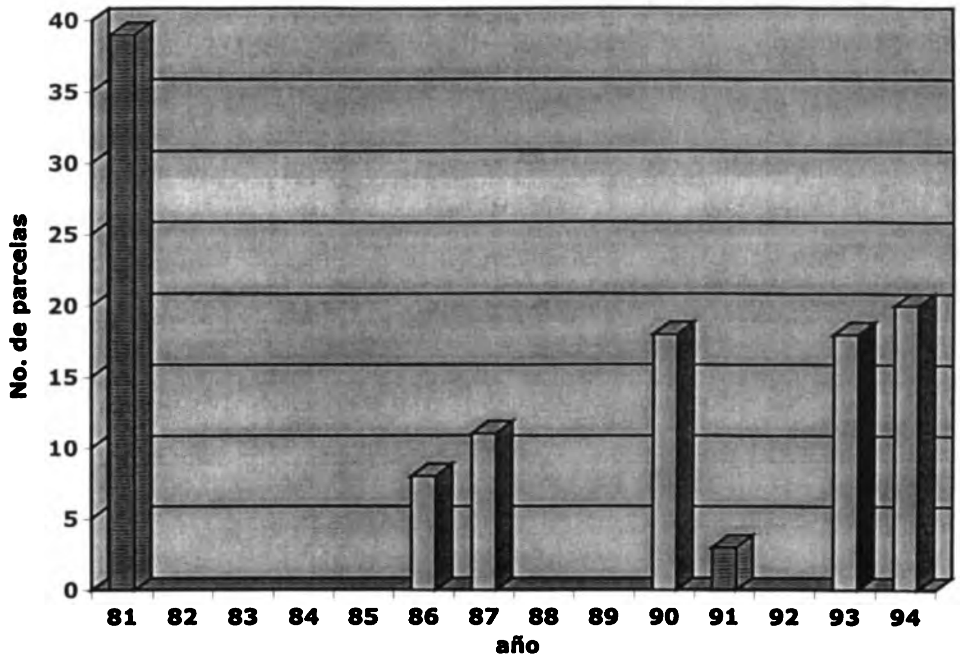

Figura 1: *Distribución de instalación de experimentos por año.*

Del total de 117 experimentos, se remedirán 42 parcelas con el fin de incrementar las series de medición (barras achuradas).

ANÁLISIS DE LA INFORMACIÓN DISPONIBLE

La información que se ha logrado recopilar, según se observa, es escasa y especialmente cuando se intenta modelar los efectos de intervenciones silviculturales. Por otra parte, en muchos de los casos, no se cuenta con la información original de los árboles medidos, sino que se tiene la información procesada a nivel de ha.

Como elementos restrictivos, se pueden destacar los siguientes:

- En una gran cantidad de experimentos, no se ha medido edad ni altura a todos los árboles. En el mejor de los casos, se ha medido una submuestra de altura total
- No existe toda la documentación de las intervenciones silviculturales y en algunos casos, en los datos, no está la información antes del raleo.
- Los ensayos silviculturales están principalmente concentrados en una sola especie, la más productiva y la que ha sido más intervenida, Raulí.
- Sólo se ha medido el diámetro a la altura del pecho (1.3 m), no hay otro tipo de diámetros
- Es un proceso largo el incorporar todos los datos en una base única debido a que en una importante cantidad, hubo que digitar información de formularios. En el resto de los casos, se ha tenido que realizar un trabajo de análisis de las estructuras, dimensiones de las variables y otras actividades.

Por otra parte, en conjunto con las empresas e instituciones participantes en el proyecto, se han planteado los siguientes aspectos, que han permitido redelinear las actividades del proyecto:

- La definición de la población objeto de modelos puede ser diferente a la población que soporta la mayoría de los ensayos silviculturales.
- La duración del proyecto es un factor limitante por lo que la mejor opción sería sacrificar la idea original de un modelo de crecimiento por uno más simple, como lo es el de rendimiento, pero que ésto vaya acompañado de la generación de una red de parcelas permanentes para la generación de un modelo más complejo en el mediano plazo.

Finalmente, como una forma de análisis de la capacidad de los ensayos históricos, de aportar información para el modelamiento del crecimiento, se han graficado algunas relaciones entre las que destacan:

- Área basal/altura dominante

    Total (todos los datos)

Por zona de crecimiento

Por especie

    Por grado de intervención

- Relación tamaño/densidad
- Relación Altura/edad (datos de análisis fustal)

Este análisis gráfico ha permitido visualizar las carencias, especialmente al momento de desagregar información por estratos y verificar tendencias y relaciones.

RESULTADOS

El resultado más importante se refiere al procedimiento de análisis que se ha hecho de la información histórica, independientemente de su aceptación o rechazo para el presente proyecto y de las etapas involucradas en la obtención de nueva información para la ejecución de modelos cada vez más precisos.

El análisis gráfico demostró la gran variabilidad de la población, la incapacidad de generar estratos importantes y poca correlación entre variables con una "supuesta relación", lo que indica que es necesario incorporar nuevas mediciones de parcelas temporales (en la segunda etapa) y otras para la tercera, según se indica a continuación.

ETAPA 1: DATOS ACTUALES

Datos

Los datos actuales, descritos en Cuadro 1, y según lo que se desprende del análisis que se les efectuó, ofrecen una gran ventaja en ahorro de tiempo y recursos. Además, permiten inferir aspectos silviculturales y de mortalidad, aunque en forma muy limitada y local.

Por otra parte, sus restricciones se refieren a la escases y poca representación de la gran variabilidad que es una característica del tipo de bosques a modelar. Originalmente se ha considerado a tres especies, las que se pueden presentar solas o en mezcla. Los datos no representan todas las mezclas para la gran variabilidad ambiental. Adicionalmente, no se ha medido la edad, lo cual es necesario recuperar, según las alternativas que se presentan más adelante.

Por lo tanto, los datos actuales permiten la generación de un modelo simplificado que es el que se describe a continuación.

Modelo 1

Modelo de rendimiento simple de construir y de utilizar, con las siguientes alternativas: con distribución de diámetros, para bosque mixto, con densidad variable.

1.1 Modelo de rendimiento en función de la altura

- Un modelo para cada subtipo forestal
- Curvas de sitio
- Densidad promedio por subtipo
- Supuesto de que la composición no cambia en el tiempo
- Sin tratamientos silviculturales
- Se requiere edad para proyección
- Regresiones:
    - G, N, %sp = f(Hdom)
    - (Dg, Hprom)sp = f(Hdom)
    - CV(dap), D10 = f(Dg, Hdom)
    - h(dap) = f(Hprom, Dg)sp
    - Recuperación de parámetros (Weibull)
    - Funciónes de volumen

1.2 Modelo de rendimiento en función de la edad

Lo mismo que el anterior (1.1), con las siguientes características:

- Usa edad como variable independiente
- Más preciso
- Posibilidad de estratificación por Indice de Sitio
- Mayor facilidad de comprensión de los resultados

1.3 Modelo de rendimiento con densidad variable (en función de la edad)

Lo mismo que el anterior (1.2), con las siguientes restricciones:

- Más datos de G por edad
- Dibujar líneas para densidades menores (no cuantificadas)
- Hay pocos datos por estrato
- Posibilidad de proyectar después de raleo

ETAPA 2: INCORPORACIÓN DE NUEVOS DATOS DE PARCELAS TEMPORALES

Datos

En esta etapa, se considera incorporar lo siguiente:

- Aproximadamente 150 parcelas "semipermanentes" con sus mediciones correspondientes y una muestra total de 1500 tarugos de incremento.
- Nuevos árboles volteados para análisis fustal en áreas geográficas y estratos deficitarios, para la construcción y/o calibración de funciones de ahusamiento y de crecimiento en altura dominante.
- Remediciones en un total de 44 parcelas con raleo.

Con la incorporación de esta nueva información, se puede generar un modelo de crecimiento, con un mayor nivel de precisión pero que aún no asegura una mayor robustez en proyecciones a largo plazo.

Modelo 2: Modelo de crecimiento a nivel de rodal

Este modelo tiene las siguientes características y restricciones:

Un modelo para los tres subtipos

Curvas de sitio

Regresiones:

Inçr. G_{bruta} = f(G, E, Hdom)

Mortalidad = supuestos sobre algún SDI (Stand Density Index)

Incr. G_{sp} / Incr. G_{tot} = f(G,..)

$Mortalidad_{sp}$ / $Mortalidad_{tot}$ = f(?)

$Hprom_{sp}$ = f(Hdom)

Incr. $(D_{10}, D90, CV)_{sp}$ = (?)

Este modelo aún no se encuentra tan desarrollado en su metodología puesto que es parte del trabajo que se está realizando para este año.

ETAPA III: INCORPORACIÓN DE DOS REMEDICIONES SOBRE LAS PARCELAS "SEMIPERMANENTES"

Datos

Los datos que se incorporan, corresponden a las dos últimas remediciones de las parcelas "semipermanentes", las cuales tienen una buena cobertura de la variabilidad.

Modelo 3: Modelo de crecimiento a nivel de rodal

Las características del modelo pueden ser las siguientes:

Curvas de sitio

Incremento dap, altura

Mortalidad o Probabilidad de mortalidad

Acrecentamiento (ingrowth)

Posibilidad de proyección de indicadores de calidad

Es necesario destacar que además de la información básica que se ha podido recuperar, se cuenta con los resultados de numerosos estudios que se han desarrollado como tesis de grado, informes o publicaciones científicas, los que se incorporan al momento de la evaluación del desempeño de los modelos.

INTERRELACIÓN CON OTROS PROYECTOS

Finalmente, en el ámbito de la cooperación entre proyectos, se han establecido algunas relaciones importantes que se refieren a la instalación conjunta de unidades demostrativas de manejo, en que los objetivos de otras instituciones se han compatibilizado con los del presente proyecto, principalmente en cuanto a los protocolos de selección de áreas, instalación y medición. Los proyectos en referencia son los siguientes:

- **Proyecto SUCRE** (Uso, Sustentabilidad, Conservación y Restauración de los Bosques del Sur de México y del Centrosur de Chile). Este es un proyecto coordinado por Reino Unido (Universidad de Edimburgo) en que participan México, España, Chile, Suecia y Reino Unido. Chile y México tendrán la misión de Instalación de parcelas permanentes para tres grandes temas que son: Viabilidad genética, Modelos silviculturales y Estudios de suelo.

- **Proyectos CONAF/Otras organizaciones**: En este caso, existen tres grandes proyectos en los cuales la contraparte nacional es la Corporación Nacional Forestal (CONAF):

Proyecto "Manejo Sustentable del Bosque Nativo". Contraparte internacional es GTZ (Org. Alemán). Se generarán estudios y documentos en algunos ámbitos tales como "Silvicultura del Bosque Nativo" Análisis desde 1940 a la fecha de las intervenciones que se han realizado por tipo forestal y especie.

Proyecto Ejecución del Plan de Ordenación de la Reserva Malleco: En conjunto con ONF (Office National du Forêt – Francia) y UE (Unión Europea) se trabajará en dos ámbitos relacionados; 1) Ejecución de intervenciones (con UE) y 2) Seguimiento ambiental de las intervenciones (con ONF)

Proyecto "Conservación y Manejo Sustentable del Bosque Nativo": en conjunto con organismos internacionales principalmente alemanes (KSW, DAAD, GTZ) es un proyecto orientado a pequeños propietarios en que el financiamiento alemán está orientado a cubrir desde la VIII a la X Región.

- **Proyecto "Parcelas demostrativas de manejo en bosque nativo":** Estas parcelas serán instaladas por el Instituto Forestal en conjunto con el presente proyecto, de tal forma que sean diseñadas con los objetivos de modelamiento de crecimiento y que además, cumplan con los requisitos de ser demostrativas, lo cual es algo bastante simple de cumplir, y que nos asegura permanencia en el tiempo, además que se realizará, en terreno, una actividad de transferencia a medianos y pequeños propietarios.

CONCLUSIONES

Para efectuar proyecciones de rendimiento, existen alternativas que dependen absolutamente de la disponibilidad de información. En el presente trabajo, el análisis permitió establecer una estrategia para el corto, mediano y largo plazo en función de los objetivos de modelamiento inicialmente propuestos y las posibilidades concretas de obtención de información.

Para el corto plazo (un año), se ha establecido que la información actualmente disponible corresponde a estudios históricos de otros proyectos institucionales y/o de empresas privadas. El análisis de esta información, tanto gráfico como estadístico, indica que el modelo factible es un modelo de rendimiento con "altura" como variable conductora. Con un esfuerzo marginal (rescate de la edad) se puede llegar a un modelo con mayor capacidad de interpretación, con la "edad" como variable conductora. Por otra parte, el modelo no soporta muchos estratos (como zonas de productividad, por ejemplo), por lo que la precisión a nivel de rodal se sacrifica por la robustez de las proyecciones a nivel medio.

Para el mediano plazo (coincidente con el término del proyecto) se ha diseñado un trabajo de terreno que incorpore variabilidad por estrato y especie, de tal forma que, a traves de parcelas temporales que incluyan extracción de tarugos y volteo de árboles, se pueda construir un modelo de crecimiento y a través de la remedición de algunos ensayos históricos (recuperados) de manejo, incorporar algunos elementos de respuesta biológica al raleo. En esta etapa se genera una capacidad de aproximadamente 150 parcelas "semipermanentes" instaladas, monumentadas y con la primera medición realizada.

El largo plazo incorpora dos remediciones adicionales a la base de datos, lo que implica un período adicional de seis años. Esta nueva información permitirá modelar el crecimiento en base a la cantidad mínima y aceptable de series con tres remediciones, lo que origina dos períodos consecutivos. Adicionalmente, se incorporan antecedentes de acrecentamiento y mortalidad, lo que permite la generación de crecimiento neto. Además, se incorporan antecedentes dinámicos de calidad de la madera.

Finalmente, el hecho de incorporar la información histórica, pese a las dificultades de recuperación y a las limitantes que conlleva ésta, ha permitido la generación de un modelo simple pero base para otros más sofisticados con un mayor nivel de precisión a nivel de rodal.

Además, ha permitido la discusión con otros grupos de trabajo y, como consecuencia lógica, el compartir procedimientos y protocolos de toma de datos, sistemas de respaldo y otros, lo cual posiciona a la Universidad Austral de Chile en un mejor lugar aún y la compromete a no abandonar en esta línea de investigación cuantitativa de nuestros bosques naturales.

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AGGREGATION AND DISAGGREGATION BETWEEN INDIVIDUAL-BASED AND DISTRIBUTION-BASED MODELS: A CASE STUDY ON PARACOU EXPERIMENTAL PLOTS, FRENCH GUIANA

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ABSTRACT

Forest growth and gap models have classically been divided into three main categories depending on the scale they refer to: stand models, distribution models or individual based models. Most of the time, a modeler chooses one of this level and designs his/her model from assumptions derived from the question the model is expected to answer to: yield prognosis, silviculture simulation, dynamic resource inventories. The question addressed in this presentation is the study of the coherence between those three scales. When a detailed model such as an individual based one has been designed, it seems easy to degrade it into a coarser one, by averaging over individual for example. At the same time, it is possible to design a model on the evolution of the average itself, regardless of the individual value distributions. If both methods lead to the same evolution of, say, the average value, then it is said that the individual based model can be aggregated.

Our paper will address this topic on two directions:

- first as a mathematical based approach to study whether this property is a usual or exceptional in dynamical system, where it will be proved related to some eigenvalues in linear systems
- second as a case study between individual based and distribution models on data in Paracou experimental plots in French Guiana, where trees have been measured individually every three years since 1984, using a Forska type individual based model on one hand and an existing Usher-like matrix model on the other.

As a conclusion, the feasability and difficulties of aggregation will be discussed.

INTRODUCTION

Since Munro's seminal work on a prognosis of forest models (Munro, 1974), it has been classical to distinguish in modeling

- A stand level where a forest stand is described by one or several global variables
- A distribution level where variables are known by their distribution laws
- An individual level, where the value of a variable is known for any tree.

Individual models can be either tree lists or spatially explicit if the location of each tree is known as well. Most of modeling activity has been devoted to derive relevant models at any of these scales (see Vanclay, 1994 for a review).

Communication between those levels is easy in regular stands, as individual level and global level can be superposed: any tree can be considered as a realization of the mean tree of the stand. Things are more delicate and less trite for heterogeneous stands, where such a natural aggregation does not hold any longer.

In this paper, we study the building of such an aggregation on long term research plots in French Guiana. The idea of aggregation is to relate in a coherent way models which can be run in parallel on the same biological systems at different organization scale, rather than emphasizing a given level more than another. We select a spatially explicit individual based model, and study aggregation on coarser organization levels using the model as a benchmark.

Our presentation is organized as follows:

- We present the forest we work in, namely Paracou research plots in French Guiana
- We present the models we use as benchmarks
- We present the methods we use in order to test the aggregation of variables
- We run all programs and present the results
- We compare the aggregation of the detailed model at final time with the outcome of the corresponding coarse model
- We discuss the results, distinguishing aggregation on the variable and mean field approximation.

MATERIALS

Study Site

The model which is used as a benchmark to illustrate aggregation and mean field approximation is built on the data from the Paracou permanent plots. The Paracou site is located 40 km west from Kourou, French Guiana (5°15'N, 52°55'W). The climate is equatorial with two seasons, an average annual rainfall of 3160 mm, and a dry season that lasts three months from August 15 to November 15. The relief consists of small hills (less than 50 m high) separated by wet areas, with medium slopes (30% maximum).

On this site 12 plots of natural rain forests were set in 1984 by the CIRAD-Forêt. Each plot is a 6.25 ha square with a buffer zone 50 m wide. From 1986 to 1988, the plots underwent three silvicultural treatments: three plots were logged for hardwood, three plots were logged for hardwood plus selective clearing, three plots were logged for both hardwood and fuelwood plus selective clearing, and the last three plots were left untouched as controls. On each plot, the circumference of every tree with a DBH (diameter at breast height) $\geq$ 10 cm is measured with a precision of 0.5 cm. Its spatial coordinates ($\pm$ 50 cm) and its species are noted too. Measurements have been carried annually from 1984 to 1995, and once every two years since. Height measurements on a sample of trees have been achieved in 1997 too. Other stand characteristics such as contour lines have also been collected. All data are gathered into a data base coupled to a GIS. A more precise description of Paracou trials is given in Favrichon (1998).

Basis Common to All Models

In order that the comparisons between models bear a sense, the models must share a common set of equations. The basic equations actually come from a individual-based spatially explicit model, that was calibrated on Paracou data (Picard *et al.*, 1999). Hence the common heart to the models with different levels of stand description and tree interactions is as follows.

The state variables of a tree are its diameter, its height and its spatial coordinates. They belong to the space

$$F = DxHxA$$

where $D = [D_{min}, +\infty[$, $H = [H_{min}, +\infty[$ and A is the square plot domain. The plot domain is actually considered as a tore, meaning that the left and right edges and the top and bottom edges of the space are wrapped together.

Forest dynamics are split up into three components that are growth, mortality and recruitment. Diameter and height growth are expressed as (see Picard *et al.*, 1999):

$$\frac{dD}{dt} \equiv a(D,L) = \frac{\Gamma(1+(\beta_0+\beta_1 D)^{-1})}{(\alpha_0+\alpha_1 L)^{(\beta_0+\beta_1 D)^{-1}}} \tag{1}$$

$$\frac{dH}{dt} \equiv b(D,H,L) = \max\left\{0;\gamma\left(\frac{\alpha_0}{\alpha_0+\alpha_1 L}\right)^{1/\beta_0} - \left(\theta+2\frac{a(D,L)}{D}\right)H\right\} \tag{2}$$

where Γ is the gamma function, $\gamma, \theta, \alpha_0, \alpha_1, \beta_0, \beta_1$ are parameters, and L is the variable that describes tree interactions. We explain more precisely later in the text how interaction between trees has been modeled with variable L. The mortality rate m is a function of diameter only (see Picard *et al.*, 1999):

$$m(D) = -\frac{1}{f_0(D)}\frac{d}{dx}\left[a(x, L_0\exp(-x/D_c))u(x)\right]\Big|_{x=D} \tag{3}$$

where $u(x) = \lambda\exp(-\lambda x)$ and λ, L_0, D_c are parameters. As for recruitment, a simple condition of constant population size is imposed:

$$\frac{dN(t)}{dt} = 0 \tag{4}$$

where N is the number of trees on the plot. Recruitment therefore compensates exactly for mortality in terms of number of trees. Sapling have diameter D_{min}. Their height is normally distributed according to $N(h,\sigma)$, where h and σ are parameters. They are randomly located on the plot. The values of all parameters are given in Picard *et al.* (1999).

The main point is the way interactions between trees are modeled through the interaction variable L. Consider the three-dimensional field defined as follows: $L(z,q)$ is the number of trees whose crown stand over $q \in A$ above the altitude z. We assume hereafter that the crown of a tree is a flat disk of radius ρD. The competitive pressure exerted on a subject tree of height H located at q by its neighbors is quantified by $L(D, H, \mathrm{q})$, which is defined as the mean value of $L(H, \mathrm{s})$ when s uniformly scans the disk $\mathrm{B}(\mathrm{q}, \rho \mathrm{D})$ of radius ρD centered at q. It can be interpreted as the mean number of trees that stand over the crown of the subject tree.

METHODS

Presentation of Aggregation and Mean Field Approximation

In order to present the ideas behind aggregation and mean field theories, we will chose as an example a virtual and simplified forest, rather than the more technical model presented above. The extension of those ideas to some more sophisticated models is conceptually easy and natural, even if sometimes more technical. We will postpone until next paragraph those technicalities, in order to focus within this one on the ideas behind the computations. Let us imagine we have a forest composed of N trees labeled by $i = 1, \ldots, N$ where each tree is known by its position $\mathrm{q} \in \mathrm{R}^2$ and diameter $D \in \mathrm{R}$. We will call an organization level a level considered as relevant for a given purpose, such as individual level, mean tree level, etc. Organization levels may differ from model to model and according to the selected variable coarseness.

Organization levels

The finest organization level for the description of our simplified forest is the one where all the variables are known for any tree, namely where we know an array

$$X = (\mathrm{q}_i, \mathrm{D}_i)_{i=1,N}$$

Such a description is called distance dependent tree description in forest literature, following Munro's classic publication on model classification (Munro, 1974). It corresponds to spatially explicit individual description in ecological literature (see Tilman and Kareiva, 1997 for a recent covering of spatial ecology). It means that both the attributes and the positions of any individual are known.

This finest level of knowledge might be irrelevant when dealing with huge populations or vast forest areas, such as the dynamics within the Amazonian Basin or the Siberian Forest. It is then suitable to have a coarser description of the forest. The coarsest description consists in giving just one figure: the mean diameter

$$D = \frac{1}{N} \sum_i D_i$$

This is a so called stand description level, which is commonly used in yield tables. It corresponds to so called global or population level in ecological literature, which has been emphasized during the so called "Golden Age" of Theoretical Ecology (Scudo and Ziegler, 1978). Aggregation is the operation consisting in computing the coarse variables from the fine ones. If we note α the aggregation operator, we can write

$$\bar{D} = \alpha(X)$$

where (i) X is the detailed description (ii) $\bar{D}$ is the coarse description and (iii) α is the aggregation operator.

Such a procedure can be used more generally between any two description levels, as soon as one level is coarser then the other one. For example, an intermediate level between the global level and the individual level is a level where the distribution function of the diameter is known, for example $p(x)$ such as $\Pr(D \in [a,b]) = \int_a^b p(x)\,dx$. There is no knowledge of any individual attribute, but a finer knowledge than the mean diameter. Such a level has been recognized as well as most important in ecological literature, and is widely used in modeling for forest management. We recognize here for simplification three nested organization levels (i) the individual level (IL) (ii) the distribution function level (DFL) and (iii) the stand level (SL). There are three aggregation operators which enable to build the information at a coarse level from the information at a finer level:

α_{id} from IL to DFL

α_{is} from IL to SL

α_{ds} from DFL to SL.

It is easy to check that $\alpha_{is} = \alpha_{ds} \circ \alpha_{id}$.

Perfect Aggregation and Modeling

For the purpose of this paper, we will consider a forest model in a narrow sense, as a program, or an algorithm, which enables to compute the state of the forest at time $t > t_0$ from the state at time t_0. According to Vanclay (1994), this prediction ability is a separatrix between inventories which describe current state and models which compute predictions. It is possible to design models for any organization level. These are the so called individual-based models at IL, matrix models at DFL and stand models at SL.

A question naturally arises, explained hereafter. Suppose we have a given forest, and we select two organization levels (i) individual level and (ii) stand level. Let us call respectively X_0 and X_0 the descriptions for those levels at time t_0. Let us select a time $t > t_0$. A model is taken as an algorithm which enables the computation of respectively state X_t or X_t at time t. We write

$$X_t = \psi_i(X_0)$$
$$\overline{X_t} = \psi_s(X_0)$$

the results of those algorithms, respectively. At time $t > t_0$, there are two ways to compute X_t:

- Either as the outcome of a model at the stand level, as $X_t = \psi_s(X_0)$
- As an aggregation from IL at final time t, as $X_t = \alpha(X_t)$.

We say there is perfect aggregation of variables (Iwasa *et al.*, 1987) if those two ways give the same result, namely if

$$\alpha(X_t) = \psi_s(X_0).$$

As $\quad X_t = \psi_i(X_0)$ and $X_0 = \alpha(X_0)$,

we have $\quad \alpha\psi_i = \psi_s\alpha$

which is the condition for perfect aggregation to apply. Iwasa *et al.* (1987) give a lemma for this condition to apply when a model is given by a set of differential equations.

Approximate Aggregation and Mean Field Theories

Perfect aggregation is seldom verified, and it can be shown (Franc and Picard, 1999) with Iwasa *et al.* lemma mentioned above that there is no perfect aggregation for the mean unless the model at the IL is linear. On the other hand, it is a well known reality shared among foresters and ecologists that stand models for the mean do work. So, why?

Most of trajectories in dynamical systems can be split into two phases: a transient regime and a steady state. A steady state corresponds to an equilibrium state, namely some characteristics remain constant. For example, an individual-based model including growth, mortality, regeneration and recruitment such as SELVA (Gourlet-Fleury, 1997) at Paracou can reach a state where distribution functions for diameters remain constant over time, even if some trees die and some other regenerate. Those demographic variations can be considered as probabilistic fluctuations around a constant steady state for diameter distribution. On the other hand, there exists for the same Paracou plots a matrix model (Favrichon, 1995), which converges towards a fixed point, which is precisely the steady distribution function of the individual-based model. This situation is very close to perfect aggregation, with the noteworthy difference that perfect aggregation is expected to be valid during the whole time lag, and not only the steady state. In approximate aggregation, there is no correspondence between the two models during the transient state. We then propose to call approximate aggregation a perfect aggregation valid during the steady state only.

It is possible to propose a link between this definition of approximate aggregation and the mean field approximations in statistical physics. Mean field approximation is a classical tool in statistical physics, dating back to the beginning of the 20th century, and presented in many textbooks (see for example Landau and Lifshitz, 1967; Plischke and Bergersen, 1994). It is now a well known tool to evaluate models in ecological sciences (Levin and Pacala, 1997). The idea is that in many physical spatio-temporal systems, analytical solutions are intractable even when spatial interaction are simple, and some approximations have to be made. In systems such as spin lattices, any cell interacts with its neighbors only. Each neighborhood is unique, as the values vary from cell to cell. It is then possible to distinguish between different organization levels for neighborhoods, which can be known individually, as distribution of values within the neighborhood, or with global variables. Mean field approximation consists in replacing any exact neighborhood of a given cell by the whole lattice scaled properly. It means that any cell interacts with the same virtual neighborhood which is the whole scaled lattice. It can be considered as an aggregation operator on the list of individual neighborhood. There is a slight difference as aggregation as it has been defined replaces a list of variables by say, the mean. Here, cells do not interact with a virtual mean neighborhood, but with the whole scaled lattice.

Towards an Extension of Munro's Classification

Classifying models seems a hopeless task, as there are so many ways to distinguish a model from another one (Vanclay, 1994). However, there exists a most widely used system proposed by Munro (1974) at the beginning of the 70's, when most of basic modeling technique had been published and were known to foresters. It relies primarily on the organization level, distinguishing three levels (individual, distribution function, and stand level) and secondarily on tree location (explicit or not taken into account) for individual-based models. We present hereafter an extension of this classification as proposed in Franc *et al.* (1999). The idea is that the finest model, that is spatially explicit individual-based model, relies on the finest organization level for both the variable (here the diameter in our simplified example) and the location of the trees. There are two ways to aggregate: (i) one is to aggregate on the neighborhood (ii) a second way is to aggregate on the variables themselves. Most of models can be displayed within a table as Table 1 having in line the organization level for the variables, and in columns for the neighborhoods. Models with finer description of the neighborhood than of the trees themselves are omitted because considered as irrelevant. The most common names are displayed in Table 2.

Table 1: *Model classification. Vertical shift from top to down is aggregation. Horizontal shift from left to right is mean field approximation. Explanation of abbreviations is given in Table 2.*

Organization level of the stand	Organization level of the neighborhood			
	Individual	Distribution	Global	Without interactions
Individual	I-I	I-D	I-G	I-W
Distribution		D-D	D-G	D-W
Global			G	G-W

Derivation of the Benchmark Models

Let us return now to the benchmark models for the Paracou forest stand, whose core equations have been presented in section 2.2. Starting from an I-I model (see Tables 1 and 2), we aggregate description variables to get a D-D model where the distribution function depends on space variables. The mean field approximation may be achieved on both models, yielding: (i) from the I-I model, a I-D model (ii) from the D-D model with a joint diameter × height × spatial coordinates distribution, a D-D model with a joint diameter × height distribution. These models may further be degraded into I-W and D-W models respectively.

Table 2: *Common names in scientific literature of models identified in Table 1.*

Label in Table 1	Common name in ecological sciences	Common names after Munro (1974)
I-I	Individual-based spatially explicit model	Distance dependent tree model
I-D	Individual-based model	Distance independent tree model
I-G	Individual-based model	Distance independent tree model
D-D	Matrix model	Matrix model
D-G	Matrix model	Matrix model
G	Global model	Stand model
I-W	Individual-based model	Tree model
D-W	Matrix model	Matrix model
G-W	Global model	Stand model

Performing Aggregation

In the individual-based models, the stand at time t is defined by a list

$$\{(D_i(t), H_i(t), q_i(t)), i = 1, \ldots, N(t)\}$$

where N is the number of trees. The temporal evolution is defined as follows:

Growth: differentiating D with respect to time for instance yields $D(t+\Delta t) = D(t) + (dD/dt).\Delta t + o(\Delta t)$. Taking $\Delta t = 1$ year, which is a small time lag with respect to forest dynamics, and using Eq.1 and 2, we obtain

$$\begin{aligned} \Delta D_i &= D_i(t+1) - D_i(t) = a \\ \Delta H_i &= H_i(t+1) - H_i(t) = b \end{aligned} \tag{5}$$

- Mortality: as a stochastic process. Let U be a number uniformly drawn between 0 and 1. If $U < m(D_i)$, tree i is removed, otherwise it stays alive.

- Recruitment: every tree that dies is replaced by a sapling (D_{min}, H, q), where $H \approx N(h, \sigma)$ and q follows a uniform law on the plot.

In the distribution-based models, the stand at time t is described by a density function f such that $f(x, y, q, t)dxdydq$ is the number of trees whose diameter is between x and $x+dx$, whose height is between y and $y+dy$, and which are located is the small area dq around q. To move from the individual-based to the distribution-based model, that is to say to shift from top to down in Table 1, the Liouville theorem is applied. It yields a transport equation for f:

$$\frac{\partial f}{\partial t} = -\frac{\partial}{\partial x}\{af\} - \frac{\partial}{\partial y}\{bf\} - mf \tag{6}$$

This equation expresses growth and mortality. Recruitment results in boundary conditions at the border of F:

As A is a tore, on the border of A periodic conditions are imposed.

On the border of H a no-particule condition is imposed:

$$f(x, H_{min}, q, t) = 0$$

On the border of D a flux condition is imposed:

$$a(D_{min}, L)f(D_{min}, y, q, t) = \frac{r(t)n(y)}{A}$$

where n is the density probability function of the normal law $N(h, \sigma)$, and r is the recruitment rate which equals the total number of dead trees per time unit:

$r(t) = \int_A dq \int\int_{DxH} m(x)f(x, y, q, t)dxdy$

Performing Mean Field Approximation

Performing the mean field approximation, that is to say shifting from left to right in Table 1, only changes the expression of the interaction variable L. Remember that the field $L(z,q)$ is the number of trees whose crown stand over $q \in A$ above the altitude z. Its mathematical expression thus is:

- For the individual-based spatially explicit model:

$$L(z,s) = \sum_{i=1}^{N} I(H_i > z) I(\|s - q_i\| < \rho D_i)$$

where $I(p)$ is the indicator function of the event p ($I(p) = 1$ if p is true, $=0$ if p is false).

For the distribution-based spatially explicit model:

$$L(z,s) = \int_A dr \int_z^{+\infty} dv \int_D f(u,v,r) I(\|s - r\| < \rho u) du$$

It can be checked that the former expression derives from the latter by replacing $f(x,y,q)$ with $\sum_{i=1}^{N} \delta(x = D_i)\delta(y = H_i)\delta(q = q_i)$. As $L(x,z,q)$ is the mean value of $L(z,s)$ when s uniformly scans the disk $B(q,\rho x)$ of radius ρx centered at q, its expression can be computed:

- For the individual-based spatially explicit model:

$$L(D,H,q) = \frac{1}{\pi(\rho D)^2} \sum_{i=1}^{N} \omega(\|q - q_i\|, \rho D, \rho D_i) I(H_i > H) \tag{7}$$

where $\omega(d, r_1, r_2)$ is the area of intersection of two discs of radius r_1 and r_2 a distance d apart.

- For the distribution-based spatially explicit model:

$$L(x,z,q) = \frac{1}{\pi(\rho x)^2} \int_A dr \int_z^{+\infty} dv \, \mathrm{INT}_D \, du f(u,v,r) \omega(\|q - r\|, \rho x, \rho u) \tag{8}$$

The mean field approximation can be achieved in two ways:

- Replace the spatially-explicit field $L(z,s)$ by an homogeneous field $L(z)$ by taking an homogeneous distribution $f(u,v)$, and proceed the calculus as previously.
- Replace the interaction variable $L(x,z,q)$ by its limit when $x \to +\infty$.

Both methods yield the same result, namely:

- For the individual-based spatially explicit model:

$$L(H) = \frac{\pi \rho^2}{A} \sum_{i=1}^{N} D_i^2 I(H_i > H) \tag{9}$$

where A is the plot area.

- For the distribution-based spatially explicit model:

$$L(z) = \frac{\pi \rho^2}{A} \int_z^{\infty} dv \int_D u^2 g(u,v) du \tag{10}$$

where the density function g represents the number of trees of diameter u and height v per unit of diameter and height.

In the absence of interactions, the model can be put in a form similar to Eq.9 and 10, with L being a reducing factor that depends on the tree diameter x only. The relationship between L and x was calibrated from field data, yielding (Picard *et al.*, 1999):

$$L(x) = L_0 \exp\left(- \frac{x}{D_c} \right) \tag{11}$$

where L_0 and D_c are the same parameters as in Eq.3.

SUMMARY

Table 3 summarizes the six models that illustrate aggregation and mean field approximation.

Table 3: *The six benchmark models.*

Stand description	Tree interactions		
	Distance-dependent	Distance-independent	No interactions
Individual-based	Eq.5 with L given by Eq.7	Eq.5 with L given by Eq.9	Eq.5 with L given by Eq.11
Distribution-based	Eq.6 with L given by Eq.8	Eq.6 with L given by Eq.10	Eq.6 with L given by Eq.11

RESULTS

Solving the Equations

Individual-based models can only be solved numerically, by simulation runs. On the contrary PDE offer analytical solutions that are exposed hereafter. The results are given here without proof, that will be published elsewhere.

No Interaction Models

The no interaction case is the simplest, because the variable L depends on the diameter only. Thus so does the diameter speed of growth a. It follows that all the trees have the same diameter dynamics. Also in the DxH space, given the initial state $(D_{\min}, H)$ of a tree, its trajectory till its death can be computed. Let $\xi(t)$ and $\phi(t, y)$ be the diameter and height temporal evolutions of a tree whose initial size is $(D_{\min}, y)$. These functions are the solutions of

$$\begin{cases} \dfrac{d\xi}{dt} = a(\xi) & \xi(0) = D_{\min} \\ \dfrac{\partial\phi}{\partial t} = b(\xi,\phi) & \phi(0,y) = y \end{cases} \tag{12}$$

These functions can be inverted into τ and χ such that:

$$\xi(\tau(x)) = x$$
$$\phi(\tau(x), \chi(x,y)) = y$$

The quantity $\tau(x)$ represents the time necessary for a tree to reach diameter x starting from $D_{\min}$. The quantity $\chi(x,y)$ represents the initial height of a tree which has reached the size (x,y).

The steady state of the distribution-based no interaction model, once mortality and recruitment are taken into account, can be computed analytically. It yields:

$$g_{\infty}(x,y) = Cn(\chi(x,y))\exp\left\{-\int_0^{\tau(x)} q(\xi(s), \phi(s, \chi(x,y)))ds\right\}$$

where C is a scaling constant which is computed so that $\iint g_{\infty}(x,y)dxdy = N$, and q is the function given by

$$q(x,y) = \lambda a(x) + \frac{\partial b}{\partial y}(x,y)$$

Distance-Independent Model

In that case the interaction variable L depends both on height and on the whole density function g. Hence Eq.6 is a non-linear PDE which cannot be easily solved analytically. However consider the operator Ξ defined as follows: given a density function h, let $L_h(z)$ be the function

$$L_h(z) = \frac{\pi\rho^2}{A}\int_z^{+\infty} dv \int_D u^2 h(u,v)du$$

and let f be the stationary solution of Eq.6 with L replaced by L_h. Then $\Xi : h \rightarrow f$. Equation 6 with L replaced by L_h can be solved analytically as previously. The stationary solution f_{∞} of the distribution-based distance-independent model verifies $\Xi f_{\infty} = f_{\infty}$. This is a way to check that a density function is indeed a stationary solution, but it does not provide it.

To actually solve the distribution-based distance-independent model, we used a numerical method, namely a fully explicit finite difference scheme. Then using the operator Ξ, we checked that the numerical method had indeed led to the stationary solution.

Distance-Dependent Model

Imagine that the initial density is spatially homogeneous. As space variables do not play any part in Eq.6, and as boundary conditions are spatially homogeneous, it follows that at any time later on the density will be spatially homogeneous. Then the model is equivalent to the distance-independent model.

Because of the boundary conditions, any stationary solution of the distance-dependent model, if it exists, must be spatially homogeneous. Then any stationary solution of the distance-dependent model, if it exists, is a stationary solution of the distance-independent model. The converse proposition is immediate. The distance-dependent and the distance-independent models thus have the same stationary solution.

Steady State

As the distribution-based model without interaction is a linear transport equation, it can be demonstrated that, starting with any initial state, the system evolves towards the same stationary state. As for the other models, we simply empirically check that they always lead to the same stationary state.

Figure 1 shows the diameter and the height distributions in the stationary state, as simulated by the five models. Observed distributions are also given as a reference. The diameter distribution is hardly different from any model to another. On the contrary the height distribution shows that there are two behaviours: on the one hand the individual-based distance dependent model alone, and on the other hand the four other models. Height has a larger distribution with the individual-based spatially explicit model than with the others.

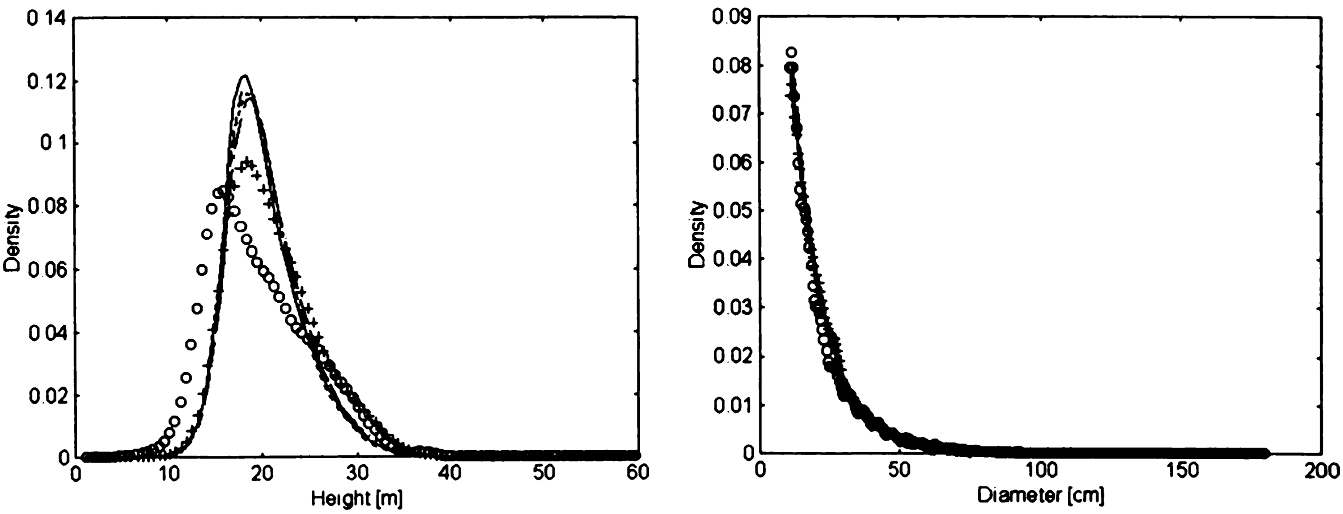

Figure 1: *Diameter (top) and height (bottom) distributions in the stationary state, as simulated by the individual-based distance-dependent model (+), the individual-based distance-independent model (---), the individual-based no interaction model (....), the distribution-based distance-independent model (-.-.), the distribution-based no interaction model (_), and as observed at Paracou site (o). For the distribution-based models, the distributions are directly obtained from the joint diameter and height density functions; for the individual-based models, the distributions are estimated from individual data by the average shifted histogram method (see Scott, 1992).*

Time to Reach the Stationary State

In the case of the no interaction model, the time to reach the stationary state can be computed: it is simply the time $\tau(D_{max})$ necessary for a tree to reach the biggest observed diameter D_{max} starting from D_{min} . As for the other models, this time was estimated by computing a dissimilarity $d(t)$ between the current state g and the stationary state g_{∞} :

$$d(t) = \int_D dx \int_H dy \, | g(x,y,t) - g_{\infty}(x,y) |$$

Figure 2 shows the temporal evolution of d for the five models. Their speed of convergence towards the stationary state is approximately the same: they all reach it in about 250 years.

DISCUSSION

Aggregation

Consider again Table 1. Moving form top to bottom corresponds to a simplification of the description of the stand. To shift from individual dynamics $dD/dt = a, dH/dt = b$ to the dynamics of the joint diameter and height distribution, the Liouville theorem was used. This theorem enables to shift from a Lagrangian point of view where individuals are followed along their own trajectories, to an Eulerian point of view where the flow of individuals is considered. This approach is very common in fluid mechanics for instance.

Consider Table 3 where individual-based models are on the top ligne and distribution-based models on the bottom ligne. The question then raised is: are the individual-based and the distribution-based models equivalent?

First, in case of no interaction, it is a long-standing result that the individual-based and the distribution-based models are equivalent in the limit where the number of individuals N is infinite (that is to say $N \to \infty, A \to \infty$, and N/A remains constant). This result is even more general, because it still stands when growth is stochasticly modeled:

$$\frac{d}{dt}\begin{bmatrix} D \\ H \end{bmatrix} = \begin{bmatrix} a(D,H) \\ b(D,H) \end{bmatrix} + \begin{bmatrix} a^{(2)}(D,H) \\ b^{(2)}(D,H) \end{bmatrix} \zeta(t)$$

where ζ is a random term such that $E(\zeta(t)) = 0$ and $E(\zeta(t)\zeta(t')) = \delta(t-t')$. This equation is an Ito stochastic differential equation and generalizes Eq.5 (where $a^{(2)} = b^{(2)} = 0$). The PDE on the distribution g is then a Fokker-Planck equation, with second-order derivative terms $\partial^2/\partial x^2$ and $\partial^2/\partial y^2$ depending on $a^{(2)}$ and $b^{(2)}$. The growth process corresponds also to a continuous Markov process. Hence the differences between the diameter and height distributions of the no interaction models in Fig.1 result from the finite size of the population and from the imperfection of our numerical schemes.Second, consider distance-independent models. It can be shown that the individual-based and the distribution-based models are also equivalent in that case (results not presented, to be published elsewhere), although the speeds of growth a and b now depend through L on the whole distribution at the stand level.

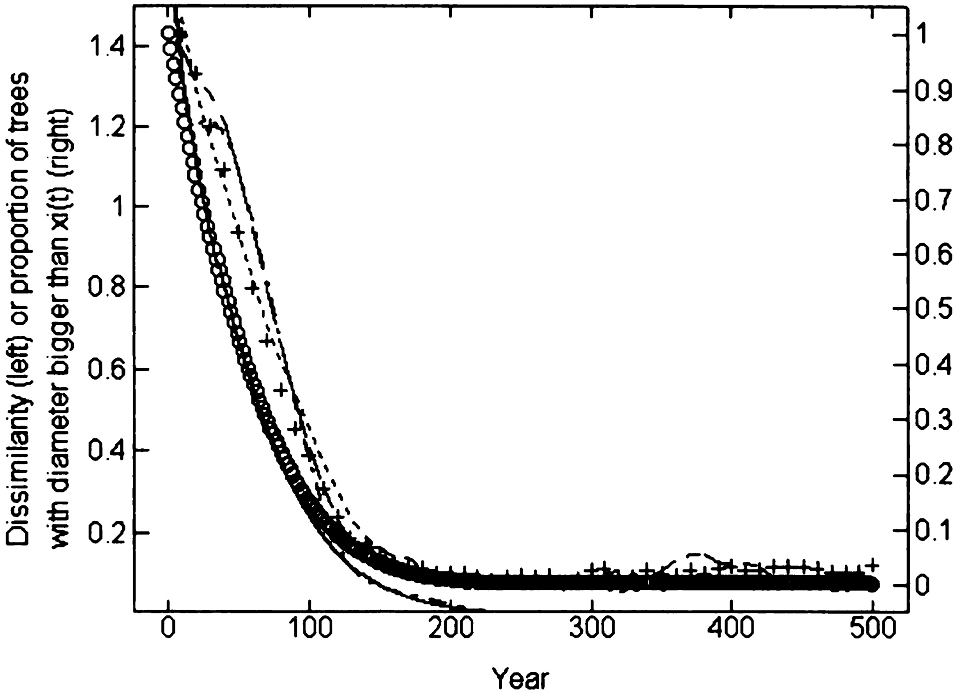

Figure 2: *Left axis: Temporal evolution of the dissimilarity between the stationary state and the current state, for the individual-based distance-dependent model (+), the individual-based distance-independent model (---), the individual-based no interaction model (....), the distribution-based distance-independent model (-.-.) and the distribution-based no interaction model (_). For individual-based models, the joint diameter-height distribution is estimated from individual data by the average shifted histogram method. Right axis (o):* $1 - F_0(\xi(t))$, *where* F_0 *is the cumulative distribution function of the diameters at Paracou site, and* $\xi(t)$ *is the diameter at time* t *according to the no interaction model (see Eq.12).*

On the contrary the individual-based distance-dependent model is not equivalent with the distribution-based distance-dependent model. Starting with spatially homogeneous conditions, it can easily be seen indeed that the distribution f remains spatially homogeneous. Then the distance-dependent distribution-based model and the distance-independent distribution-based model have the same solution. These two models have therefore the same stationary state. Fig.1 shows that the individual-based distance-dependent model and the distribution-based lead to different height distributions in the stationary state. This discrepancy can be understood by reformulating the individual-based model in terms of dynamic point process. A supplementary term then appears in the PDE of the distribution f, that accounts for the internal structure of the spatial pattern of trees (to be published elsewhere).

Mean field approximation

The change from distance-dependent models to distance-independent models is achieved through the mean field approximation. The mean field approximation can here be achieved by supposing that the interaction field L is independent of space variables, or by replacing the interaction variable L by its limit $\lim_{r\to\infty} L(x,y,q)$ and the density function f by its spatial mean

$\frac{1}{A}\int_A f(x, y, s)ds$. Increasing the diameter x is equivalent to increase the range of interaction between trees. Indeed two trees are interacting if their crown overlap, and crown radius is proportional to x. So the limit $x \rightarrow +\infty$ corresponds to the situation where the subject tree interacts with all the trees on the stand. As L is by definition a spatial mean value of the field L, when $x \rightarrow +\infty$, L tends towards the global mean value of L on the whole stand.

It has been said already that the individual-based distance-dependent model was not equivalent with the individual-based distance-independent model. In the distance-dependent model, spatial effects arise because tree interactions (namely competition for light) tend to produce a regular pattern (see Picard *et al.*, 1999). This regular pattern reduces the strength of competition, thus resulting in a different height distribution. This cannot be accounted by the mean field model, where by definition no spatial effect is taken into account. On the contrary the distribution-based distance-dependent model is equivalent with the distribution-based distance-independent model, as soon as initial conditions are spatially homogeneous. This merely follows from the fact that the mean field approximation is equivalent, in that case, with the homogeneity of f. Yet it would be possible, even if hard with an analytical treatment, to take into account the structure of tree pattern through a covariance function. The two models then would differ.

No noticeable differences between the distance-independent models and the no interaction models may be observed in Fig.1. There are indeed more differences between the individual-based and the distribution-based models, which are known to be equivalent, than between the distance-independent and the no interaction models. The two models fit because the individuals trajectories in the space *(D, H)* tend rapidly towards a common curve, which results in a D *versus* H relationship. It is therefore almost equivalent to consider L as a function of H or of D. As the L *versus* D relationship that was calibrated on field data is equivalent with the L *versus* H relationship that is obtained by "freezing" g to g_∞ in Eq.10, the equivalence between the two models is thus realized at the steady state. This equivalence is however approximate because: (i) It holds at the steady state, not during the transients; (ii) If the density *N/A* of trees changes, g_∞ changes whereas the steady state of the no interaction models is left untouched, thus resulting in a discrepancy between the models.

Time to the Stationary State

There is a discussion on whether or not the distance-independent models reach their stationary state faster than the distance-dependent models. As pointed out by Bolker and Pacala (1998), this question remains unsolved in general. It has been observed in some case that the distance-independent model was going faster indeed (Pacala, 1995). However with our models, no difference can be noticed.

The individual-based models have also been compared with a matrix model that has been calibrated independently on the same stand of natural rainforest in French Guiana (Favrichon, 1998). The matrix model takes biodiversity into account by distributing the species into five groups: understory shade-tolerant, canopy shade-tolerant, emergent midtolerant, canopy shade-intolerant, and pioneer species. A transition matrix is then adjusted for every group. Figure 3 shows the temporal evolution of total basal area, as simulated by the matrix model and by our individual-based models. The initial burst that appears in the matrix model results from the group of pioneer species which have high rates of growth and then decay. As species diversity is not taken into account in the individual-based model, this peak does not appear. However before reaching the stationary ceiling, all models present the same rate of evolution towards the stationary state.

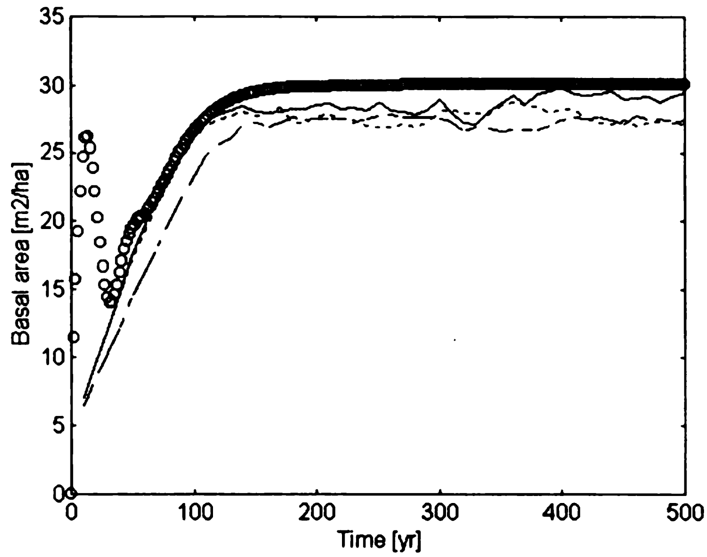

Figure 3: *Temporal evolution of the total basal area, from the matrix model (o), the individual-based distance-dependent model (__), the individual-based distance-independent model (....), and the individual-based no interaction model (---).*

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LONG-TERM STUDY OF AGROFORESTRY SYSTEMS BASED ON STRUCTURED TREE CLUSTERS

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SUMMARY

This report describes the design and preliminary results of an agroforestry study established on a 30-acre field in southwestern Arkansas. The reasons behind this study are as follows. One tenth of the trees that a forester plants provides at the end of rotation about three quarters of all discounted returns. It is proposed to plant these crop trees (loblolly pine, *Pinus taeda* L., 50 per acre) surrounded by nurse trees (shortleaf pine, *Pinus echinata* L.). The area between rows of tree clusters is utilized for forage and beef production. The coexistence of trees, forage, and livestock is natural and can be mutually beneficial for biological and managerial reasons. The objectives of this study are to determine tree spacing and schedules for tending trees (pruning and thinning), forage, and animals that will optimize economic, social, and ecological benefits. We will test three types of structured rows, four within-row distances, three thinning intensities, and three levels of pruning for two agroforestry systems (improved agro-silvicultural system and an agro-silvo-pastoral system) in three replications.

INTRODUCTION

Growing loblolly pine (*Pinus taeda*) trees and raising cattle for market are among the most attractive and common rural activities in the southeastern United States. Usually these enterprises are undertaken separately. Yet, there are strong reasons for growing cattle, their forage base, and trees together, especially in the area of southern pine forests of the United States: "Silvopastoral agroforestry has great potential in the United States but perhaps nowhere is it greater than in the pine belt of the south and in the west" (Garrett 1994, page 6).

The coexistence of trees, forage, and livestock is natural and can be mutually beneficial for several biological and managerial reasons. Root systems of established pines are deeper than those of forage species. This fact minimizes (though does not exclude) competition for soil nutrients and moisture between pines and forage species. During the early years of growth, crop trees occupy a small percentage of the land. The remaining land is covered by competing vegetation, which often severely retards pine growth. Livestock grazing reduces competition between trees and shrubs. As a result, grazing substantially increases diameter and height growth of coniferous species (Sharrow 1994). Another reason for increased growth is natural (manure) and artificial fertilizers applied near the trees. In their turn, trees provide shade and wind shelter for cattle. These advantages could contribute to a substantial increase in income over growing trees or cattle separately (Clason 1995, Harwell and Dangerfield 1991, Lewis 1988).

Agroforestry is sometimes viewed as a developmental tool for third world countries. Yet, it has significant potential to raise income levels for farmers in the southern US. Conditions similar to those in developing countries, including small acreage bases, low family income levels and lack of capital to expand existing operations, mark many farming operations in this region. Agroforestry, because of its increased utilization of existing space and the mutualistic nature of the agricultural and forest-based land uses, provides strong benefits not readily obtainable to large, production-based agricultural operations. Rural land owners who adopt agroforestry techniques would benefit directly from both long-term timber harvest income and from short- and medium-term agricultural income from forage, and livestock production. An additional and highly important consideration for small farmers is that risk is spread over a number of crops. Farmers engaged in multi-product agroforestry spread the risk commonly associated with market fluctuations by diversifying their investment.

Besides a possibility of increasing the income per unit area, the system to be tested will provide a sustainable flow of returns. While the returns from the forestry component will materialize 15-25 years after the planting of the crop trees, the agricultural and horticultural components will provide most of their returns during the initial period, when growth of these components is at a maximum. Agroforestry also fits the human life cycle. As individuals become older, they prefer less strenuous activities such as timber management. If a farmer switches to agroforestry in his middle years, then this transition will occur naturally.

The assumption of this study is that there is an optimal combination of agricultural and forestry activities. Optimal means a combination that maximizes the total sustainable return from all the components. Sustainable encompasses all ecological concerns related to land management. The aim of this study is to find this optimum.

OBJECTIVES

1. Implement a study to determine the best spatial configuration of two-species tree clusters and rows in the framework of an improved agro-silvicultural system and an agro-silvo-pastoral system.
2. Initiate monitoring of the economics and ecological impacts of these agroforestry systems to be continued over the life cycle of system (the 25-year timber component is the longest).
3. Use the results of monitoring in adaptive management and modify the original designs on the basis of that feedback.

RATIONALE AND SIGNIFICANCE

Usually trees are planted uniformly. This pattern minimizes intraspecific competition between trees but maximizes interspecific competition between trees and understory vegetation, which occupies the area between trees. In agroforestry where trees are planted less densely than in plantations, the situation is opposite: intraspecific competition between trees becomes desirable for improving their form, and understory vegetation, instead of being a handicap, becomes valuable forage. For these reasons the uniform spacing of trees loses its advantage. Many previous agroforestry studies broke with the forestry tradition and planted trees in widely spaced single or multiple row configurations (Garrett 1994, King 1989, Lewis et al. 1985). Uniformity was retained only within rows where trees of the same species and age were planted at equal distances.

Sharrow (1991) took the next step: he planted trees in clusters. His clusters are circular, 5 feet in diameter, with five tree seedlings in each. Within clusters trees were spaced uniformly. The distance between clusters was 25 feet. Sharrow's (1991) research and simulations that he cites show the advantages of aggregated tree planting: "More forage could be produced by agroforests stocked with 900 trees/ha in clusters that those with only 450 trees/ha in conventional single tree grids" (Sharrow 1991, page 171). Still, he favors row configurations: "Single or double-row patterns appear to offer the most promising combination of tree and understory production in agroforestry systems which emphasize achieving high levels of forage production while maintaining tree production levels near maximum. Ease of managing livestock, constructing fences, access with mechanical equipment, and concentration of thinning wastes are also enhanced by row patterns compared to grids" (Sharrow 1991, page 173).

This study is a further step toward heterogeneity. Unlike the clusters used by Sharrow (1991), ours are structured clusters. The structure refers to spacing of trees within the cluster, their number, choice of species and time of planting. The need for heterogeneity becomes obvious as soon as we recognize that trees serve two different functions: (1) produce high quality sawtimber and (2) improve the form of sawtimber trees and provide pulpwood.

Traditional forestry waits till trees establish competitive hierarchy out of original uniformity at the time of planting. In agroforests, spatial and temporal heterogeneity can be imposed from the start to facilitate the separation of trees according to their function. We planted crop trees in centers of clusters. They are surrounded by nurse trees, which are supposed to shade crop trees from sides, but not from above. Because nurse trees are located on the cluster periphery, they would get more light and could outcompete core trees. To prevent this danger of overshading and discover the best cluster structure, we will test various distances between crop and nurse trees as well as distances between nurse trees. Choice of species, cluster size, and planting time can also be used to control the relationship between crop and nurse trees.

Usually forest management starts with 500-800 trees per acre. Yet, about three quarters of all returns come from several dozens of crop trees. Ideally, planting 50 trees would change dramatically the cost/benefit ratio. In reality, additional trees are needed to improve the shape and quality of the final crop, and to allow for mortality. However, these spare trees need not be planted in a regular fashion.

Our approach is focused on the final product of the forestry component: about 50 crop trees per acre, to be harvested at the end of a rotation when each cluster will produce one sawtimber-size tree. The final harvest will provide the same merchantable volume as do regular plantations. Although as compared with regular plantations the output of intermediate forest products (short pulpwood) will be diminished, the most valuable final harvest will not be sacrificed.

To sum up, our cluster design is intended to:

1. Provide space for non-forestry components and operation of agricultural machinery by minimizing area occupied by trees;
2. Reduce the cost of planting and managing tree growth;
3. Improve quality of crop trees by surrounding them with nurse trees;
4. Avoid or minimize a reduction of final harvest;
5. Afford a more natural appearance and thus enhance aesthetic values as compared with regular plantations.

The efficiency of various cluster designs will be evaluated in the context of an improved agro-silvicultural system and an agro-silvo-pastoral system described below.

METHODS

Agroforestry Systems

Our study compares two most promising agroforestry systems: an agro-silvicultural system and an agro-silvo-pastoral system. An agro-silvicultural system includes growing trees and hay production (improved four-species forage mix). An agro-silvo-pastoral system involves grazing on the improved forage pasture after trees reach (at about four years) the cow-resistant height of 10 feet (since the results of this study are intended to be demonstrated to and applied by farmers and foresters who are more comfortable with the English systems of measures, we will describe the experimental design and results in English rather than SI units).

The study has been established on a 30-acre field of located at the Southwest Research and Extension Center of the Arkansas Agricultural Experiment Station in Hope, AR during September 1997-March 1998. 27 acres are used for the main study. This area is divided into two equal portions, one for hay and another for beef production. Each portion contains three replications. Thus, the area for each treatment block is 27/(2 x 3) = 4.5 acres. The remaining 3 acres are used for comparative studies.

Metal fence posts are placed every 144 feet, outside the outer lines of three-line rows. Besides preventing mowing the trees, the posts help to identify tree clusters so that it is not necessary to nail tags to the trees or paint numbers on them. The posts are positioned across every seventh loblolly pine cluster (24 x (7-1) = 144).

Controlled Factors and Variables

This study will maintain or modify as necessary a single level for the following factors: (1) crop tree species; (2) nurse tree species; (3) distance between tree rows; (4) distance between crop trees within rows; (5) length of rotation; (6) forage species; and (7) density of animals. Several levels will be tested for the following variables: (1) row structure (number of lines in a row and distance between them); (2) distance between nurse trees; (3) thinning schedule and (4) pruning options. All testing will be done in three replications for the two agricultural systems.

Some of the listed variables such as density of pines and forage production involve a tradeoff between benefits to the forestry and agricultural components. Others such as forage fertilization and wide tree spacing intend to boost growth of agricultural plants, animals, and pines.

Single-level Factors

Tree Species

Loblolly pine has proven to be the most successful species for productive forest management in the southeastern United States. This species will provide crop trees to be harvested at the end of rotation. Nurse trees, which surround the crop trees in each cluster, will get more light. If they were planted simultaneously with crop tree seedlings, they could overshadow them. In this study we have planted shortleaf pine (*Pinus echinata*) as nurse trees. Because this species does not grow as fast as loblolly pine, both species can be planted at the same time.

Distance Between Tree Rows

The alleys between pine rows are 30 feet wide to facilitate tree growth and agricultural operations. Heavy thinning will increase the width of alleys from 30 to 34-40 feet.

Distance Between Crop Trees

The distance between the centers of loblolly pines within rows is 24 feet. It is expected that each cluster will produce one loblolly pine tree with diameter 15-16" at the end of the rotation. The nurse trees in will be utilized as pulpwood.

Length of Rotation

It will be the age that maximizes the combined annual financial return. The length is approximately 25 years long.

Choice of Crops

A four-species mix that includes forages tested for this area (AU Triumph tall fescue, common bermuda grass, Marion lespedeza, and LA-S1 ladino white clover) has been established. It is expected that species composition will respond to the current level of shading. Legumes will be reseeded in the later years as necessary.

Density of Animals

Cross-bred steers will be grazed from weaning until around 700 - 800 lbs. The initial stocking rate for each season will be based on the average A.U.M. (Animal Unit Month) forage production of the soil series corrected for estimated shading effects. Average A.U.M. values are available from the U.S.D.A.-N.R.C.S. Forage fertilization, supplemental feed and herd health practices will be based on current recommended procedures.

Levels of the Variables

Row Structure

Tree rows consist of one or three lines of trees. The crop trees (loblolly pine) were planted in the inner (central) line. Nurse trees were planted in the two adjacent, side lines. In three-line rows two distances between lines are tested: 4 and 6 feet. These rows are referred to as 3L4 and 3L6 rows Accordingly, the widths of three-line rows are 8 or 12 feet. The width of single-line rows (referred to as 1L) is 0. The width of agricultural alleys (AL) are always 30 feet. Large inter- and intra-row distances between crop trees make buffer zones between clusters unnecessary. Each cluster is a sample unit. The crop trees in the adjacent rows are staggered. The rows run in the north-south direction to increase the sunlight for forage.

To facilitate studies of forage production and hydrological regime within and between the rows and at the same time randomize the location of clusters in order to minimize the effect of site variability, the layout is a combination of random and systematic designs. For each row one distance between trees is selected at random from the chosen values (see below). The rows alternate regularly. The east-west cross-section of the field has the following dimensions:

3L4	AL	1L	AL	3L6	AL	3L4 ...
8′	30′	0′	30′	12′	30′	8′ ...

This sequence of rows with the associated alleys (3L4, AL, 1L, AL, 3L6, AL) will be referred to as a strip.

Distance Between Nurse Trees

Four distances between nurse trees are tested: 3, 6, 8, and 12 feet. A single distance is used for each strip. These distances were selected at random.

Thinning of Crop Trees

Four seedlings of crop trees were planted one foot apart in each cluster to provide for mortality and selection. They will be thinned to leave one tree per cluster within three years after planting.

Thinning of Nurse Trees

Three levels of thinning intensity are tested:

0 - no thinning;

1 - thinning half of the nurse trees as soon as they can be sold as long pulpwood (minimum requirement is 4" with bark at the height of 25');

2 - thinning all nurse trees as soon as they reach the size of long pulpwood.

These levels are assigned to the entire strip at random.

Pruning of Crop Trees

Pruning of pine growing for sawtimber is profitable for regular plantations. This operation promises to be even more important in the agroforestry context because of low stand density that encourages production of large branches and good accessibility of trees. Nurse trees will not be pruned. Based on the previous experience, including plots established at Hope, three levels of pruning are tested:

Height	Age	Level				
		0	1		2	
		Pruned length	Pruned length		Pruned Length	
16	5	0	8.0	(50%)	9.5	(60%)
24	8	0	12.0	(50%)	16.0	(67%)
32	11	0	16.0	(50%)	21.0	(67%)

The ages are approximate and pruning will be based on the average tree height. The pruning levels are assigned to the entire strip at random.

Cluster Codes

Each cluster can be identified by code such as 3L4-D8-T1-P2 describing:

- Row structure (1L, 3L4, and 3L6).
- Distance between nurse trees (D3, D6, D8, and D12 corresponding to the distances of 3, 6, 8, and 12 feet).
- Thinning code (T0, T1, and T2).
- Pruning code (P0, P1, and P2).

Number of Clusters and Replications

The total number of treatment (types of clusters) is:

3 x 4 x 3 x 3 = 108

Within each 4.5-acre block we can replicate each type two times:

(4.5 x 43560)/(108 x 36.67 x 24) = 2

This would allow researchers in the future to test another treatment by treating half of the clusters.

Comparative Studies

Regular 8 x 10 Plantation

To compare our design with regular forestry practice, we will plant three control blocks of loblolly pine. Each block will have 9 trees in 9 rows. Rows are 10 feet apart. Within rows trees are 8 feet apart. There are 81 trees in each block and 81 x 3 in three blocks. Required area (243 x 80)/43560 = 0.45 acres.

Competition Mortality

Most of experience gained in Hope is about growth of spaced trees. We avoid competition mortality by wide initial spacing and timely thinning. This study gives us an opportunity to investigate competition mortality, which is an important component of stand dynamics. This can be done be planting 36 x 36 (= 1296) seedling at the closest distance that permits planting and tree measurements (about 2').

Wide Spacing Trial

Growing crop trees without nurse trees is tested separately. The spacing is 24 x 34 feet. Nine trees per treatment is sufficient. Treatment includes the three levels of pruning. For three replications we need 9 x 3 x 3 x 4 = 324 seedlings and (81 x 24 x 34)/ 43560 = 1.5 acres.

Schedule of Activities

The pasture allocated for this study was prepared by mowing and chemical suppression of the existing vegetation (see Preliminary Results). The trees were planted in February-March of 1998. To prevent animals from damaging young trees in the treatment which includes beef production, until pines reach the height of 10 feet, the land is used for forage production with no grazing included. Afterwards, cattle (preferably unbred, because pine straw is somewhat toxic to unborn calves in pregnant cows) will be allowed to graze. Grazing will begin in the spring to coincide with forage growth.

Height and diameter of all trees will be measured during the dormant period every two years up to the age of 16 years and, when their growth slows down, every three years thereafter. Records of all activities and accompanying costs and returns will be maintained.

During the first five growing seasons (from February through September) and contingent upon funding thereafter, the amount of forage production, its quality, species and elemental composition will be measured between hay harvests using micro-plot harvests(4 by 4 feet). The distance of the micro-plots from trees will be recorded to document the effect of shading. Total annual biomass production will be computed after every season. These data will be used to adjust cattle stocking rate and provide input to calculate the total productivity for each treatment. Cattle production will be determined from weight gains. Forage production during the grazing season will be determined using 4x4 feet exclosure cages placed at intervals from the trees for shading documentation.

DATA ANALYSIS

Economic Analysis

Comparison of investment alternatives related to the agroforestry alternatives will be performed in a number of different ways. Present net worth (PNW) is the most commonly recognized method. Normally, PNW values are computed by analyzing the stream of discounted cash flows that are expected to occur within the life of the investment. Two different types of investments are considered in this study: agricultural returns from beef, hay and forage, and a forest-based investment from pine pulpwood and sawlogs.

Investment valuation of agricultural scenarios will be done as follows: net annual income streams are evaluated on a PNW basis for a defined period of time. In dynamic scenarios, when periodic changes are made in the production base, such as crop rotation, or phasing out one crop in favor of another, calculations are more difficult, but still relatively straightforward. If there is a permanent election to remain in agricultural production, rather than converting land to a different opportunity, such as a shopping mall, equivalent annual income streams are perhaps the best of the available valuation techniques to use across alternatives. PNW values can be easily converted to equivalent annual income values. Internal rates of return are slightly more difficult to calculate, but can be accomplished without too much difficulty.

Additional considerations that weigh on the nature of forest investment are the various incentives available to non-industrial land-owners. Currently, early amortization of investment expenses is available at up to $10,000 per year. Investment expenses may be recovered in as little as seven years using this scheme. Additionally, one time investment credits and capital gains treatment of returns are available. Other incentive programs, such as the Stewardship Incentive Program (SIP) and the Conservation Reserve Program (CRP), both of which are federally-subsidized cost-share programs, provide additional relief from initial high investment costs. All investment analysis should be done on an after-tax basis.

To be viable, agroforestry, in addition to its environmental benefits should be profitable. This is a guiding idea of this study. All considerations presented above allow us to predict that, given the range of crops, enhanced efficiency of land and labor use, the proposed system will increase return at least on 25-30% as compared with either forest management or agriculture alone.

Competitiveness of Forestry Investments

Forestry investments are often criticized as being Anon-competitive@ with agricultural or financial instrument investments. This is not the case for several reasons. First, in the southern U.S. rich agricultural soils are, in most cases, ideally suited for pine growth. Silvicultural growth rates of 12 to 20% per year give rise to value growth rates of 9 to 15% during the Awonder years@ of pine establishment and early growth. This period of high growth is the same period that we propose to analyze in our agro-forestry design. Given the relatively low stocking rates planned for this study, volume and value growth on the study plots will be maximized.

The second reason underscoring the competitiveness of forest investments in the south is that long-term real price appreciation, spurred by continued strong demand, has created extremely favorable market conditions for pine thinnings and harvest sawlogs. And, finally, investment tax credits coupled with early amortization of forestry investment expenses works with existing incentive programs (Stewardship Incentive Program and Conservation Reserve Program) to reduce investment requirements. Additionally, capital gains treatment for timber proceeds provides an additional incentive for timber investments.

Statistical Methodology

The use of fixed effects in regression (dummy or categorical variables) and the ANACOVA models (continuous variables in ANOVA) makes our design statistically manageable. The fundamental premise of both techniques is decomposition of the error term extant within the general linear model. While the error term in these mixed models becomes quite complex, its reduction is not difficult with modern computing capabilities.

The regression model we propose to use in determining significant differences in investment value will contain both treatment effects and continuous variables. It is given by:

$$V_0 = / \text{ (Structure + Type + Distance}_C \text{ +Distance}_N \text{ + Thin)}$$

where Structure is cluster or row structure, Type is line, cluster, or row arrangement, Distance $_C$ is distance of nurse trees from crop trees in row, Distance $_N$ is distance between nurse trees, and Thin is thinning intensity factor. This formula represents only a general approach to be revised in the future to extract needed information. For example, this mixed effects model may be expanded to include the difference in wood quality between various treatments, ease of machinery operation, and economies of scale.

PRELIMINARY RESULTS

Ground Preparation

(1) layout and flagging the plots (September-October 1997); (2) spraying Roundup to suppress competing vegetation (October 1997); (3) broadcasting clover (October 1997); (4) flagging tree clusters for planting (January 1998, Figure 1); (5) flagging the competition study (January 1998); (6) putting out T-posts to mark and protect tree clusters (April 1998).

Tree Planting

(1) planting shortleaf pine (*Pinus echinata* L., February 1998); (2) planting loblolly pine (*Pinus taeda* L., February 1998); (3) replacing shortleaf pine that died (March-April 1998);

Vegetation Control

(1) spraying Oust (2 oz per acre) and Velpar (1 qt per acre) to control competing vegetation within tree clusters (March 1998); (2) spraying tree clusters with Poast Plus (0.5 lbs/acre, August 1998).

Hay Harvesting and Fertilization

(1) first cutting, raking, baling, and weighing of hay (31,000 lb, May 1998); (2) applying 350 lbs/acre of 17-17-17 (May 1998); (3) second cutting, raking, baling, and weighing of hay (48,850 lb, July 1998); (4) third cutting, raking, baling, and weighing of hay (27,900 lb, July 1998).

Emergency Problems

Due to the severe drought, this was the worst year in history to plant tree seedlings. Despite the best care we took, 25.2% of loblolly pine seedlings and 38.2% of shortleaf seedlings have died. We will replant missing trees in February 1999.

EXPECTED RESULTS

The study will develop and test agroforestry management systems for the southeastern United States. In addition to being profitable, each system will realize environmental benefits beyond those found in simpler agricultural and forestry ecosystems. As a result of employing no-till practices, decreasing erosion, and diversifying land use, this study will promote sustainable land management. Increased biodiversity, improved soil fertility and higher returns for landowners will combine to create an agroecosystem, which is ecologically and economically more sustainable than current systems.

By its nature, agroforestry studies require long-term observations. To advance sustainable and viable land management, such studies have to be started at some time, and the sooner, the better. Besides its design, this study has an advantage of dealing with the loblolly-shortleaf pine forest type, which is the second largest (after oak-hickory type) in the Southeast. Since the oak-hickory type is compatible with growing loblolly and shortleaf pines, the results of this study may be as widely applicable as can be expected from any agroforestry study. To make the expected results portable to other sites, we will try to formulate them in relative terms with wider applicability. For example, along with recommending to thin surrounding trees at, say, age 14 years, we would also indicate that this event is to be scheduled when diameter increment of core trees drops below 90% of the increment of open-grown trees.

One result of this study will be available immediately after three years. It is the layout of the study and all subsequent measurements. The value of this study is in the information on the interaction between the agricultural output and the spatial arrangement of trees. This information could be analyzed in many ways and we do not insist that ours is the best. However, we are certain that the data to be collected will provide new information and we intend to make it useful for all interested researchers who may analyze it differently than we are proposing.

We are pleased that our cluster design, even before testing, has attracted the attention of southern agroforesters. Dr. Terry Clason of Louisiana State University Agricultural Center is planning to convert one four-year old plantation into an agroforestry study with structured clusters and establish anew another study using the described cluster design (personal communication of January 9, 1997).

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ENSAYOS DE PROGENIE Y PROCEDENCIAS EN CHILE. ANÁLISIS ESPACIAL (ASREML) EN *NOTHOFAGUS ALPINA*, UN ESTUDIO DE CASO

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RESUMEN

El diseño de una prueba genética es una de las decisiones más importantes que el mejorador tiene que enfrentar para llevar a cabo un programa de mejoramiento genético. Un elemento complementario lo constituye la forma de analizar los datos, no obstante los análisis genético son tan buenos como los datos que los alimentan.

El artículo tiene dos objetivos, primero hacer un análisis histórico de los diseños y análisis genéticos realizado por el Instituto Forestal y organizaciones afines en sus programas de mejoramiento genético de ***Eucalyptus spp***. y ***Pinus radiata***, y en segundo lugar introducir y discutir el análisis genético tradicional mediante (BLUP), en el modelo animal en relación al mismo modelo, pero considerando en este último el modelamiento de la covariación como una media móvil autoregresiva (ARMA), basada en la distancia entre parcelas. Para ilustrar las bondades y problemas de esta última tecnología se han considerado un ensayo de progenies. La prueba genética es un ensayo de progenies de ***Nothofagus alpina*** de un año de edad, donde se evalúa la supervivencia. El diseño es de un árbol una parcela en bloques al azar. Para el análisis se ha utilizado el programa ASREML de Gilmour et al (1999). Se analizan varios modelos, en los que se obtienen los parámetros de varianza espacial para cada uno de ellos. Se observan incrementos diferenciales en verosimilitud. Finalmente se establecen recomendaciones para utilizar esta tecnología de análisis genético.

SUMMARY

The progeny and provenance tests in Chile. Evaluation by spatial analysis (ASREML) in ***Nothofagus alpina***, a case studies. The genetic test's design is one of the most important decisions that the breeder has to face to carry out a genetic improvement program. The way of analyzing the data constitutes a complementary element, nevertheless the genetic analyses are as good as the data that feed them.

The article has two objectives, first to make an historical analysis of designs and genetic analysis developed by the Chilean Forest Institute and related organizations in its ***Eucalyptus spp.*** and ***Pinus radiata*** genetic improvement programs, and second to introduce and discuss the traditional genetic analysis thorugh BLUP, in the animal model in relation to the same model, but considering in this last one the covariance modelling as a autoregresive mobile average (ARMA), based on the distance among plots. To illustrate the goodness and problems of this last technology it has been considered a one year old ***Nothofagus alpina*** progeny trail, where the survival is evaluated. The design used consists of one tree plot in randomized blocks. For this analysis it has been used the Gilmour's et al (1999) ASREML program. Several models are analyzed, in which the parameters of spacial variance for each one of them are obtained. Differential increments are observed in the

additive genetic variance and the heritability. Finally, there are pointed out some recommendations to use this genetic analysis technology.

INTRODUCCIÓN

El propósito de cualquier diseño de experimentos es proporcionar el máximo de información al menor costo posible, por lo mismo el diseño de un experimento involucra tanto a la metodología estadística como a su análisis económico.

Particularmente en el establecimiento de pruebas genéticas, el diseño estadístico debe permitir discriminar las diferencias de potencial genético del material evaluado, para los sitios donde será utilizado operacionalmente (Talbert y Bridgwater, 1981). A su vez, la selección del diseño más apropiado dependerá de la habilidad del mejorador para identificar y controlar las fuentes de variación (bloques, procedencias, familias, entre otras), de su capacidad analítica para resolver el modelo y de criterios de eficiencia estadística-económica que permitan ahorrar tiempo, dinero, personal y recursos materiales sin disminuir la validez de las deducciones a obtener. Los ensayos genéticos forestales presentan serias limitantes por la variación edáfica y topográfica de los sitios forestales, esta dificultad se incrementa cuando se prueban una gran cantidad de grupos genéticos. Esto unido al tiempo que requieren las pruebas genética en madurar y a las innumerables prácticas de mantención que se realizan en los ensayos, obligan al mejorador, dentro del espíritu de mantener las cosas lo más simple que sea posible, a disponer de un procedimiento analítico que permita identificar todas las fuentes de variación que están incidiendo sobre el valor genético de los árboles de la prueba.

Gracias al advenimiento de la tecnología del análisis genético desde la genética animal hacia la genética forestal, el mejorador forestal ha visto las enorme proyecciones en la aplicación de modelos mucho más eficientes y robustos, que hasta hace algunas años le eran totalmente desconocidos. La aplicación forestal de los modelos de genética animal, comenzó en el Congreso IUFRO de Hobart de eucalipto, en 1995, en específico el uso del modelo animal o también conocido como modelo de árbol individual (Borralho, 1995), este ha demostrado una gran flexibilidad para una amplia variedad de diseños genéticos forestales.

La evaluación genética se realiza utilizando la estimación de los componentes de varianza en modelos mixtos a través de la máxima probabilidad restringida (REML), y asumiendo términos aleatorios Gausianos. El procedimiento REML maximiza la probabilidad conjunta de todos los contrastes de los errores, más que todos los contrastes de la máxima probabilidad ordinaria de acuerdo a Searle et al. (1980). El procedimiento REML permite trabajar con datos desbalanceados, los cuales son muy comunes en los diseños genéticos forestales debido a diversos factores que los afectan durante su vida útil.

Gilmour et al. (1995) desarrollo un nuevo algoritmo para resolver las ecuaciones de partición en un modelo lineal mixto. Ellos lo denominaron algoritmo de la Información Promedio (AI) y es similar al algoritmo original FS (Fisher scoring) propuesto por Patterson y Thompson (1971). El programa ASREML (Gilmour et al, 1997b) ha incrementado sustancialmente la utilidad y el desarrollo de la metodología de los modelos mixtos para el análisis de una variada gama de problemas que surgen de la investigación biológica y agrícola. El ASREML permite estimar los componentes de varianza en grandes conjuntos de datos desbalanceados. El análisis espacial también se encuentra implementado, después de acumular los autores más de 500 análisis en programas de mejoramiento de plantas anuales en Australia durante las últimas décadas.

Cullis y Gleeson (1991) presentaron una aproximación para el análisis espacial de experimentos de campo. Ellos originalmente usaron un algoritmo FS, el que probó ser demasiado lento y engorroso para grandes pruebas de campo. Gilmour et al. (1997a) presentó un modelo extendido para la modelación espacial de la variación en las pruebas de campo. Ellos usaron el algoritmo AI para fijar un modelo con tres componentes de variación espacial.

Verbyla et al. (1998) presentó un método para el análisis de experimentos y datos longitudinales usando curvas "spline" suavizadas. Ellos mostraron cómo la "spline" cúbica suavizada admite una formulación de modelo mixto, lo que coloca esta forma no paramétrica como un modelo mixto. Esto entrega el mecanismo para incluir curvas "splines" en modelos para el análisis de experimentos y datos longitudinales. La ventaja de usar estas curvas en el caso de datos longitudinales es particularmente importante, debido a que la modelación de la covarianza es lograda implícitamente como para los modelos de coeficiente aleatorio.

Cullis et al. (1998) y Frensham (1998) consideraron el análisis de pruebas multisitios en la que la modelación de la estructura de la covarianza genética entre ambientes es lograda mediante la variación espacial dentro de una prueba. Frensham (1998) extiende estos modelos dentro de un método unificado via la formulación de un modelo mixto y presenta ejemplos del análisis de una gran prueba de multisitio usando ASREML, que involucra un modelo con más de 70 parámetros.

El presente artículo hace un análisis histórico de los diseños y análisis genéticos realizado por distintas organizaciones y empresas forestales, con énfasis en el Instituto Forestal y organizaciones afines en sus programas de mejoramiento genético de ***Eucalyptus spp***. y ***Pinus radiata***. Adicionalmente introduce y discute el análisis genético tradicional mediante (BLUP= Best Linear Unbiased Prediction), en el modelo animal en relación al mismo modelo, pero considerando en este último el modelamiento de la covariación como una media móvil autoregresiva (ARMA), basada en la distancia entre parcelas, con esto se persigue: (a) determinar los componentes que determinan una variación global, es decir a gran escala en el ensayo, (b) determinar una variación natural o tendencia local y (c) determinar variaciones extrañas, inducidas por el procedimiento experimental. El artículo, debe ser entendido como un estudio de caso, el cual pretende introducir operacionalmente la aplicación del análisis espacial en las evaluaciones de ensayos genéticos forestales.

MATERIAL

Se analiza la evolución histórica de las pruebas genéticas en los distintos programas de mejora genética desarrollado en Chile, y los métodos utilizados para el análisis genéticos. También se discuten los principales problemas y beneficios de las metodologías utilizadas.

Debido a que la tecnología del modelo animal, o también conocida como el modelo del árbol individual (Borralho, 1995), se ha popularizado en el ambito forestal, ésta ha sido adoptada como base de los presentes análisis. La aplicación se basa en los estudios de Gilmour et al (1997a) y Gilmour et al (1997c) y se lleva sobre la base de datos de un ensayo de progenie de ***Nothofagus alpina***, localizado en la costa de la VIII región de Chile (37°35´S; 73°30´O).

Es ensayo, denominado Antiquina, corresponde a un diseño de 30 bloques al azar, en que se prueban 27 progenies y tres testigos, en parcelas de un árbol una parcela (figura 1). El mejorador dispone de una detallada hoja de vida del ensayo, en la que se incluye: fecha de la selección y preparación del sitio, maquinaria utilizada, tipo y calificación del personal que realizó la preparación del sitio, control de malezas pre y post plantación, su dosis y forma de aplicación, fertilización, con su respectiva dosis y forma de aplicación, fecha de plantación, como se realizó la plantación, quienes realizarón la plantación, como se distribuyo el trabajo de plantación, y una detallada cronología de los cuidados culturales.

METODOLOGIA

Modelo lineal espacial mixto.

De acuerdo Gilmour et al (1997a), el modelo asume que existen datos para n parcelas de forma tal que los ensayos están indexados por filas y columnas en un arreglo de f x c. El arreglo se asume contiguo, la extensión de varios arreglos separados o arreglos irregulares se consideran válidas. También se asume que $y_i(\mathbf{s}_i)$, i = 1,...,n es una realización de una variable aleatoria $Y_i(\mathbf{s}_i)$, donde { $Y_i(\mathbf{s}_i)$: $\mathbf{s}_i \in \Re^2$} i = 1,...,n. En muchos experimento de campo, {$\mathbf{s}_i$} tiene dos vectores de coordenadas cartesianas de los centroides de las parcelas, los cuales son localizados en una malla regular. Si **y** es el vector de los datos de las parcelas (altura, DAP, volumen, rectitud, supervivencia entre otros) en un determinado orden, por ejemplo de acuerdo a la columna, el modelo para **y** es:

$$y = X\tau + Zu + \xi + \eta$$

donde, $\tau^{(tx1)}$ es el vector de efectos de efectos fijos con la matriz de diseño $\mathbf{X}^{(nxt)}$, $\mathbf{u}^{(bx1)}$ es el vector de efectos aleatorios con una matriz de diseño $\mathbf{Z}^{(nxb)}$, $\xi^{(nx1)}$ es un vector de error aleatorio, espacialmente dependiente y $\eta^{(nx1)}$ es un vector aleatorio con media cero y cuyos elementos son pares independientes. También se asume que $(\mathbf{u},\xi,\eta)$ son independientes.

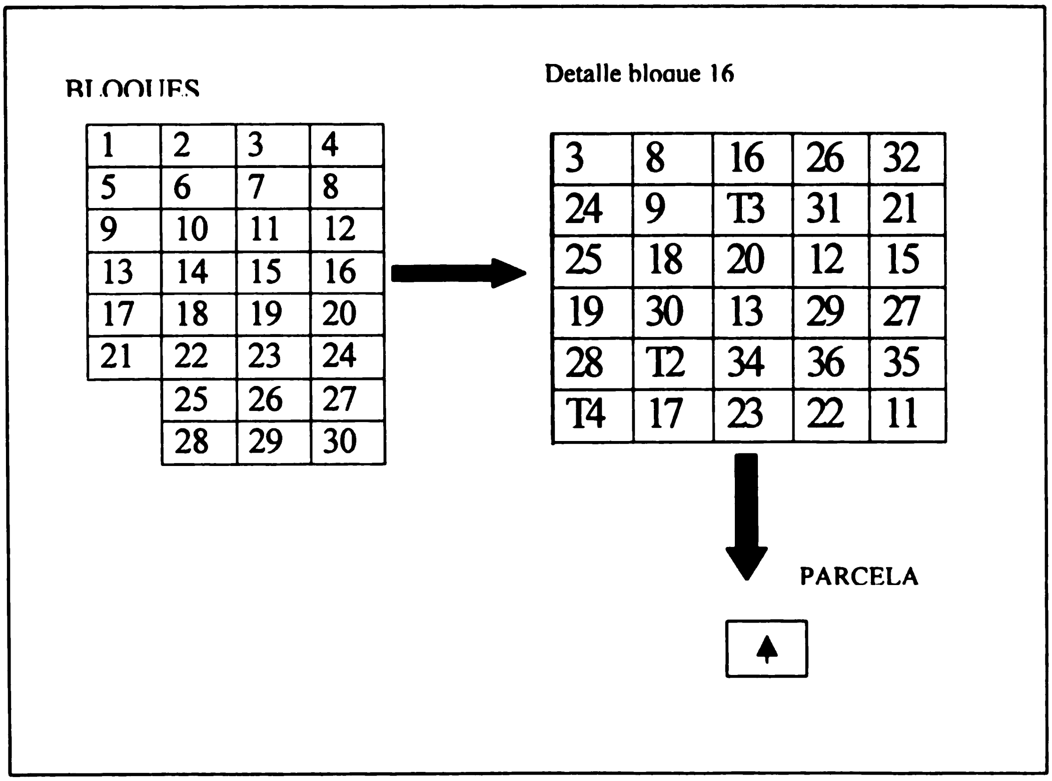

Figura 1: *Diseño en bloques completamente aleatorizados de la prueba genética de progenie de Antiquina, de raulí (Nothofagus alpina).*

Los detalles teóricos de la estimación de los componentes de varianza del modelo y del variograma, se encuentran en Gilmour et al (1997a, 1997c) y los procedimientos operacionales en Gilmour et al (1999).

Aplicación del modelo a un ensayo de progenie de rauli (*Nothofagus alpina*)

Para el análisis de las progenies de rauli se analiza la variable supervivencia (SUPER). Esta es una variable binomial de (vivo=1/muerto=0), que para efectos de análisis se ajustan a un modelo de árbol individual (Borralho, 1995), con base en el modelo binomial. Los modelos de enlaces considerados son dos: un modelo LOGIT($y=1/+e^{-Y}$) y un modelo PROBIT($y=(\Phi Y)$, donde y son los datos de la escala e Y es el valor ajustado sobre la escala base.

El modelo LOGIT tiene la siguiente estructura:

LOGIT (SUPER) = mu + bloque + random (arbol) + error

Y el modelo PROBIT la siguiente:

PROBIT (SUPER) = mu + bloque + random (arbol) + error

Las estimaciones de los componentes de varianza se realizan mediante el programa propuesto por Gilmour et al (1999). Los modelos con base en el modelo binomial se evalúan de acuerdo al nivel de la máxima verosimilitud (LogLikelihood). El mejor de los modelos anteriores se transforma a un modelo normal siguiendo el procedimiento establecido por McGuirk (1989).

$$h^2_{normal} = h^2_{binomial} * p*(1-p)/z^2,$$

p es la incidencia promedio

z es el valor de la ordenada en una distribución normal para una proporción "p".

Es importante destacar que la especie raulí, es una especie de polinización abierta, por el viento. Luego él el coeficiente de parentezco (r) utilizado corresponde al de medios hermanos (half sibs).

Al modelo seleccionado sobre la base del modelo binomial se le incorporan los elementos espaciales (filas y columnas), para de esta forma verificar la existencia (a) de componentes que determinan una variación global, es decir a gran escala en el ensayo, (b) determinar una variación natural o tendencia local y (c) determinar variaciones extrañas, inducidas por el procedimiento experimental. Finalmente, la bondad del modelo se evalúa de la misma forma que en el caso anterior. Agregando elementos gráficos para su mejor comprensión.

RESULTADOS

Diseños experimentales

Un análisis comparativo de los distintos tipos de diseños de ensayos genéticos utilizados en los programas de mejoramiento genético en Chile, específicamente del Instituto Forestal (INFOR) en el mejoramiento genético de eucalipto, de los programas de mejoramiento genético de especies nativas financiados por FONDEF (Universidad Austral, Instituto Forestal, Corporación Nacional Forestal y empresas forestales) y de empresas forestales, en *Pinus radiata* y *Eucalyptus spp.* se indica en Ipinza (1998a y b).

De las distintas alternativas de diseños experimentales disponibles para el establecimiento de pruebas genéticas, la más simple y difundida la constituye los diseños en bloques completamente al azar. Posteriormente dependiendo de las características de los bloques y del tipo de parcela utilizado para representar cada tratamiento se configuran diferentes esquemas de diseños.

Dentro de esta metodología, los ensayos de progenies establecidos por INFOR han hecho uso de cuatro esquemas diferentes. En orden cronológico los diseños que se han utilizado se pueden resumir de la siguiente forma:

- Bloques de familias compactas : Corresponde a un diseño utilizado a fines de los años '80, propuesto por el Dr. J Shimizu, y que equivale en el diseño de campo a lo que se denomina diseño de parcelas divididas (split plot). En cada bloque se distribuyen al azar las procedencias y posteriormente dentro de cada procedencia se aleatorizan las progenies en forma anidada. Las progenies se representan en cada bloque como parcelas de 4 plantas en línea. Un análisis detallado de este tipo de diseño se indica en Panse y Sukhatme (1963).

- Bloques completamente al azar: Este enfoque se adopta como la solución a un problema evidenciado en el diseño anterior, en el cual la agrupación de cada procedencia en un sector del bloque induce un sesgo como consecuencia de que estas no exploran toda la variabilidad ambiental que el bloque puede representar. Esta situación resultaba particularmente importante en las pruebas de progenies de eucaliptos, donde el gran número de familias a considerar obligaba al uso de bloques de gran tamaño. En este esquema se distribuyen aleatoriamente las progenies dentro de cada bloque, sin considerar la procedencia de cada una. En este caso cada progenie se representa en todos los bloques a través de parcelas de 4 plantas en línea. De esta forma se consigue una mejor distribución de las progenies dentro del bloque, evitando su agrupamiento en función de la procedencia. Este diseño ha sido el más utilizado por los programas de mejoramiento genético de *Pinus radiata* en Chile por las empresas forestales.

- Bloques incompletos: Este enfoque ha sido adoptado como consecuencia del gran número de familias a ensayar, las cuales demandan bloques de un tamaño tal que hace insostenible la premisa de homogeneidad intrabloque. Este esquema permite probar un gran número de familias, utilizando bloques pequeños y reduciendo la variabilidad dentro de ellos. Particularmente se ha utilizado una variante de los bloques incompletos denominada "Latice", la que se caracteriza por presentar combinaciones de grupos de familias formando repeticiones separadas. En este esquema las progenies se han representado por parcelas de 3 o 4 plantas en línea. Su uso en Chile se ha popularizado con el advenimiento de programas computacionales que simplican la contrucción y aleatorización de esta clase compleja de diseños experimentales. Williams y Matheson (1995) explican el uso de diseños en latice generalizado y describen un programa computacional denominado ALPHA+.

- Bloques al azar con parcelas de un árbol (single tree plot): En primer lugar es necesario indicar que más que un diseño, este corresponde a una configuración específica, en que una parcela está conformada por un árbol. La adopción de este esquema obedece a la necesidad de reducir el tamaño de los bloques, de modo de asegurar la homogeneidad de sitio al interior de ellos. Este esquema permite disminuir el tamaño de los bloques o consecuentemente probar más familias en una misma superficie que utilizando parcelas mayores. Resulta particularmente útil cuando el número de progenies a ensayar es muy alto y demanda el uso de bloques de gran superficie. Adicionalmente resulta muy apropiado cuando se contempla como uso final de la prueba su conversión en un huerto semillero de plántulas o semilla. En este esquema se distribuyen al azar las progenies dentro de cada bloque y se representan por parcelas de una planta. Además este tipo de configuración (Ipinza, 1998b) se puede utilizar con uno de los diseños anteriormente citados. También este diseño se está popularizando en los ensayos genéticos de *Pinus radiata* en Chile.

En el ámbito general en Chile, para diferentes especies, los ensayos de genética forestal se establecen usando preferentemente Diseños de Bloques Completamente al Azar. Lo anterior obedece a que es el sistema más simple que considera el uso de bloques y también a que es un diseño fácil de entender, establecer, monumentar y evaluar. Adicionalmente es un sistema robusto ante pérdidas que se puedan experimentar durante la vida del ensayo. Las estimaciones del valor genético de los árboles mediante BLUP mejoran sustancialmente cuando el diseño tiene bloques.

El uso de bloques contribuye a que los miembros de una familia sean expuestos a varios microambientes dentro del área del ensayo, y de esta forma puedan hacer un muestreo de la variación ambiental del área. Así al obtener el promedio de las familias en cada bloque, se eliminará gran parte del error ambiental y las medias familiares representarán el verdadero valor genético de las familias. Por otra parte, en la medida que han mejorado las capacidades tecnológicas de análisis de información, y en la medida que se ha adoptado mayor conciencia en cuanto a la importancia de la homogeneidad de los bloques, se han desarrollado y adoptado variaciones sobre el sistema de bloques tradicionales.

Sin menos cabo que los modernos procedimientos de definición de las estrategias de mejora genética tienden a determinar el tipo de diseño a utilizar, el enfoque propuesto y utilizado en Chile en el último tiempo apuntan precisamente a permitir disminuir el tamaño de los bloques, o a poder probar más familias en un mismo bloque. Para esto último, se utilizan básicamente dos esquemas diferentes: En uno de ellos se utilizan los bloques al azar convencionales, pero se disminuye el tamaño de las parcelas con que se representa a cada familia. En el caso extremo se constituye en un esquema de un árbol una parcela (Single Tree Plot) donde cada progenie se representa por un árbol en cada bloque.

El segundo enfoque apunta al uso de sistemas de bloques incompletos (o sub-bloques), donde en cada unidad homogénea de terreno se distribuye sólo un subconjunto de las familias a probar. Estos diseños han sido reconocidos por Friedman y Namkoong (1986) como apropiados para probar un gran número de familias o para mantener pequeño el tamaño de los bloques en zonas de alta variabilidad ambiental. Entre las alternativas que se emplean están el "Set in Blocks" y los Latices. Como se ha indica en los apartados anteriores este último diseño es más complejo y requiere más esfuerzos y recursos para su establecimiento, monumentación, evaluación y procesamiento de la información. Por otra parte el análisis de la información suele complicarse cuando se pierden observaciones. El diseño "set in block", descrito por Shutz y Cockerham (1966), divide los tratamientos en un número semi-independientes de diseños en bloques completamente aleatorizados. La pérdida de información por mortalidad - hasta cierto límite - puede provocar que el análisis pueda aún realizarse como un(os) diseño(s) completamente al azar. Su uso ha sido recomendado para la estrategia de mejoramiento genético de ***Eucalyptus globulus*** para Chile (Ipinza et al 1994a), no obstante su uso no esta muy extendido en el país.

En el cuadro 1, se muestra la evolución de los distintos tipos de diseños utilizados en Chile. Para la construcción de este cuadro se ha obviado el objetivo del diseño, es decir si fue establecido para hacer una selección entre familias, si fue construido para hacer una selección dentro de las familias o si cumple ambas funciones. Sin menoscabo de los anterior, el único diseño que no es adecuado para hacer selección dentro de las familias, es aquel diseño que presenta la configuración de un árbol una parcela.

Metodologías utilizadas para el análisis genético forestal en Chile

Para entender de mejor forma la evolución en Chile en este aspecto dividiremos el análisis en aquella metodología utilizadas para calcular los componentes de varianza y las utilizadas para predecir los valores genéticos.

Componentes de varianza

Para la estimación de los componentes de varianza se ha utilizado preferentemente el sistema estadístico SAS (SAS/STAT® User's Guide: Version, Fouth Edition, Volume 1 y 2), específicamente el procedimiento VARCOMP. Los métodos que utiliza VARCOMP, son varios, un análisis detallado puede encontrarse en Land et al (1986), Sander (1986) y Stonecypher (1992). En Chile, en un principio, en la década del 80, fue muy utilizado el método conocido como TYPE1, que corresponde a una forma de calculo de la diferencia en suma de cuadrado, lamentablemente está opción depende si los datos están balanceado, por lo que su uso en los diseños genéticos forestales es mucho menor. Este se uso en las evaluaciones juveniles de los ensayos de progenie y procedencia del Instituto Forestal (Ipinza et al 1994b; Alvear y Prado, 1994; y Prado y Alvear, 1994). El método más utilizado en la actualidad para estimar los componentes de varianza es conocido como REML, que es la maxima verosimilitud restringida. REML maximiza la verosimilitud que es independiente de los efectos fijos (Walsh y Lynch, 1997). Si bien es cierto que REML es un método robusto su uso estuvo limitado por la capacidad en memoria RAM de los computadores personales. Apiolaza et al (1994) realiza en Gainesville (EE.UU) un completo análisis genético en ***Pinus radiata*** utilizando SAS y el método REML, en un macroprocesador.

Cuadro 1: *Evolución en Chile de los diseños utilizados para establecimiento de pruebas de progenies*

AÑOS	PINO$_1$	EUCALIPTO$_2$	RAULÍ$_3$
1980-1988	Bloques al azar		
1989-1991	Bloques al azar	Bloques Fam. Compactas Bloques al azar	
1992-1995	Bloques al azar	Bloques al azar	
1996- 1997	Bloques al azar Bloques al azar (STP$_4$) Bloques incompletos	Bloques al azar Bloques incompletos (Latice)	
1998	Bloques al azar Bloques al azar (STP$_4$) Bloques incompletos	Bloques al azar Bloques incompletos	Bloques al azar (STP)

$_1$ Pinus radiata
$_2$ Eucalyptus spp.
$_3$ Nothofagus alpina.
$_4$ STP (=Single Tree Plot), un árbol una parcela

Posteriormente se hacen disponible en Chile, programas provenientes de la genética animal como el DFREML (Meyer, 1991). Este programa permite estimar los componentes de varianza y covarianza para variables continuas mediante REML. Se comenzó a utilizar con mucho éxito a partir de 1995 en los estudios de análisis genético y de evaluaciones genética mediante BLUP en ***Pinus radiata*** y ***Eucalyptus spp.*** , para las distintas organizaciones y empresas forestales de Chile. Con esta introducción aumento el uso del denominado modelo animal o modelo de árbol individual en Chile. Parte de los componentes de varianza del primer catálogo de valores genético de ***Pinus radiata*** (Borralho et al, 1996) fue estimado mediante DFREML y VCE3 (Groeneveld, 1994).

Es importante destacar que en esta misma fecha algunas empresas forestales comenzaron a utilizar el procedimiento MIXED de SAS, el cual permite ajustar una variedad de modelos lineales mixto a los datos. Al igual que ASREML, el procedimiento MIXED soporta REML y análisis espacial. También se ha utilizado, en forma muy local el programa GAREML (Huber, 1993), el que utiliza REML para la estimación de los componentes de varianza y la predicción de los valores genéticos. El programa GAREML soporta sólo modelos univariados.

A partir de 1997 se comenzó a utilizar el programa ASREML (Gilmour et al, 1997), que permitía estimar los componentes de varianza bajo un modelo mixto general, mediante REML. Mediante él sé realizarón los análisis genético individuales de los ensayos de progenie y procedencia de ***Eucalyptus globulus*** (Ipinza et al, 1998b) y ***E. nitens*** (Ipinza et al, 1998a), además los análisis multivariado y multisitio de ***E. nitens*** (Ipinza y Molina (1998a; Ipinza et al 1998a; Ipinza et al 1998c), ***E. globulus*** (Ipinza y Molina, 1998b) y ***E. camaldulensis*** (Ipinza y Molina, 1998c). El programa ha evolucionado bastante, haciendose muy amistoso con el usuario, y funcionando en computadores personales bajo una amplia gama de sistemas operativos.

Por último, han exististido algunos esfuerzos en prospectar otros sistemas tales como los métodos bayesianos, específicamente el "Gibbs Sampling" en ensayos de progenie y procedencia de ***E. Nitens*** (Fernández et al, 1998). La estimación apropiada de las varianzas y en especial de las covarianzas es de vital importancia para una precisa y robusta estimación de los valores genéticos de las familias y de los árboles individuales.

Valores genéticos

Un análisis detallado de las metodologías utilizadas para determinar el valor de mejora o valor genético es realizado por Gezan y Torres (1998) y Borralho (1998a y b). Dichos autores (op. cit) indican varios métodos utilizados en la jerarquización de los distintos grupos genéticos:

- Promedio simple
- Promedio de los promedio de parcelas
- Promedio de los mínimos cuadrados ordinarios
- Promedios de mínimos cuadrados generalizados
- Indices de selección.
- Mejor predictor lineal (BLP)
- Mejor predictor lineal insesgado (BLUP)

Desde la década del 80 se han utilizado tradicionalmente en ***Pinus radiata*** los promedios de los promedios de parcela, generandose así un único valor representativo para cada familia. Los puntajes estándar promediados corrigen las diferencias de variabilidad entre diferentes bloques, dividiendo la observación original por la desviación estándar del bloque en el que ella se encuentra. Posteriormente se calculan los promedios familiares corregidos por las medias del bloque y del sitio, para obtener los promedios de los promedios de parcela y finalmente los promedios familiares (Balocchi et al, 1991). Estos valores familiares se han utilizado para seleccionar familias para cruzamientos controlados y para depurar huertos. Ahora si, el desbalance es tal, que algunas familias no están representadas en uno o más bloques, cualquier variante utilizada del promedio de promedio de parcela producirá inconsistencias en las estimaciones (Gezan y Torres, 1998).

A partir de la década del 90, también en ***Pinus radiata*** se han utilizados índices de selección familiar, donde se combina la información fenotípica individual con el valor promedio de la familia y combina estos valores usando las heredabilidades familiares y para individuos dentro de las familias como coeficientes para obtener los valores del índice (Balocchi y De Veer, 1994). Los valores obtenidos con el índice, para cada individuo, son posteriormente usados en el proceso de selección.

También en ***Pinus radiata*** y en forma extensiva en 1993, se uso el programa RESI5, un índice de selección restringido escrito por el Dr. N. Jackson, P. Cotterill y C. Dean, su forma de uso puede encontrarse en Cotterill y Dean (1990). El programa RESI5 permite el cálculo de un índice de selección multicriterio para información procedente de mediciones de árboles individuales, medición de progenitores, promedios de familias de hermanos completos y de medio hermanos. La técnica del BLP, tampoco se ha usado en forma intensiva en Chile, su utilización ha sido muy local y en programas de mejoramiento genético de eucalipto, en una empresa forestal.

Desde mediados de 1995, se ha utilizado el BLUP, tanto en ***Pinus radiata*** como en ***Eucalyptus spp.***, para predecir el valor genético de las progenies como de los progenitores. El uso de DFREM (Meyer, 1991) se vió limitado por no disponer de los errores estándar de los valores genéticos, por lo menos para la estructura de datos de padre desconocidos. Posteriormente, se publicó el primer catálogo de valores genético de ***Pinus radiata*** en Chile (Borralho et al, 1996), para su realización se utilizó el programa PEST de Groeneveld (1990), éste permite la predicción y estimación multivariada, y permite la inclusión de modelos fijos, aleatorios y mixtos. Es un programa muy fácil de usar ya que tiene una semejanza con SAS. El programa PEST sólo permite la estimación de los BLUP y BLUE (estimador de los efectos fijos), no permite la estimación de los componentes de varianza, los que deben ingresarse en forma externa al programa.

El catálogo de valores genético de ***Pinus radiata*** (Borralho et al, 1996) predijo el valor genético de 82.211 árboles, las variables consideradas fuerón el volumen y la rectitud, de modo que el mejorador puede construir un índice combinado entre las dos variables al incorporar adecuados ponderadores económicos. El índice final permite seleccionar individuos para la generación avanzadas y construir huertos semilleros de polinización abierta o controlada, considerando selecciones hacia delante y hacia atrás.

Con relación a los ensayos de progenie y procedencia de eucalipto, el programa utilizado para predecir los valores genéticos ha sido el ASREML (Gilmour, et al 1997b, 1998 y 1999). Se han confeccionado los catálogos mediante análisis multivariado y multisitio de ***Eucalyptus camaldulensis*** (Ipinza y Molina, 1998c), ***E. globulus*** (Ipinza y Molina, 1998b) y finalmente ***E. nitens*** (Ipinza y Molina, 1998a e Ipinza et al 1998c) . Las variables consideradas han sido el díametro y la altura en una cantidad variable de replicas de los ensayos. De esta forma el mejorador puede utilizar unos ponderadores económicos para obtener un índice combinado y de esta forma proceder a la selección de árboles individuales para los propósitos que estime conveniente.

Análisis espacial de la variable supervivencia

Componentes de varianza del modelo de árbol individual para la variable SUPER

A continuación se muestra en el cuadro 2, los componentes de varianza para el modelo LOGIT y PROBIT.

Cuadro 2: *Componentes de varianza para el modelo Logit y Probit*

COMPONENTES	LOGIT	PROBIT
Arbol	0,22981	0,0770754
Varianza [1]	1,000000*3,29	1,000000

[1] De acuerdo a Gilmour (1999), la verdadera varianza del modelo LOGIT, es ($=\pi^2/3$)

Estimación de la heredabilidad de los modelos binomiales para la variable SUPER

Las heredabilidades con su respectivo error estándar para los modelos basándose en el modelo binomial se indican en el cuadro 3.

Cuadro 3: *Heredabilidades, error estándar y la máxima verosimilitud (Log-Likelihood) para el modelo Logit y Probit.*

	LOGIT	PROBIT
$h^2_{binomial}$ ± error estándar	0,0653 ± 0,1190	0,0716 ± 0,0000
LogLikelihood	-2856,69	-2202,38

Las heredabilidades son muy semejantes, un elemento discriminante es utilizar el modelo con mejor verosimilitud (Borralho, Comunicación personal, 1999), aunque en este caso también los valores son semejantes. De acuerdo al cuadro 3, el modelo elegido es el PROBIT.

Transformación al modelo normal para la variable SUPER

La incidencia promedio (p) es 0,92 y z = 0,1486628

Luego,

h^2_{normal} = 0,0716* 0,92*0,08/0,0221006, para PROBIT

h^2_{normal} = 0,24, lo cual es razonable y similar a otros estudios (Chambers et al 1995). A modo de comparación la h^2_{normal} para el modelo LOGIT es 0,22.

Análisis espacial de la variable SUPER

Al usar el modelo animal o de árboles individuales como línea base, el modelo 1 de error AR1 x AR1 aumenta la máxima verosimilitud restringida en 400,81, tal como se muestra en el cuadro 4. El modelo 1 utilizado tiene la siguiente forma:

PROBIT (SUPER) = mu + bloque + random (arbol)

En la figura 2 se muestran los variogramas muestrales del modelo 1, 2 y 3. Los variogramas son gráficas de los residuos después de ajustar los respectivos modelos e indican las posibles tendencias en cambios sistemáticos en una o ambas direcciones (filas y columnas). El variograma presenta en la coordenada Z los residuos. La columna en la coordenada Y, y la fila en la coordenada X, ambas son distancias entre los centroides de las parcelas, es importante destacar que cuando los residuos son cero existe un perfecto ajuste, los residuos positivos forman montañas y los negativos valles.

Cuadro 4: *Modelos ajustados a supervivencia*

Modelo	Modelo de varianza	Natural	Parámetros de varianza	Máxima verosimilitud restringida	Cambio en la vero-similitud
Animal	bloque$_1$, árbol$_2$	-	2	-2202,38	
1	bloque$_1$, árbol$_2$	AR1 x AR1	3	-1801,57	400,81
2	bloque$_1$, árbol$_2$, row$_3$	AR1 x AR2	4	-1672,75	128,82
3	Bloque$_1$, árbol$_2$, row$_3$, spline$_4$	AR1 x AR2	5	-1426,39	246,36
4	Bloque$_1$, árbol$_2$, row$_3$, spline$_4$	AR1 x AR2 Error de medición	6	-1117,84	308,55

$_1$ efecto fijo
$_2$ efecto aleatorio
$_3$ row (efecto aleatorio), representa un factor basado sobre un índice de fila incluido en la matriz Z.
$_4$ spline (row), representa un componente spline aleatorio incluido en la matriz Z.

La estrategia es ir absorbiendo estas irregularidades mediante la incorporación de sucesivas variables o funciones. El variograma muestral base, del modelo 1 (figura 2a, indica que dentro de cada fila el comportamiento entre columnas es relativamente similiar, pero entre filas se observa una tendencia en etapas, lo que sugiere la incorporación de un componente adicional debido a la fila. El modelo 2, de error AR1 x AR1, ajustado tiene al factor fila como un elemento aleatorio adicional y tiene la siguiente forma:

PROBIT (SUPER) = mu + bloque + random (arbol) + random (row)

Las razones de la existencia de esta gradiente en etapas pueden ser de muy distinto origen. Probablemente ellas obedecen a variaciones microambientales naturales o inducidas durante el establecimiento o manejo del ensayo. En este caso en particular, el ensayo está instalado en un terreno con una ligera pendiente principal que baja en el sentido de la fila 48 hacia la fila 1, situación que coincide con la variación observada en el variograma 2a, y que parece ser la fuente principal que explica esta forma de variación.

Adicionalmente y de acuerdo a la forma en que fue establecido el ensayo, las plantas de relleno se concentran desde las filas 24 a la 1, por cuanto al iniciarse el establecimiento del ensayo desde la fila 48 hacia la 1, en la medida que no se disponía de todas las plantas requeridas para cada progenie, estas se reemplazaban por plantas de relleno. Esta variación del material considerado en el ensayo también obedece a un patrón de variación orientado en el sentido de las filas, lo que puede constituir otra fuente que constribuya a la explicación de la variación observada en el variograma 2a.

Después de ajustar el modelo 2, la verosimilitud aumenta en 128.82, en la figura 2b, se puede observar el nuevo variograma muestral de este ajuste. En el se observa como una tendencia, un suave valle central entre filas, lo cual indicaría la incorporación de un efecto fila suavizado en el modelo del error. Para mejorar este efecto de tendencia global se ha procedido a ajustar un efecto "spline".

El modelo 3, de error AR1 x AR1, ajustado tiene una spline como un elemento aleatorio adicional y tiene la siguiente forma:

PROBIT (SUPER) = mu + bloque + random (arbol) + random (row) + spline(row)

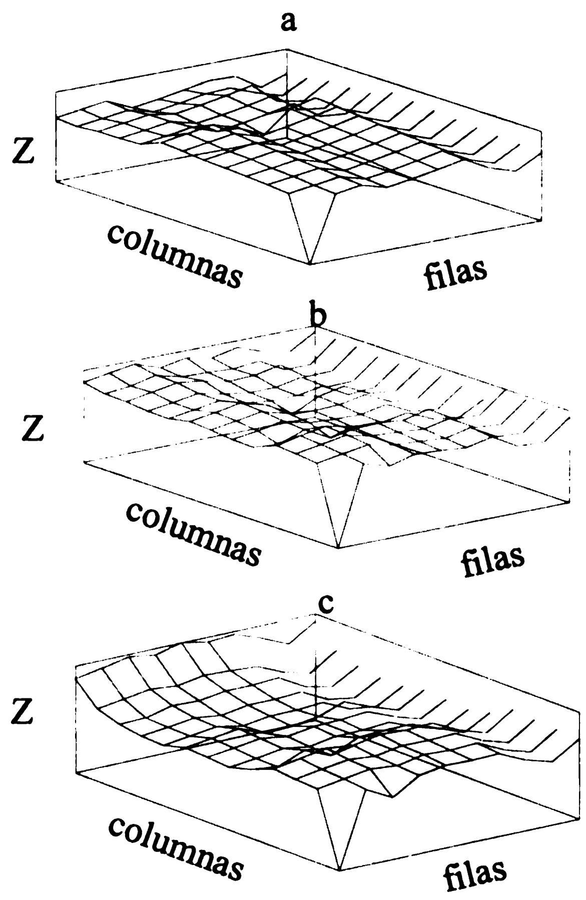

Figura 2: *Variogramas muestrales calculados para el modelo AR1 X AR1, 1, 2 y 3. (a) modelo 1: arbol + AR1xAR1, (b) modelo 2: arbol + row + AR1xAR1, (c) modelo 3: arbol + row + spline (row) + AR1xAR1.*

Las razones de esta tendencia global pueden ser consecuencia del orden natural en que están enumerados los bloques del ensayo, lo que determina que el establecimiento y la realización de prácticas culturales se efectúen en el sentido determinado por el trazo entre las corrdenadas "fila 48 columna 1" hacia la "fila 1 columna 20". De esta forma, este sentido determina que las plantas del inicio sean plantadas, regadas y fertilizadas antes que las del final. Estas operaciones no tardan más de dos días en ejecutarse, pero aún así podrían ser una fuentes que explique en alguna forma el patrón de variación observado.

Después de ajustar el modelo 3, la verosimilitud aumenta en 246,36, en la figura 2c, se puede observar el nuevo variograma muestral de este ajuste. En este nuevo variograma muestral se observa una tendencia de los residuos a aumentar en las columnas superiores. Un probable efecto ambiental que queda al descubierto puede estar determinado por un camino próximo al ensayo y paralelo a las columnas, las cuales están a una distancia de él que aumenta en la medida que las columnas tienen valores más bajos. De esta forma un probable gradiente de compactación asociado a este camino afectaría en forma más intensa a la columna 20 y disminuiría su efecto hacia la columna 1, situación que coincide con la variación que representa el variograma 2c.

Esto obviamente está indicando que el próximo efecto a incorporar en la ecuación sería un efecto aleatorio columna. No obstante se ha considerado suficiente con los propósitos de mostrar la técnica - con esta variable supervivencia - llegar hasta el modelo 3 como modelo final. Los autores consideran que la aplicación del modelo espacial se encuentra en el límite de aplicación cuando la supervivencia es muy alta (92%). Se sugiere que se repita este análisis cada dos años para determinar como evoluciona la supervivencia.

Finalmente, se incluye en el modelo 4, la varianza "nugget" o medición del error la cual mejora significativamente el ajuste del modelo, incrementando la verosimilitud a: 308,55. Este valor estaría reafirmando que aún es posible identificar e incorporar nuevas fuentes de variación al modelo. La forma del modelo 3 es igual a la del modelo 4, agregandose a esta última el error, tal como se indica a continuación.

PROBIT (SUPER) = mu + bloque + random (arbol) + random (row) + spline(row) + error

CONCLUSIONES

Los diseños experimentales estructurados en bloques completamente al azar constituyen el tipo principal de diseños utilizados en Chile, en cualquier programa de mejora genética forestal. Cuando se requiere probar una gran cantidad de grupos genéticos, tales como familias y procedencias existe la tendencia a utilizar diseños en bloques incompletos, y con una configuración de un árbol una parcela.

En Chile normalmente, el análisis genético realizado para estimar componentes de varianza de los efectos aleatorio se calculan sobre la base de la máxima verosimilitud restringida (REML). Esto es una opción que la presentan la mayoría de los programas estadísticos utilizados en las evaluaciones genéticas.

La aplicación del modelo animal o modelo del árbol individual sé esta utilizando cada vez con mayor intensidad en el país. La predicción de los valores genéticos de las progenies localizadas en los ensayos genéticos se realiza preferentemente mediante la técnica del mejor predictor linear insesgado (BLUP). La supervivencia es una medida de adaptabilidad a factores ambientales específicos, por lo que debe evaluarse en forma períodica.

El análisis espacial requiere que las parcelas esten localizadas en términos de filas y columnas. El análisis espacial se vislumbra como una interesante herramienta para descubrir tendencias productos de fertilidades distintas en el suelo del ensayo, compactación del suelo, aplicación de cuidados culturales, tales como riegos, aplicación de herbicidas, pesticidas entre otros. El análisis espacial requiere en forma obligada que el mejorador disponga de una detallada hoja de vida del ensayo, ya que será la única forma de poder explicar la conductas de los variogramas. Por esta razón el análisis espacial será una herramienta adecuada para hacer auditorías técnicas de las pruebas genéticas.

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SESSION III

”DATA MANAGEMENT AND DATA ANALYSIS”

SCIBOS: UN SISTEMA CIENTÍFICO DE INFORMACIÓN DESARROLLADO EN LA UNIDAD DE MANEJO DE BOSQUES NATURALES / CATIE, COSTA RICA.

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RESUMEN

La utilización de sistemas de manejo de información es un aspecto cada vez más importante en el desarrollo de proyectos de investigación, Estos sistemas facilitan la administración de datos, tanto para el análisis directo de grandes volúmenes de datos, como para almacenamiento seguro de información. La Unidad de Manejo de Bosques Naturales (UMBN) del CATIE inició desde 1997 el desarrollo de un modelo de manejo de datos que facilite el proceso de análisis en las investigaciones en manejo de bosques naturales, este sistema asiste en los procesos básicos de un sistema de información, pero incorpora nuevos conceptos relacionados con la naturaleza dinámica de los datos provenientes de investigaciones científicas diversas. Este Sistema es la base para una iniciativa de CATIE en establecer una red de sitios de investigación. El Scibos se encuentra en la etapa de validación y una vez ajustado el sistema será utilizado como sistema para la red.

Palabras Clave: Sistemas de información, bases de datos, manejo de información, Investigación forestal.

ABSTRACT

In the development of scientific research, the use of information systems is vital. These systems are capable of managing data for analysis and storage. The Unidad de Manejo de Bosques Naturales (UMBN) of CATIE, since 1997 is developing a data management model for data analysis in natural forest management research. The system incorporates basic concepts of scientific data and scientific processes, and is capable of managing multi-Source data. After validation, this system is going to be the basis of a research network.

Key Words: Information Systems, Databases, Information Management, Forestry research.

INTRODUCCIÓN

La utilización de sistemas de manejo de información es un aspecto cada vez más importante en el desarrollo de proyectos de investigación, especialmente si se toma en cuanta la creciente tendencia a redes colaborativas entre institutos de investigación. Estos sistemas facilitan la administración de datos, tanto para el análisis directo de grandes volúmenes de datos, como para almacenamiento seguro de información. Hoy en día, los cambios rápidos en el mundo de la informática han permitido concentrar esfuerzos en elaborar herramientas amigables al usuario final, dejando de ser los sistemas de información un fin para convertirse en una verdadera herramienta de apoyo.

Los modelos de sistema de información del mercado, fueron diseñados para resolver problemas de tipo gerencial, y no han satisfecho la dinámica del proceso de investigación. Entre los principales problemas se incluyen: Poca flexibilidad, sistemas complicados y caros, orientados a transacciones y no análisis, se requiere un infraestructura cara para su mantenimiento, nueva información de investigaciones de diferente índole, implica un cambio sustancial en la estructura del sistema.

La Unidad de Manejo de Bosques Naturales (UMBN) del CATIE inició desde 1997 el desarrollo de un modelo de manejo de datos que facilite el proceso de análisis en las investigaciones en manejo de bosques naturales. A dicho sistema se le llamó SciBos (Sistema Científico de Información en Bosques Naturales), y constituye una herramienta eficaz y flexible en un ambiente moderno de trabajo. El SciBos representa una herramienta moderna para el manejo de información útil para cualquier centro de investigación con múltiples líneas o áreas de investigación.

El SciBos, es un sistema de información especial, orientado a la información científica, y su flexibilidad permite incorporar múltiples bases de datos. Para su diseño se consideraron varios aspectos importantes:

- SciBos debía ser un sistema flexible, capaz de adaptarse a los cambios constantes en la información científica.
- Las capacidades de análisis básicas del sistema (primitivas) deben ser tales que permitan hacer cálculos que no hayan sido predeterminados, de esta forma se garantiza la posibilidad de hacer análisis según peticiones del investigador.
- Control de los datos de investigaciones. Se despersonalizan las bases de datos, pero se mantiene control sobre el proyecto al que pertenecen.

Sistemas de Información y Sistema Científico de información.

Un sistema de información (SI) es un conjunto de elementos que interactúan entre si para apoyar las actividades de una empresa. Cualquier SI realiza cuatro actividades principales: entrada , almacenamiento, procesamiento y salida de información.

El sistema científico de información SCI, además de ser un SI que trabaja con información de proyectos de investigación científica, intenta modelar la dinámica del proceso de investigación. El SCI debe ser capaz de adatarse a la información y no lo contrario como cualquier otro SI. El SCI realiza cada una de las actividades antes mencionadas de manera especial, permitiendo gran flexibilidad.

Entrada de Información

Al iniciar un ensayo experimental, es necesario definir un diseño de muestreo. Este diseño incluye niveles de muestreo, tratamientos, distribución de bloques, metodología de medición, variables a medir, etc. Esta información es registrada en el SCI como una base de diseño experimental, el cual se puede asociar a uno o varios ensayos. El SCI puede tener muchos diseños experimentales diferentes, lo cual se traducirá en estructuras de datos diferentes que el SCI podrá manipular de manera trasparente.

Una vez definido un diseño experimental, el SCI, a diferencia de un sistema de información estándar, permite la inserción tanto de juegos completos de datos como la actualización de registros específicos de un juego de datos existente. Esto es importante, puesto que en el proceso de investigación científica, la integridad de un conjunto de datos es importante, y puede diferir de un ensayo a otro en virtud de los objetivos concretos de investigación.

La definición del diseño experimental, permite además la creación de formularios de campo que faciliten y garanticen la toma de datos en el campo.

Almacenamiento de Información

Un SI convencional, pose una estructura interna determinada para el almacenamiento de información, esta estructura se basa en un modelo concreto de datos Relacional, jerárquico, etc. Si se tiene un conjunto de datos que se desean insertar en el sistema, estos deben ser procesados y adaptados para cumplir con la estructura definida. Además cada dato forma parte de una bolsa común de datos (figura 1).

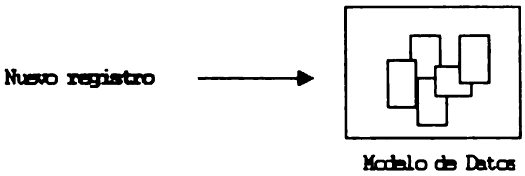


Figura 1. modelo conceptual de un SI convencional. Su estructura definida a priori, sólo permite la inserción de datos en forma de nuevos registros, y no nuevos conjuntos de datos que no correspondan al modelo definido.

Esta característica de SI limita el proceso de investigación de datos, dado que, como se dijo anteriormente, los ensayos experimentales pueden diferir en cuanto a estructura bajo diferentes objetivos de investigación. Así por ejemplo si el SI es para manejo bosques naturales, pero se establece una nueva línea de investigación para plantaciones forestales, sería necesario desarrollar un nuevo SI o modificar el que se tiene, para poder utilizar el SI con los nuevos datos.

Al contrario del SI el SCI, puede incorporar nuevos conjuntos de datos basados en los objetivos de investigación; esto lo logra gracias a su diseño dinámico, en donde cada conjunto de datos puede permanecer de forma independiente, como sub-sistema, habiendo definido ciertas características generales (figura 2).

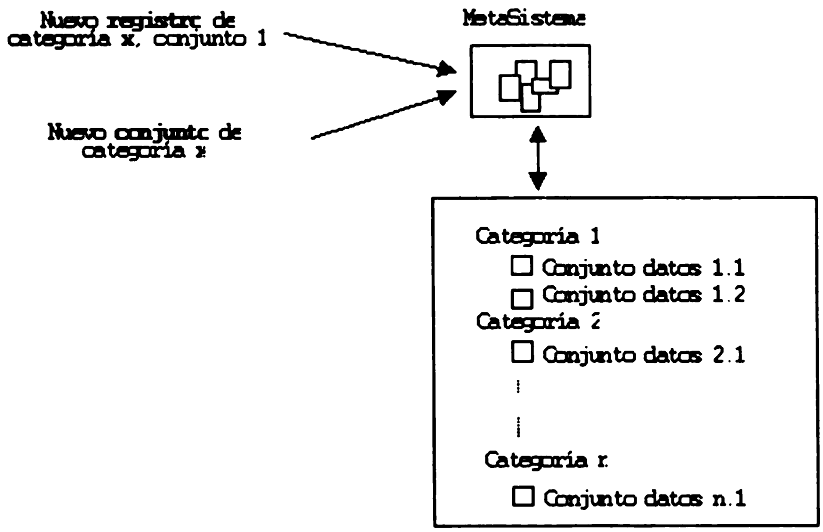


Figura 2. Modelo conceptual de SCI. Observe que las entradas del sistema pueden ser tanto nuevos registros de información sobre algún conjunto de datos existente, como un nuevo conjunto de datos.

Así, volviendo al ejemplo anterior, si la nueva línea de investigación se define en el SCI, la categoría plantaciones forma ahora parte del Sistema y entonces es posible el almacenamiento de conjuntos de datos sobre plantaciones.

Procesamiento de información

Del mismo modo en que no es posible en un SI convencional insertar nuevo conjuntos de datos que difieran de la estructura definida, las rutinas y procedimientos definidos en el SI se basan el la estructura de datos, lo cual imposibilitaría cualquier nuevo tipo de análisis, para nuevas formas de datos.

El SCI por el contrario tiene un conjunto de funciones básicas de análisis y agrupamiento que tiene carácter general, y que permitirían almacenar nuevas rutinas de análisis. Por ejemplo, para el cálculo de volumen de un grupo de especies se utiliza una función de volumen determinada. En el SI convencional, una vez definido el procedimiento, no es parte del sistema cambiarlo. Ahora bien si se especificó una nueva función de volumen, pero ahora para una especie determinada, el SI no puede incorporar la nueva función si no es por medio de la reprogramación del sistema. En el SCI es posible incorporar estas nuevas funciones, dado que cuenta con un evaluador de expresiones matemáticas.

Salidas de Información

Como es natural, las salidas de un SI son vitales para facilitar procesos posteriores de análisis. El SCI permite tener múltiples salidas como:

- - Archivos de texto
- - Bases de datos
- - Gráficos
- - Reportes impresos

SCIBOS: UN SISTEMA CIENTÍFICO DE INFORMACIÓN

El SciBos es un sistema científico de información que permite la administración, control y análisis de información generada a partir de investigación científica. Su capacidad va más allá de un sistema convencional, dado que permite tener información proveniente de diferentes ensayos experimentales y registrarlos junto con la información metodológica y de estructura en el sistema (metadatos). El SciBos incorpora cuatro componentes fundamentales en su diseño:

- Control de Información
- Recuperación
- Análisis
- Sistema Dinámico

Control de Información

Gracias a la habilidad del SciBos de servir como un sistema administrador de datos, es posible crear y modificar nuevas tablas que serán el almacén de nuevos datos experimentales. Así por ejemplo, si la nueva información corresponde a fauna y no a árboles, también se pueden registrar todos los detalles sobre los campos que se han codificado por su naturaleza categórica, y tener un registro que posteriormente puede definirse como un estándar para futuras investigaciones.

Además, la actualización de nueva información se puede hacer bajo un ambiente controlado, donde se puede asegurar la calidad de la información, eliminando errores propios del proceso de digitación.

Recuperación

Cada vez que se registró alguna base de datos en el SciBos, se construye una base de conocimiento sobre la base de datos, lo que permite posteriormente localizar dicha información con búsquedas simples.

A través del SciBos es posible buscar información a cualquier nivel. Por ejemplo, primero se puede buscar por país, luego por tratamiento, luego por una familia en particular, etc. El sistema regresa todas aquellas bases de datos que correspondan, de esta manera, facilita la recuperación de cualquier base de datos, indiferentemente de cuál sea su origen, y de quién haya hecho el diseño experimental.

Análisis

El SciBos es una herramienta genérica de análisis, que provee las herramientas básicas para poder agrupar la información de cualquier forma. Luego es posible realizar operaciones sobre ellas, para así lograr una infinidad de cálculos, almacenando nuevas rutinas desarrolladas por el investigador. Esta es una virtud del SciBos, su apertura permite la evolución de las bases de información y la modificación o adaptación de procedimientos convencionales.

Sistema Dinámico

El SciBos fue diseñado para crecer. Así por ejemplo es posible que los resultados de análisis sobre las bases de información, queden registrados como resultados ya calculados, que faciliten la utilización de la información a investigadores posteriores. Además, se diseñó pensando en la posibilidad de ir incorporando "Plug-Ins", para facilitar la incorporación de nuevas funciones de cálculo más especializadas.

Interfaz del SciBos

El SciBos es un sistema que funciona en Red y consta de tres módulos: Administración, Inserción, Usuarios.

Módulo Administrador

El módulo de administración (Figura 3) permite el control centralizado de la información. El administrador posee herramientas para el manejo de bases de datos (creación, edición, etc.), así como para el control de las bases de datos categorizadas por tema de investigación. Además tiene control sobre la creación de formularios de campo y sobre los metadatos.

La interfaz del administrador (Figura 4), permite a la persona encargada de administrar el sistema tener acceso fácil y rápido a las labores de mantenimiento y actualización de la información de bases de datos del sistema.

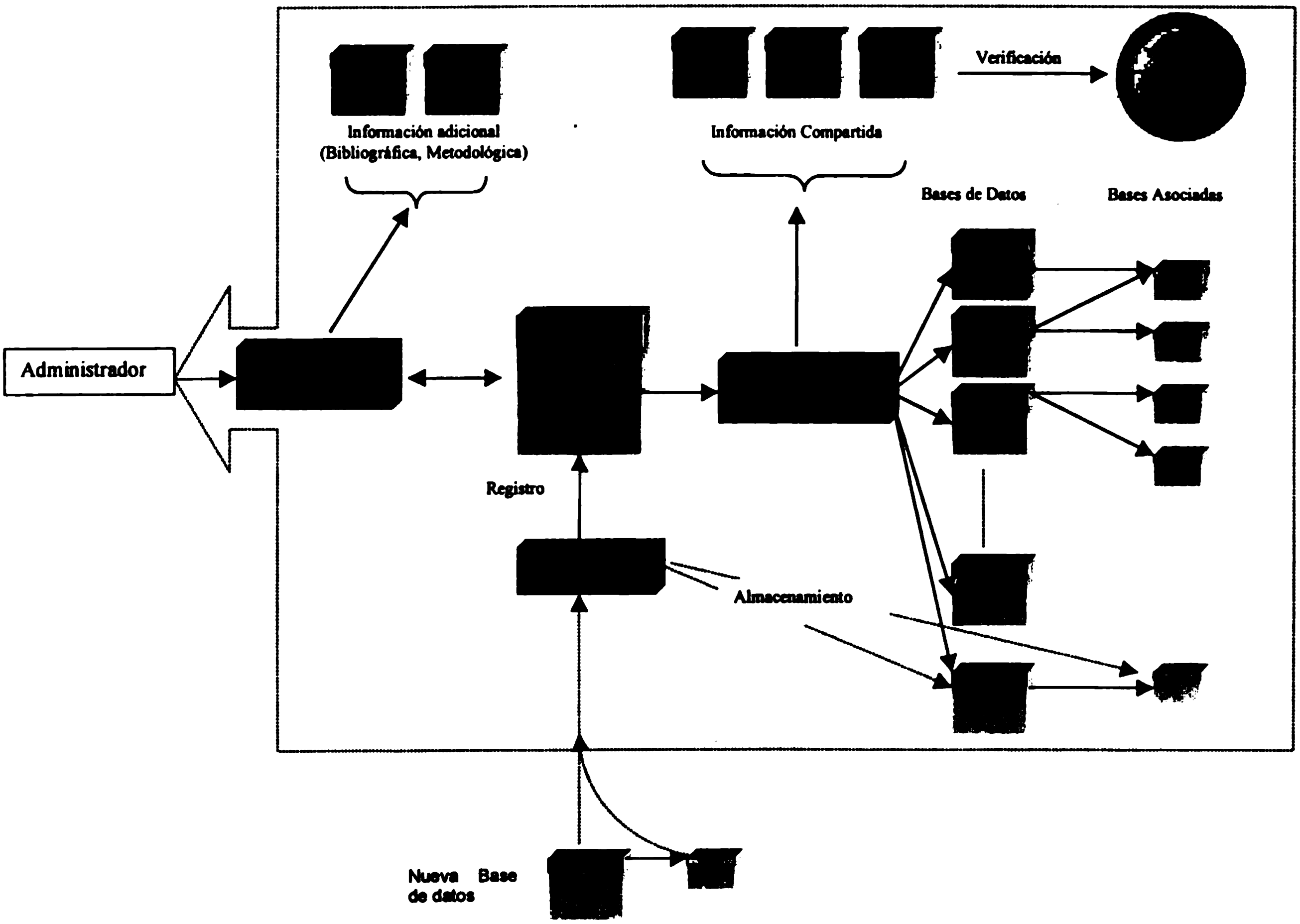


Figura 3. *Esquema de funcionamiento del módulo administrador*

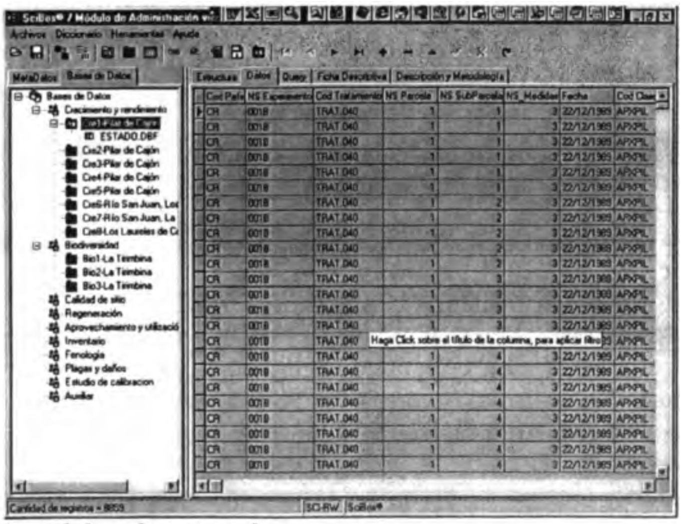
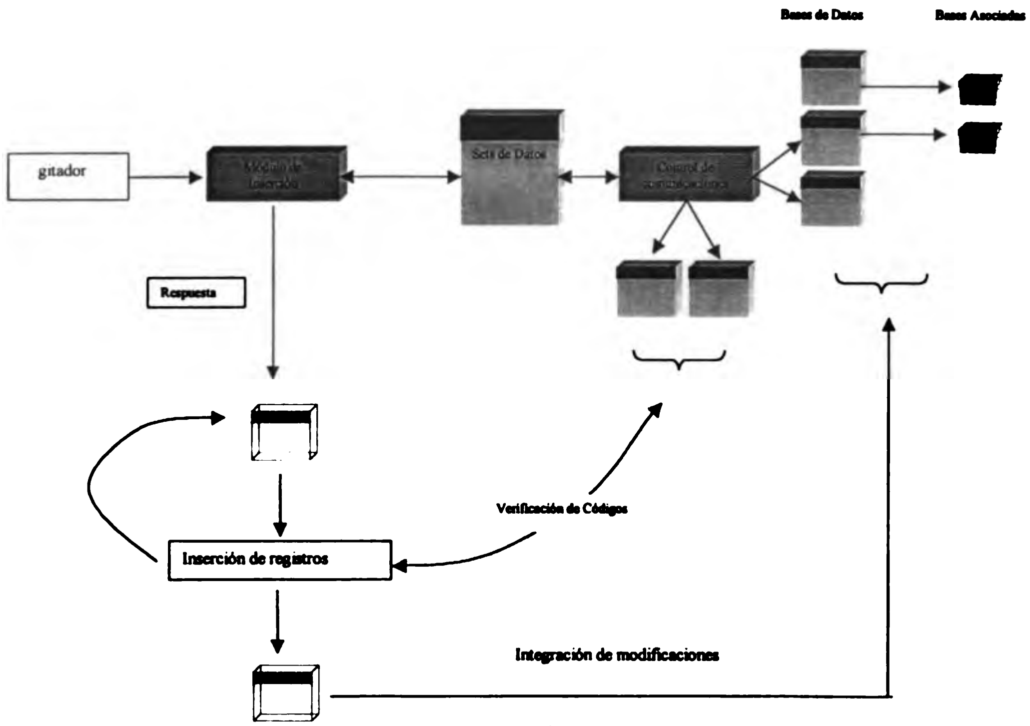


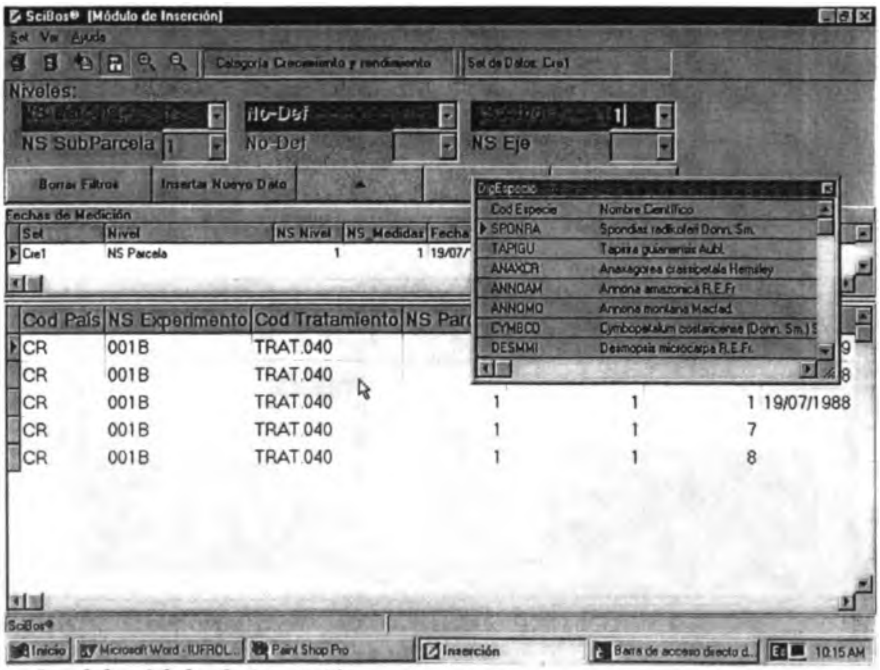
Figura 4. *Interfaz del módulo administrador*

Módulo de Inserción

El módulo de inserción (Figura 5 y 6), es un módulo sencillo, que permite la actualización de las bases de datos con la información de campo recopilada. Este módulo es de acceso restringido, al igual que el de administración, cuyo control queda determinado por el administrador.



<u>Figura 5.</u> *Esquema de funcionamiento del módulo de inserción*



<u>Figura 6.</u> *Interfaz del módulo de inserción*

Módulo de Usuarios

El módulo de usuarios (Figura 7 y 8), permite al investigador realizar búsquedas en las bases de datos por diferentes tópicos, así por ejemplo si desea obtener los juegos de datos que tengan información sobre una especie, género o familia particular, el sistema le devolverá las bases de datos correspondientes, el usuario posteriormente tendrá diferentes herramientas de análisis, tanto de agrupación y clasificación como herramientas matemáticas.

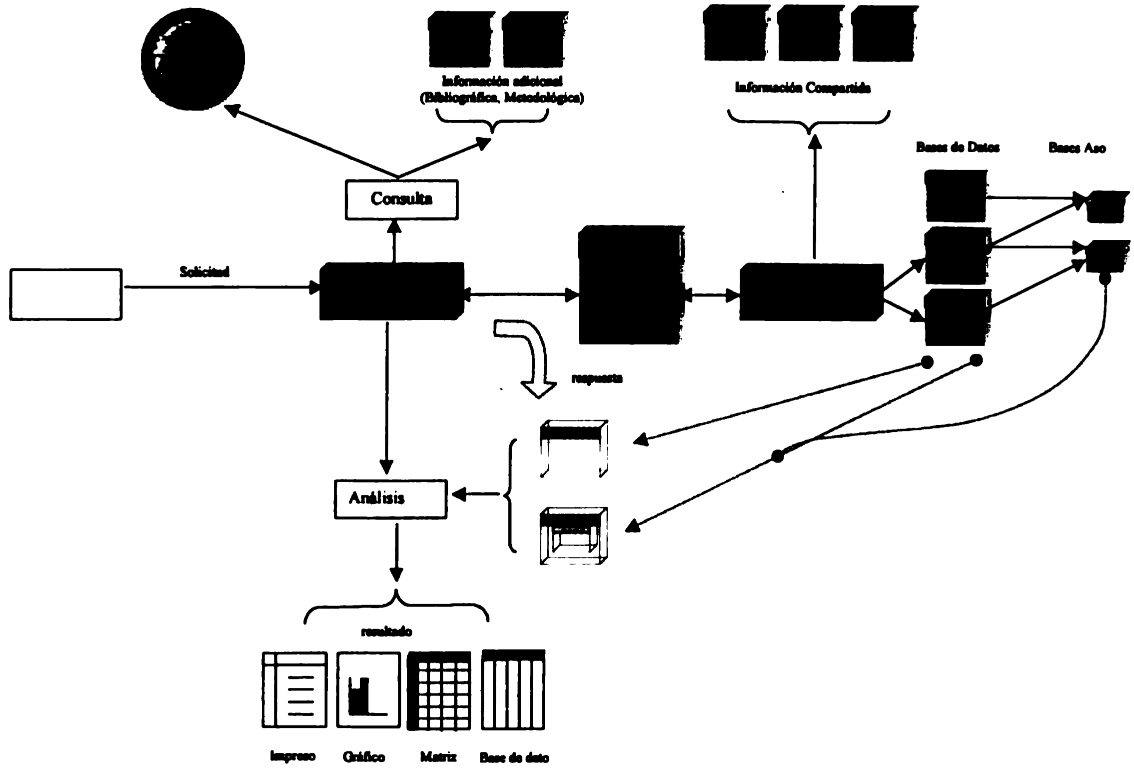


Figura 7. *Esquema de funcionamiento del módulo de usuarios*

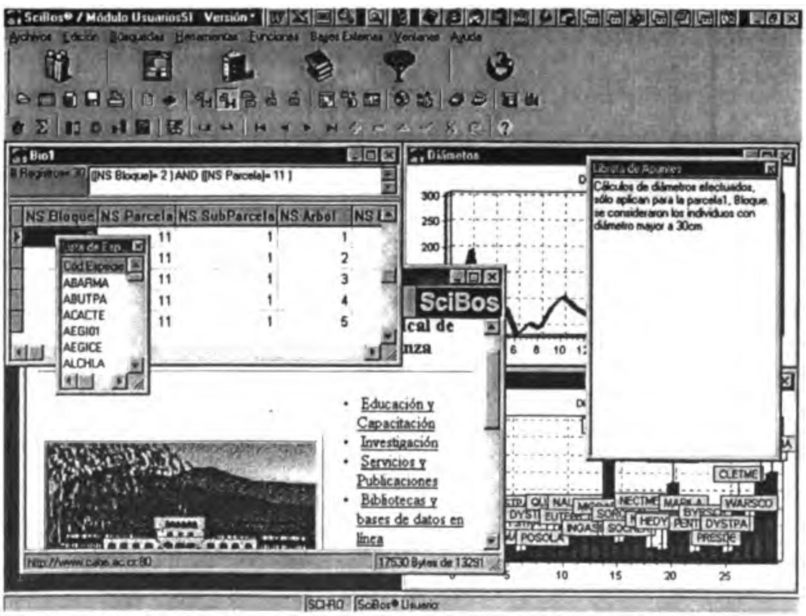


Figura 8. *Interfaz del módulo de usurarios*

Este sistema permite el manejo distribuido de bases de datos, lo que sería muy util en casos de redes de sitios de investigación y tener control de información incluso fuera del CATIE, vía internet.

El SciBos tiene conectividad directa con el web, lo que permite buscar información a través del sistema.

SciBos como Herramienta para Una Red de Sitios

Dada la naturaleza de la investigación forestal, particularmente la relacionada con el manejo de bosques naturales, la conformación de redes de investigación es un mecanismo que tiene un gran potencial en América Latina. CATIE ha venido colaborando con varias instituciones de investigación forestal de la región, con el propósito de consolidar una "Red Neotropical de sitios clave de Investigación a largo plazo".

Para esta iniciativa, el SciBos es de fundamental importancia, pues permitirá, entre otras cosas:

- contar con un sistema único para la toma, el manejo y análisis de la información, y la capacitación;
- facilitará la comunicación entre los miembros de la Red en los aspectos relacionados con el manejo de la información;
- permitirá la estandarización de metodologías, pero al mismo tiempo dará la flexibilidad al investigador de explorar nuevas posibilidades de análisis;
- propiciará el empoderamiento de los investigadores para hacer el análisis de sus datos, pues los hará menos dependientes de los analistas, con la consecuente ventaja de permitirles profundizar en el análisis de la información;
- podría facilitar el compartir el aprendizaje entre los investigadores miembros de la Red;
- hará fácilmente accesible a los miembros de la Red, información tal como: datos de campo, formularios de campo, fórmulas, descripción de las investigaciones, información sobre la Red y sus miembros, metodologías y publicaciones relacionadas.

El valor de la información depende en gran medida de la forma como esté ordenada y accesible para los usuarios. En este sentido, el SciBos será una herramienta estratégica para asegurar que la información es ordenada de tal manera que facilite su mejor aprovechamiento.

Perspectivas del SciBos

A la fecha el SciBos se encuentra en la etapa final de desarrollo dentro de la UMBN del CATIE. Los siguientes pasos consistirán en validarlo como modelo para el almacenamiento, manejo y análisis de información forestal. Esta validación será realizada por los propios investigadores del CATIE, luego de la cual sería necesario hacer los ajustes necesarios para asegurar que el SciBos es realmente una herramienta valiosa para la investigación forestal.

Luego de estas etapas de validación y ajustes, vendría una etapa de extensión del sistema, mediante la instalación del mismo en las instituciones miembros de la Red, lo cual deberá ir acompañado de un programa de capacitación.

Posterior a este período de implementación y capacitación a los miembros de la Red, se prevee una nueve etapa de ajustes al SciBos, a manera de incorporar las sugerencias que podrían aportar los miembros de la Red, así como los nuevos desarrollos tecnológicos en el campo de la informática.

Con todo esto se espera que el SciBos se convierta en un instrumento clave para poner a disposición del sector forestal la información necesaria para apoyar la toma de decisiones para el manejo forestal sostenible.

COMBINING MULTIPURPOSE RESOURCE INVENTORY DATA IN A FOREST INFORMATION SYSTEM BASED ON SAS/AF®

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ABSTRACT

The results of the second Swiss National Forest Inventory (NFI) originate from several data sources. Data from aerial photography and terrestrial samples were assessed and combined in a two phase sampling design. Additionally data from geographic information systems (GIS) and models are used for data analysis.

A graphical user interface (GUI) based on SAS/AF® was developed to compile parameters to generate specific results for a certain attribute. In the background the connection to an ORACLE 7 database, the data aggregation, the calculation of estimators and the presentation of results is controlled by the SAS programming and macro language. This approach ensures consistent results in a multi-user environment.

The objective of the paper is to introduce the concept of the data analysis procedure and to present future enhancements towards a forest information and monitoring system. Focus is on methods to combine data from different spatial and temporal scale, the implementation of models for volume and growth scenarios and the development of interfaces to standard geographical information systems (GIS). These extensions are essential to improve the capability of the software tool to apply as an integrated monitoring tool and to support decision makers efficiently.

Keywords: Swiss national forest inventory, data analysis, forest and landscape information system, SAS®

INTRODUCTION

The second Swiss National Forest Inventory (NFI) is based on several data sources. Measurements from aerial photography and field survey as well as information from questionnaires and GIS are combined in a two phase sampling system. All relevant data are stored in an ORACLE 7 database. The data analysis tools (Schnellbächer and Köhl 1996) are based on the Statistical Analysis Software (SAS ®). The data analysis software supports the access to the database, calculation of estimators and the presentation of results in graphical and tabular form. It was especially developed to analyse sample-based inventory data from several data sources and for successive occasions on a national level. This means that the software design should allow the management of a huge amount of multipurpose inventory data on categorical and metric scale for state and change detection. In the following it is called a Forest Inventory and Monitoring Analysis System (FIMAS).

It has powerful tools to carry out one and two phase data analysis specified by a set of parameters which control the flow of the data query and analysis steps.

The modular architecture of the software allows to create access interfaces to other data bases, GIS tools based on ARC-INFO and other vector or raster based GIS tools.

In the following the Swiss NFI concept and the data analysis software package will be presented. Emphasis is on the features supporting the analysis of inventory data on successive occasions and on future enhancements referring data management and data retrieval performance.

SWISS NFI

General Introduction

About 1.2 Mill ha i.e. 29% of the total area of Switzerland (ca. 4.2 Mill ha) is covered by forest. Main tree species are spruce, fir and beech. The first national forest inventory was carried out between 1983 and 1985. About 11'000 field plots were surveyed and permanently marked. After a ten years period the second field survey was conducted between 1993 and 1995. About 5'400 permanent and about 1'000 new field plots were measured.

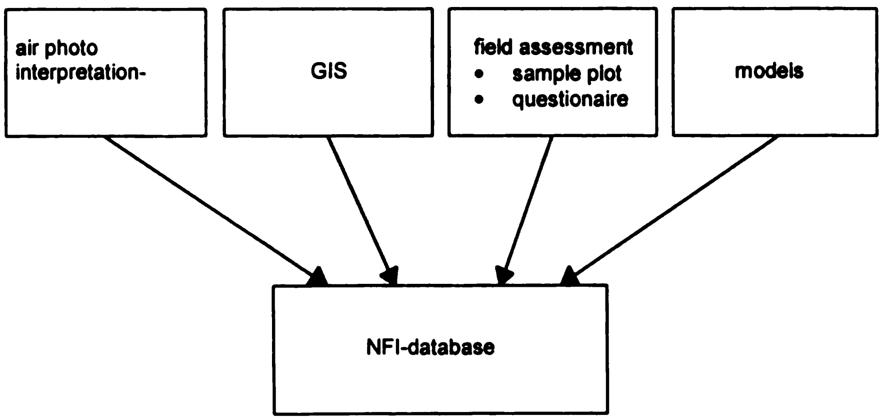


Figure 1: *Data sources in the Swiss NFI*

More than 170 attributes from aerial photography (canopy closure, tree species composition etc.), field samples (tree and plot attributes), inquiries (silvicultural, harvesting and management techniques)and GIS (Geology, soil, ownership etc.) were assessed (c.f. Figure 1).

In a second step about 300 derived attributes were calculated.

The statistical design of the second inventory is a two phase sampling approach (double sampling for stratification with ratio estimators) (Köhl 1994; Köhl und Brassel 1997). In a first phase black and white aerial photographs (1:30'000) were interpreted. From a systematic sample of about 160'000 aerial photography plots (grid width: 500m) the forest area and several other measurements inclusive attributes for stratification were derived. In a second phase a set of attributes from about 6'400 terrestrial forest plots located on a subnet (grid width: 1.44 km) was assessed.

The inventory results are calculated separately for cantons, production or economical regions and are combined to results on the national level. Models are applied e.g. for tree volume estimation, growth figures and scenario modelling and also to derive site indexes, naturalness, accessibility etc.. The direct assessed attributes are mainly categorical data, attributes measured from the single trees on the plot are primary measured on a metric level. An aerial photo or field plot is defined as the sampling unit, for data analysis, single tree data have to be aggregated to plot figures.

The concept of the third Swiss forest inventory generally will base on the double sampling approach and continuous forest inventory (CFI) estimators. The first phase data source and the interpretation techniques to assess the forest area and the attributes for stratification probably will be differ from the current approach. The set of attributes referring to non wood goods and services (NWGS) and ecological parameters will be enhanced. This refers especially to the assessment of biodiversity indicators, or -more specific- to the assessment of structural diversity of forest stands and their spatial arrangement.

The Swiss NFI can be characterised as a periodic sample based inventory following the CFI concept i.e. a certain amount of permanent plots are measured at successive occasions. Thus the NFI allows both to inventory as well as to monitor the Swiss forests. Since the concept of monitoring focuses on the detection of change, also periodically conducted continuous forest inventories are monitoring systems if the inherent rate of change of an attributes of interest is small compared to the absolute figure at a certain point in time (e.g. growth figures versus standing volume).

In particular by means of satellite remote sensing data it would be possible to establish a country wide forest or landscape monitoring system with much higher temporal resolution as can be accomplished by a terrestrial survey.

Swiss NFI Database Organisation

- The data stored in the NFI database can be distinguished in direct assessed and derived attributes. The latter ones are a combination of direct assessed attributes derived by a model or by a definition. Derived attributes can be managed in different ways:
- permanent storage (e.g. single tree volume, diversity indices). Internal and external scripts are used in case of complex models (tariff volume, assortments, classification/lookup tables, etc.)
- processing during runtime by means of views or algorithms etc. (e.g. volume per ha)

Figure 2 shows further differences of NFI data. Beyond the data source (external, aerial photography, field plot, ...) and the sample size, data can be divided into two hierarchical levels:

- attributes assessed on the plot level
- attributes assessed on the subplot level(single tree attributes e.g. diameter and height as well as derived attributes e.g stem volume).

Figure 3 shows the entity relationship (ER) diagram of the Swiss NFI database.

As can bee seen from Figure 2 and 3 the subplot data are stored in childtables (tables on a subordinate level) of the plot data tables although they have to be aggregated to the plot level for data analysis.

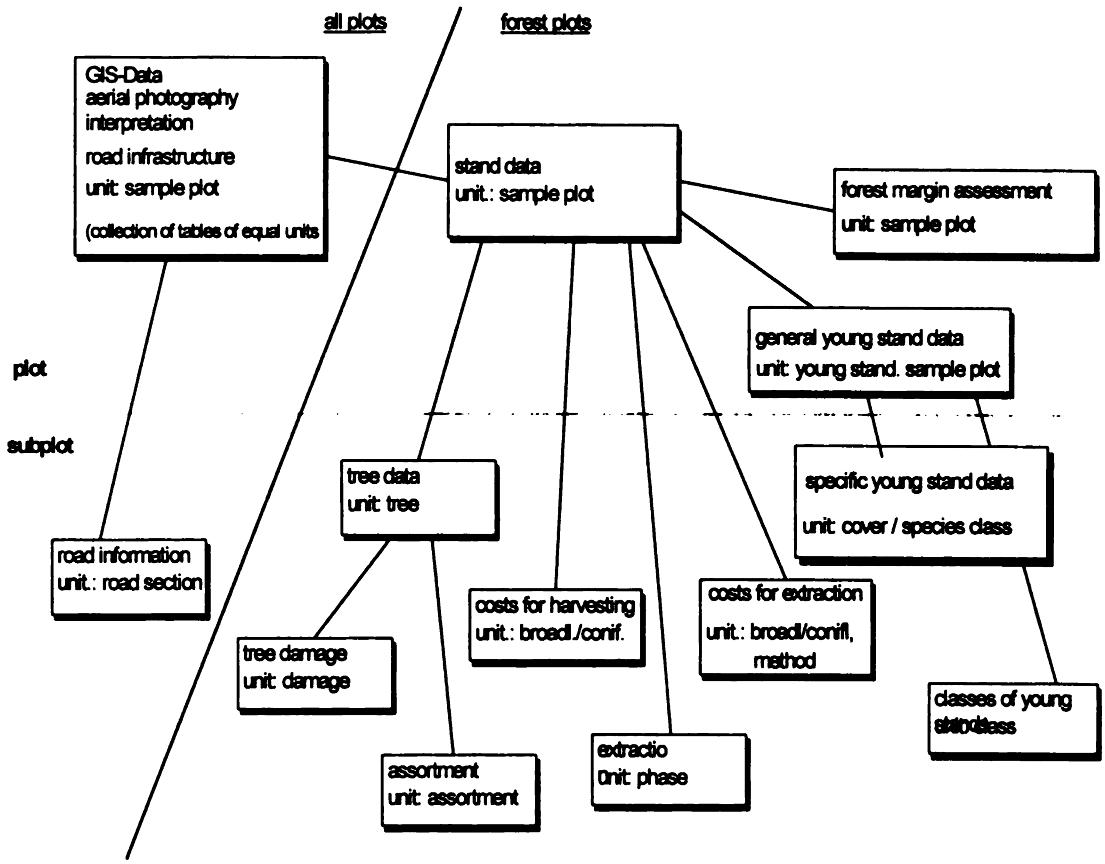


Figure 2: *Database hierarchy of the Swiss NFI*

The advantages are:

- the number of subunit classes (e.g. the no. of tree species) is flexible,
- the information level is high, all options of data analysis are available.

However the data analysis requires extended knowledge of the data structure.

Although the data storage on the plot-level would lead to a clear and user friendly data base structure there are some crucial disadvantages existing:

- the restrictions in data analysis due to aggregation (loss of information because the subunit data are represented by a single figure),

- for each subunit class a fix number of columns in the plot unit table has to be defined which lead to inflexibility in the management of the database.

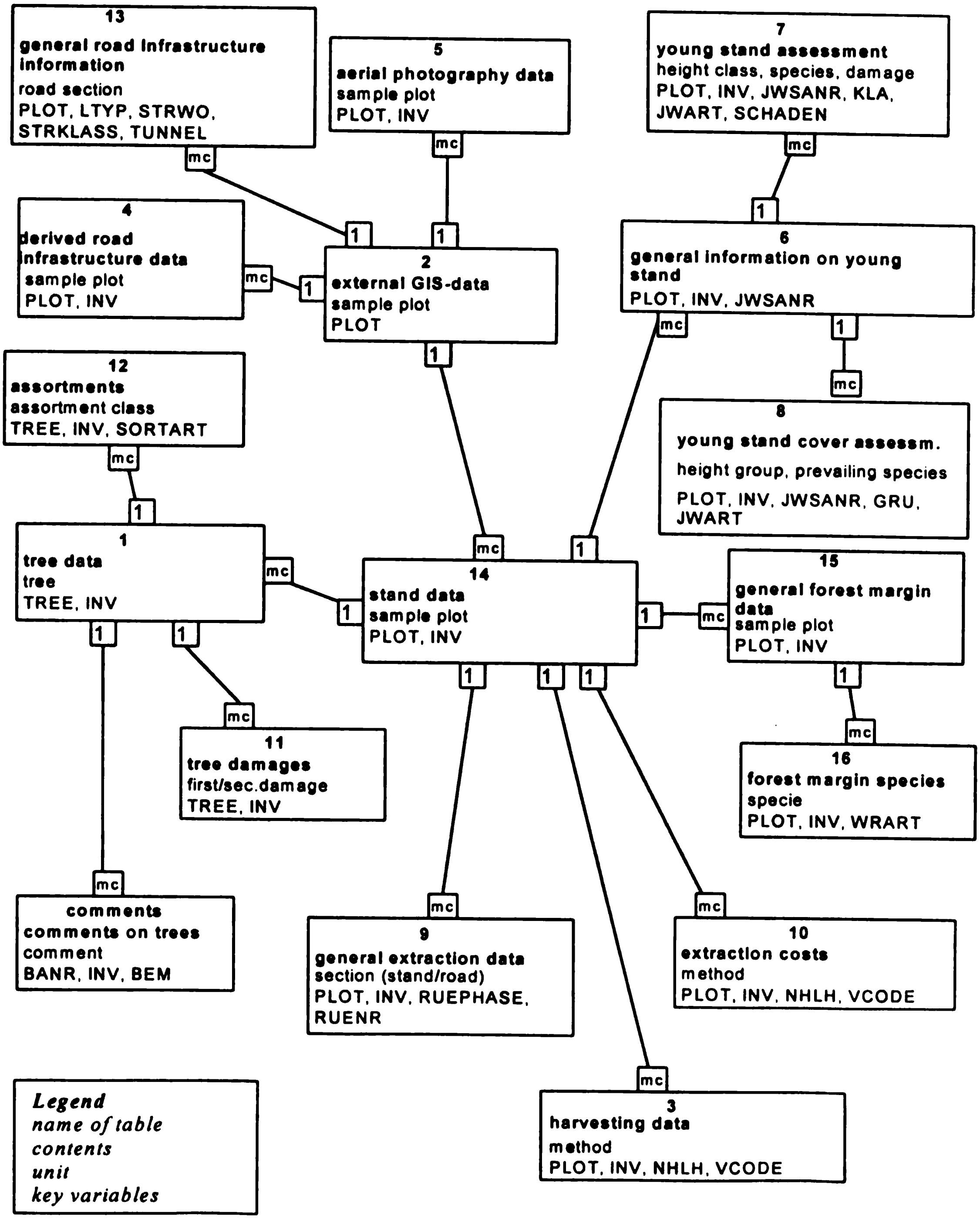


Figure 3: *Entity relationship (ER) diagram of the Swiss NFI database*

With focus on the flexibility of the data analysis the storage on subplot level was preferred. To distinguish between the single inventory occasions a inventory code is assigned to plot and tree data. To calculate CFI estimators a 'tree history code' was establish in addition to the inventory number. This code is assigned to each single tree and gives detailed information on the tree status for each occasion. Between different occasions trees can exceed a certain threshold diameter (ingrowth or ongrowth trees), furthermore trees can disappear for several reasons (mortality or cut) finally their state of vitality can change. The fate of every single tree between each inventory occasion is recorded and decoded (Kaufmann, in prep.). This type of history code in combination with a code for the inventory occasion is a very flexible technique which allows to monitor all attributes on plot and sub-plot level.

Beyond physical tables, frequently used data sets compiled from different tables were accessed by views. Views avoid data redundancy and the data sets retrieved by a view need not to be updated. This is important in case of permanent data input in the database. Although the use of views raises flexibility the query performance might be unsatisfying in particular if nested views are used.

Data Analysis

The data from the field and aerial photography sample of the first Swiss NFI were stored in a file system and analysed by software written in FORTRAN77. Although this software tool was designed to analyse inventory data from successive occasions, the development of an advanced FORTRAN77 based software tool was dismissed for efficiency reasons.

There was a strong need recognised to adapt a multi-user environment realised by an easy and intuitive to understand graphical user interface (GUI). This tool should allow:

- interactive menu driven data analysis, even for people without advanced skills in SAS-programming and database engineering
- quick and easy access to a broad range of forest inventory relevant *information* rather than to retrieve *data* directly from files or databases.

To reach this goal an ORACLE database was set up to enable standardised data access for several users. Additionally the software tool FIMAS, based on the SAS® system was developed to profit from a large set of standard data analysis and management procedures provided by this software system. This means that the inventory analysis bases on predefined data sets to be evaluated and standardised analysis algorithms to be used. The results are provided in aggregated (tabular) form according to the parameters the user has to define in the GUI. Beyond the user friendly access to inventory data, this approach assures consistent inventory results which is one of the most important properties of the FIMAS.

In particular with regard to transparency, consistency and the GUI application tools available in the SAS/AF Software, the decision to develop a SAS based analysis software turned out to be very efficient. ORACLE databases and SAS- based analysis tools are also utilised by NFI departments of other European countries. Data storage in ASCII files and FORTRAN77 programming language for data processing is applied less frequent.

In general the FIMAS is designed to provide information for a certain reference date a well as to calculate change figures. Thus the software tool generally can be characterised as a forest information and also as a forest monitoring system. Until now there was no intention to develop a geographical forest information system since the results from the Swiss NFI are inherently statistical data without a direct point-accurate spatial context. Growing stock figures e.g. show totals for a certain area and must not be interpreted without their sampling error. For forest planning purposes on the stand level e.g. NFI data are not satisfying due to a small number of terrestrial plots located in single stands.

Future developments will deal with statistical methods to combine NFI data with data on the forest enterprise level. Those methods would support a GIS based decision support system (DSS) which provides planning relevant information significantly. Such an information system would be a powerful tool for decision makers, since quantitative and spatial analyses can be combined. Information on the statistical precision of the data supports the interpretation of the analysis results.

TECHNICAL ASPECTS

The SAS System

The SAS system is a data analysis and programming system originally developed as a statistical software package. Meanwhile it converted to a high level data analysis tool. The release 6.12 comprises a wide variety of tools for data management, data exploration, statistical data analysis, tabular and graphical reporting tools. Beyond advanced and powerful statistical procedures, special software tools for operations research, quality control, econometrics, time series, GIS applications etc. are available. These software products contain standardised procedures for the calculation of statistics, producing tables, graphs, reports, etc. User defined parameterisation specifies the way the procedure works. These procedures guarantee consistent results on the one hand and allow a flexible parameterisation of the procedures on the other hand.

The SAS macro facility enables to manage complex data analysis comprising various data management steps and statistical procedures. It comprises a macro processor and the macro language and allows to pack a SAS language code into a named unit. The name references the text stored in the unit and allows to work with the name rather with the stored text. Thus a macro is a logical analysis unit to be invoked by a reference name and the parameters according to the macro definition. The macro language is an open code which provides all features of a 3GL programming language. The FIMAS architecture is completely based on the SAS macro facility.

The SAS/AF application programming interface (API) contains a set of tools to create interactive window applications. A special screen control language (SCL) enables the communication between the window menus and the SAS system. SCL controls the flow of the applications based on the window-input of the user.

The components of the SAS system can be combined and utilised for various tasks. In the following a brief description of the SAS tools utilised for the ORACLE7 database access of the FIMAS will be given.

SAS provides interfaces to several types of data base systems like ORACLE, SYBASE etc. In general there are different tools available to access databases interactively from SAS. In the FIMAS, the PROC-SQL pass through facility (SAS Institute 1994) was implemented. This tool allows to query data directly from ORACLE tables and to store the results in a SAS data set. For the data retrieval ORACLE specific structured query language (SQL) statements and commands (SQL*PLUS) have to be submitted (Koch and Loney 1995). Moreover it is possible to enhance the query statements with elements of the SAS programming and macro language i.e. the query can be controlled directly by SAS macro variables. Thus the 'pass through facility' enables complex data retrieval procedures which can be compared to the capabilities provided by the procedural language SQL (PL/SQL) (Urman 1996).

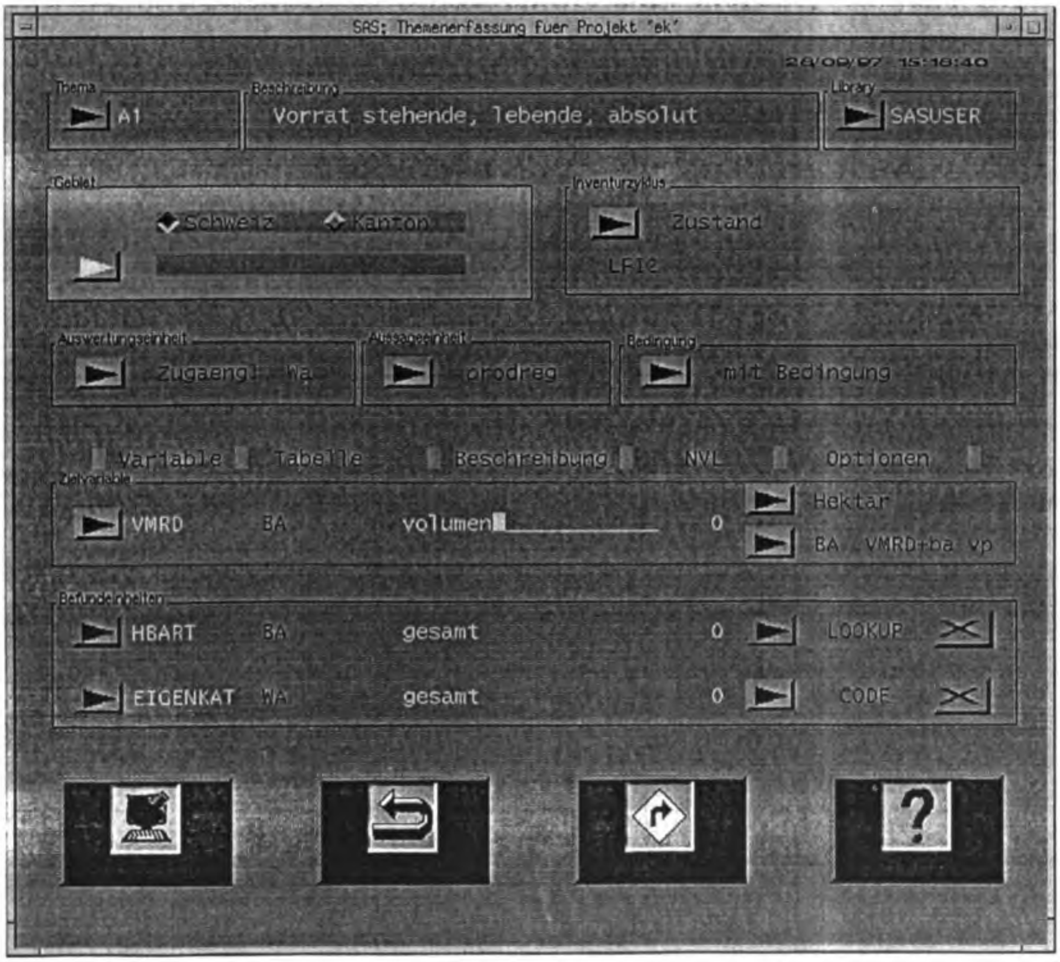
However there are some difference between the ORACLE and SAS specific SQL 'dialects'. There are two example of powerful SQL*PLUS functions which are not implemented in the SAS PROC-SQL:

- the NULL value function which assigns a specified value to NULL values during runtime.
- the DECODE function reassigns specific value to categorical data types or combine a group of specific values a new category. This function enables various operating of data indexing, decoding and data grouping.

The FIMAS components

The FIMAS comprises three independent components of data analysis:

- interactive definition of data analysis parameters,
- data query and calculation of estimators (online or batch),
- presentation of results.



<u>**Figure 4**</u>*: Main window for the definition of data analysis parameters*

The window for interactive parameter selection is given in Figure 4 and comprises the definition of

- the inventory unit e.g. total land area, forest area, accessible forest area,
- the inventory perimeter (unit of analysis) e.g. regions geographic prestratification,
- the type of analysis (state/change),
- the target variable e.g. tree volume,
- the attribute to which the target variable is related to e.g. forest area, percentage,
- stratification, the response variable or target variable is calculated separately for discrete classes of maximal two attributes (smallest units of estimator calculation) e.g. volume per ha grouped by different regions or ownership categories.

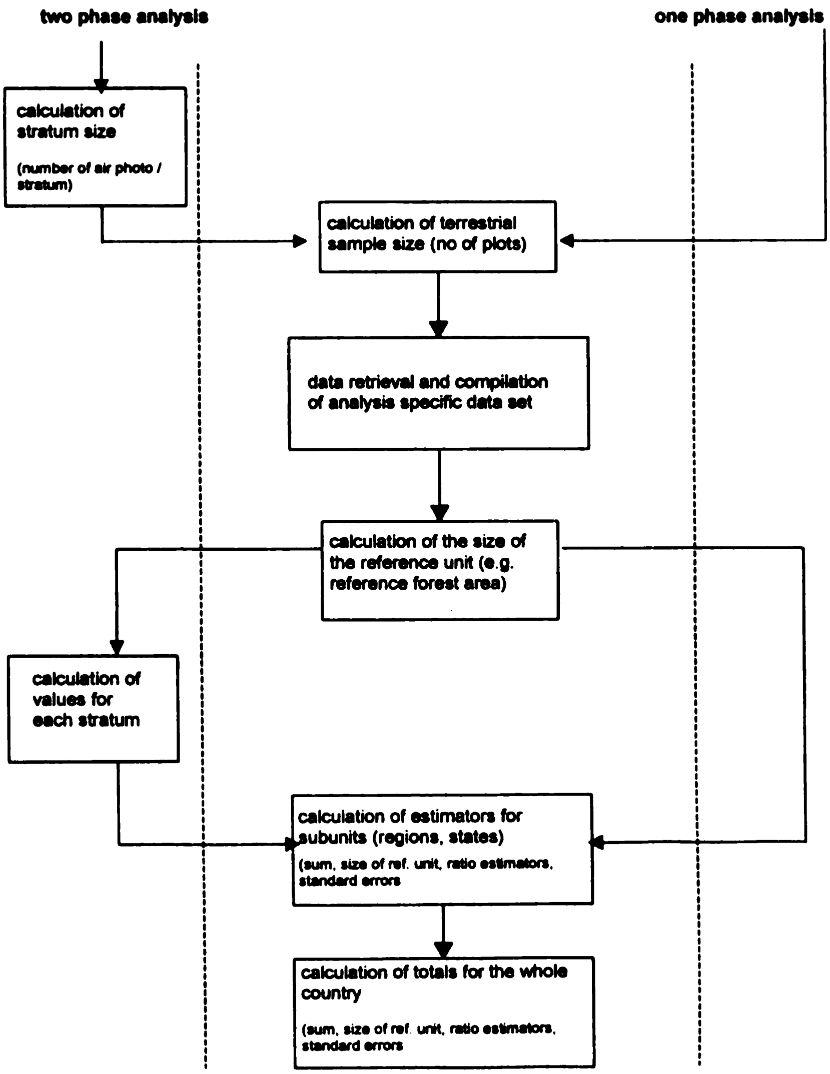


Figure 5: *One phase and two phase data processing flow*

The data processing flow is given in Figure 5. The differences between one and two phase data analysis are depicted schematically.

In Figure 6 the data analysis flow of the FIMAS is shown. The analysis unit comprises the user interface to define the analysis and to control the data processing. The access to the database is organised by the software tools described above, which ensure controlled, consistent and correct data retrieval. This means e.g. that in case of building a table of ratio estimators (e.g. volume/ha grouped by ownership categories and tree species) the reference units of the analysis (forest area assigned to the specified categories) are disjunct to assure additive tables. The results derived by the analysis unit are permanently stored in SAS tables. The report tools work as a third independent unit which presents these results upon user request.

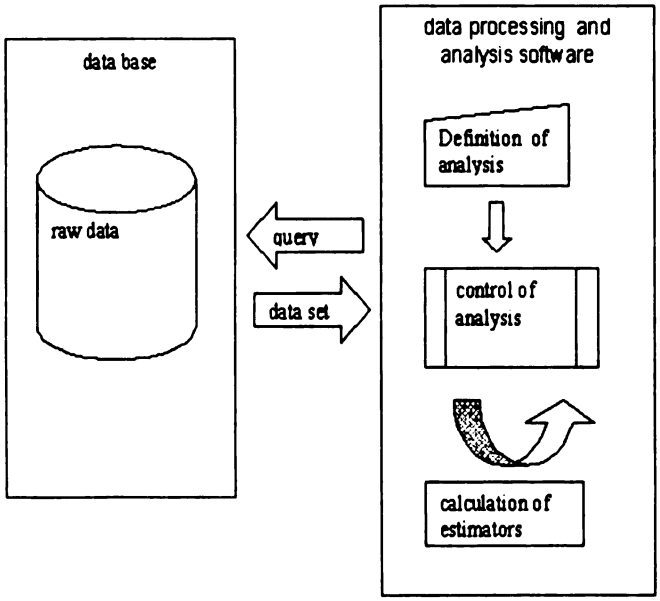


Figure 6: *Data analysis flow*

FUTURE DEVELOPMENTS AND OUTLOOK

OLAP techniques

The architecture of the ORACLE7 relational database management system (RDBMS)and also most other RDBMS are optimised for online transaction processing (OLTP) i.e. to create, update or retrieve one or few individual records out of a mass of records. Data redundancy is minimised by normalisation of data tables.

The data analyst however is mainly interested in a higher level aggregated view of the data such as totals for certain dimensions (strata) which is typical for inventory data to be analysed. This could be e.g. a table of growing stock figures grouped by the dimensions region and tree species which is available from the FIMAS. Tables created for data analysis typically contain redundant data which simplify the data access.

The concept of online analytical processing (OLAP) describes a class of technologies that are designed and optimised for data analysis (pilot software 1999). Since information to be retrieved for data analysis from a relational database usually is multidimensional a query could involve scanning most or all records in a database. Those queries could be handled much more effective and faster by OLAP. OLAP servers deal with summarised data whereas OLTP applications deal with atomised data. OLAP furthermore typically processes time-series. This is very important for the analysis of inventory data from successive occasions, growth trend calculation etc. OLAP applications tend to be subject oriented and allow a more intuitive access to information as it is the case with a relational data model. Main advantage is a high access-performance to information which is relevant for decision making, i.e. access to aggregated data. From these considerations the FIMAS shows several characteristics of an OLAP system. However the more dimensional, aggregated data are processed as a result from data analysis serving as the source tables for the reporting unit (c.f. Figure 6). A gain in data analysis performance could be expected if aggregated data would be already available in the data analysis step. It is an experience from the recent data analysis operation that simultaneous access of several users in combination with queries retrieving a mass of data leads to a poor performance of the ORACLE7 server. One solution could be to store frequently requested totals and subtotals as additional variables in the raw data tables. Another approach to raise the data analysis performance is to organise the data access in the analysis unit by an OLAP system.

Spatial Data Base Engine (SDE)

The FIMAS could be compared to a data warehouse system (Mattison 1997) where several users have access to information originating from different data sources. The degree of data aggregation can be varied from extraction of tree-specific data to a single statistic representing the sum or mean of the whole inventory area. Currently GIS and inventory data are available referring to a certain sample point referenced by a Gauss Krüger grid system. The resolution of the data available is 500 x 500m. So the spatial context is restricted to the (dimensionless) grid points where the information is assigned to. Future developments are focusing on interfaces to GIS software like SAS/GIS or ARC-VIEW which allow direct access to spatial as well as statistical information. The Environmental Systems Research Institute (ESRI) developed the spatial database engine™ (SDE™), a middleware tool which enables to store spatial data in a RDBMS (ESRI 1998). The SDE seems to be a promising tool for adding a spatial dimension to the inventory and monitoring data.

Spatial analysis queries allow to retrieve information e.g. about the vicinity of a certain point to create buffer zones, to measure distances to any other objects or to calculate landscape metrics of a certain area. This results from a special data model which adds a spatial data type to the RDBMS.

The FIMAS might organise both the access to the RDBMS and to the SDE Server and could invoke an SDE application. In this context the abilities of the SAS/GIS software to build an interface to the SDE will be investigated.

Other future developments focus on the integration of modelling tools which enable interactive growth scenario modelling by the FIMAS. The models are based on data originating from forest growth and yield plots and also from the field plots of the terrestrial NFI sample. Modelling parameters are e.g. harvesting and thinning rules.

Forest And Environmental Information Systems (EIS)

Forest information systems can be seen as a special realisation of environmental systems. under the roof of environmental systems several categories can be distinguished:

- Monitoring and control systems, which are mainly part of a typical measurement - , steering - and control - cycle
- Conventional information systems, which are systems for storage, integration and retrieval of data from different sources
- Analysis systems, which support the analysis of environmental data with means of complex statistical and mathematical algorithms and procedures. To this group belong image processing, simulation and prognosis systems.
- Decision support systems, which support decisions by providing objective methods for analysing alternatives and methods for rational decisions
- Integrated environmental system are systems which cannot be assigned to one of the above mentioned categories but combine different aspects.

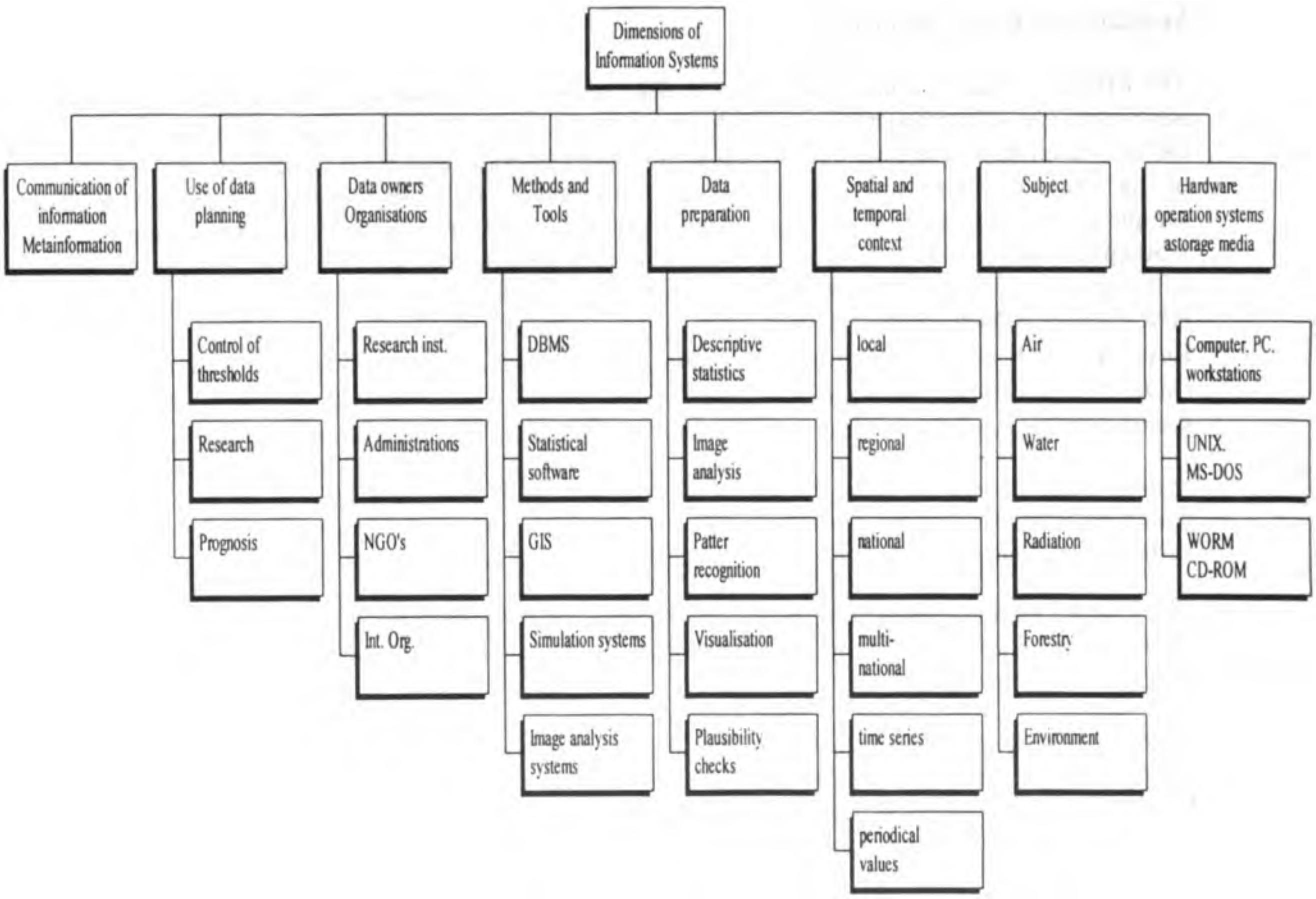


Figure 7: *Dimensions of EIS*

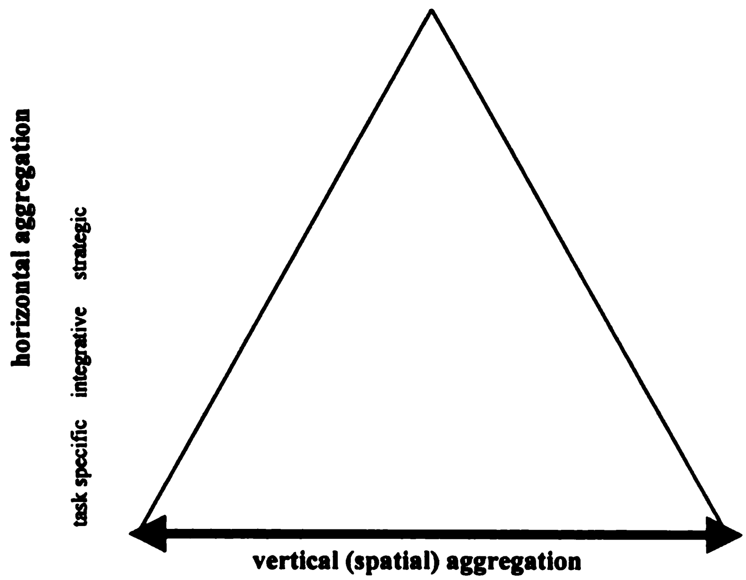


Figure 8: *Pyramid architecture of an EIS*

EIS have technical, spatial and temporal relations. The dimensions of EIS are summarised in Figure 7. Planning, implementation, maintenance and utilisation of EIS have to consider issues such as communication, data owners, use of data, methods and tools, data preparation, hardware and software. According to Günther (1998) the main objectives of EIS are:

- to support the administration in their environmental management and planning
- to implement an efficient environmental monitoring, including data capture, analysis and forecasting
- to support the management of environmental emergencies
- to make environmental information available to the executive branch as well as to the general public
- to protect past investments by co-ordinating existing system solutions by integrating them into a common system architecture

The design of EIS has to take into account the need for a horizontal and vertical aggregation, which is reflected in the Pyramid architecture of EIS (Figure 8). Depending on the hierarchic level of a potential user the information has to be aggregated to a specific content. For lower hierarchic levels the information has to be task-specific with a high thematic and spatial resolution. Mid level administrators have to be provided with integrative information with a moderate spatial resolution and top level administrators need information highly aggregated, i.e. strategic information with a very loose spatial context. EIS- specific basic components for data retrieval have to take the different levels of vertical and horizontal aggregation into account and provide tools for user specific information retrieval and result presentation.

As a conclusion, the FIMAS implemented on the base of the Swiss NFI data can be seen as a nucleus for the development of an EIS in Switzerland.

Acknowledgement

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MIRA: AN INFORMATION SYSTEM FOR THE MONITORING OF TREE GROWTH ON FORESTRY AND AGROFORESTRY PLANTATIONS

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ABSTRACT

During the 1980's CATIE and the national forest management institutions of Central America (Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama) developed and adopted a standardized methodology for the establishment and continuous measurement of growth plots for multi-purpose trees species on forestry and agroforestry systems. Based on this methodology, over 15,000 research plots were established throughout the Region. To management all this information the MIRA information management systems was developed. MIRA stands for *Manejo de Información sobre Recursos Arbóreos* or "Tree Resources Information Management System in English". The MIRA system manages data in a structured format on climate, study sites, soils, forest species, seed sources, tree measurements, and the production of various forest products. The MIRA network of study plots and statistically designed experiments under a wide variety of climatic, edaphic and topographic conditions and management practices has made possible valuable silvicultural research and technology transfer. The MIRA system has provided the source data for numerous scientific publications, including growth and yield models for multi-purpose tree species.

More recently, by way of an agreement between CATIE and CIFOR (Center for International Forestry Research in Bogor, Indonesia), the MIRA system has been converted into a bilingual (English and Spanish) software package operating under *Windows95*. At the same time the network of users has expanded to include organizations outside of Central America and private companies. Currently the system has been distributed to organizations in various countries, including private companies. The MIRA system not only has proven to be a useful tool for data management and analysis within a given organization, but has become a vehicle to bring different groups together to exchange experiences and pool data. One unexpected outcome is that many private companies have been willing to pool their data at the plot summary level. This has allowed analyses to be carried-out invilving a variety of growing conditions, that would have been impossible will smaller data sets.

Potential uses of MIRA are: a system for the monitoring and evaluation of tree growth in research and reforestation programs, a standardize methodology for the collection of field data, information storage and integration, to promote information interchange, and to create networks between researches, projects, companies, countries or regions.

If you are interested in learning more about the MIRA system contact the author.

SOFTWARE FOR PROCESSING PERMANENT PLOTS

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ABSTRACT

In the past 4 years, the Bolivia Sustainable Forest Management Project (Bolfor) has been working with Permanent Plots. During this period, the need has arisen for tools to help process the information generated in these plots. Also, the current forestry standards in Bolivia require mandatory installation of "permanent monitoring plots" for each concession or private property, with an average area of 1 ha per each 1,000 ha under management. This has increased the installation of permanent plots and, therefore, there is an increased need for prompt processing of data from these new plots.

Currently, Bolfor is in the final process to release the version 1.0 of a software named SISPPERM "System for Processing Permanent Plots". SISPPERM fulfills the above needs and it takes into account the different field stages, from installation to the different measurements and data analysis. The first two stages emphasize the validity and dependability of data by debugging procedures. Tools to display information are provided, organized in tables with different levels and formats. Also there is a graphic interface (currently in Surfer) to better visualize the information.

SISPPERM has the capability of calculating growth indexes and different levels of growth and yield analysis. The program has built-in data grouping and selection procedures that facilitates data manipulation.

SISPPERM was developed in FoxPro for the database, and we are testing freeware statistical routines written in C and C++.

As a practical application of the SISPPERM, examples are shown with data of permanent plots for three sites: a) Las Trancas'94, in indigenous lands, b) Amazonic, a private property, and c) Tarumá, a concession.

INTRODUCTION

In the past 4 years, the Bolivia Sustainable Forest Management Project, BOLFOR, has been working with Permanent Plots. The first projects were carried out by Gullison (1995) in the region of Chimanes and Claros and Licona (1995) established plots in Las Trancas, Lomerío. Since then, Bolfor has installed permanent plots in many other locations and has conducted analysis of information from these plots.

PERMANENT PLOTS DATA

Next, the different locations are described in which Bolfor has participated in the installation, measurement, and evaluation of permanent plots. These plots have been installed and measured by thesis and work-experience students financed by Bolfor, and by researchers of the Project.

Chimanes

The Chimanes Forest is located at 66°00' and 67°00' W and 14°30' and 16°00' S. The height of the study site is approximately to 230 masl and the mountain Eva Eva reaches a maximum height of 800 masl. The subtropical humid forest extends from the Southwest of the Department of the Beni, between the provinces Ballivián, Yacuma and Moxos. It is intersected by preandean foothills of Eva Eva, with an approximate area of 1.5 million ha, divided in protection areas, production forest, and indigenous territory.

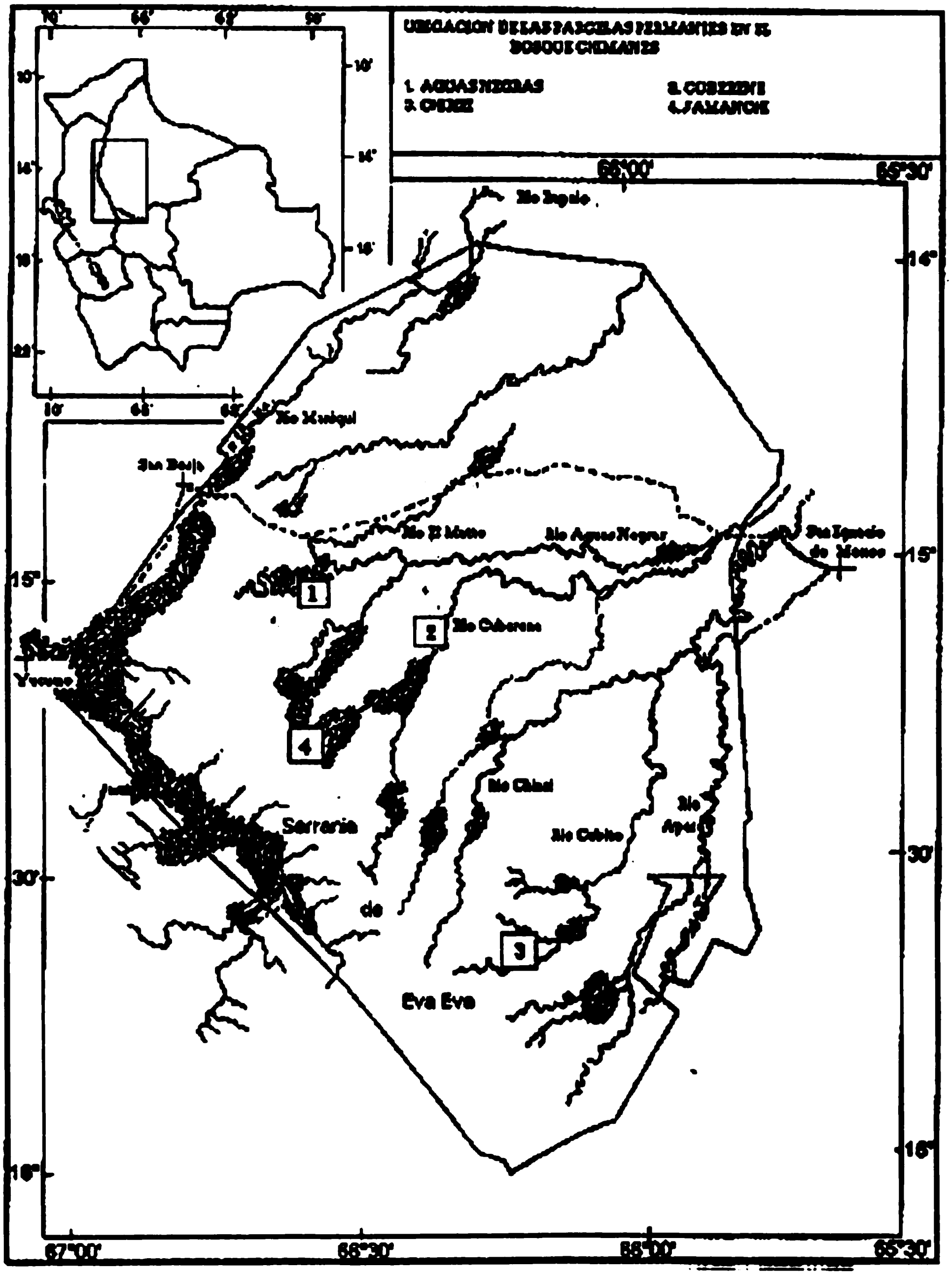

Figure 1. *Location of permanent plots in the production forest of Chimanes.*

In 1992, Gullison (1995) installed permanent plots in Chimanes in 5 locations: a) 10 plots of 20 x 500 m in Fátima, Monte Verde, Jamanchi, and Cuberene, and b) 11 plots of 20 x 360 m in Aguas Negras. In these plots, two measurements were conducted in 1992 and 1994 with the objective of making continuous measurements of 18 species (Leaños and Saravia, 1998).

From 1995, Bolfor continues with the measurements of these plots, carrying out census of all the species and considering some ecological characteristics that influence in the growth of the trees. These measurements were carried out in 1995 and 1997. The Figures 1-4 show the location, distribution, and the forms of these plots and their subplots.

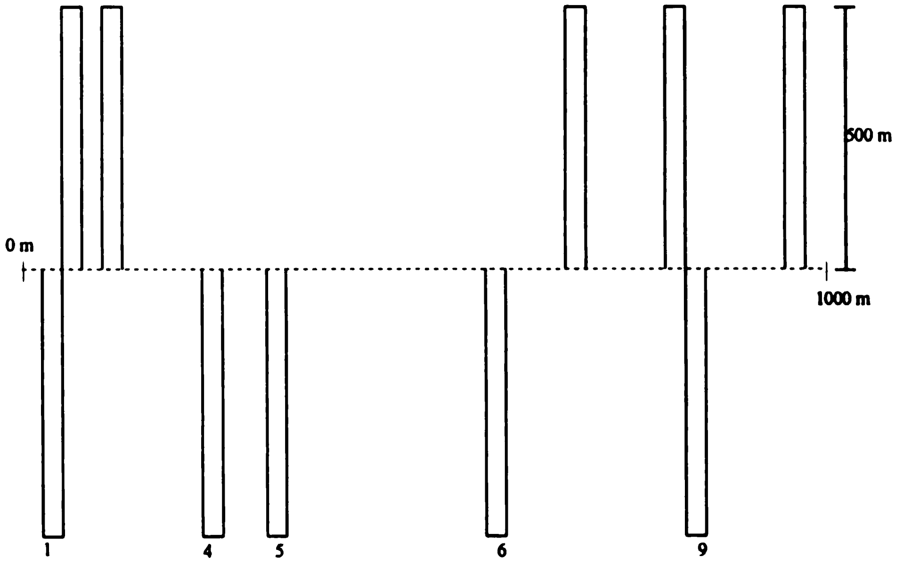

Figure 2: *Layout of permanent plots in: Chirizi, Cuberene, y Jamanchi.*

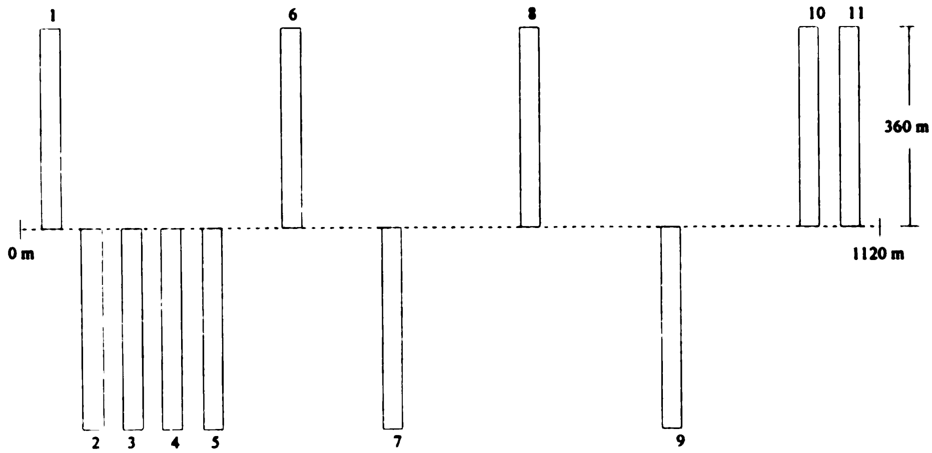

Figure 3: *Layout of permanent plots in Aguas Negras*

Analyzing the data, I found problems with consistency among the measurements carried out by Gullison and the one carried out by Bolfor in 1995. Therefore, I suggested a new measurement with the same methodology of 1995, so that the data are comparable and we can use the same analysis with both data sets.

Claros and Licona (1995) installed the permanent plots of Las Trancas '94 in September of 1994. The study area consists of 400 ha (2000 x 2000 m) in the subtropical dry forest of the area of Las Trancas, Lomerío, indigenous lands of the Chiquitano people.

The distribution of the plots was systematic in the whole study area. For the installation of the plots, 10 transects were established (2000 m each) with orientation South-to-East, separated by 200 m. These constituted access roads. Along these transects were paths 80 plots were uniformly distributed (8 plots for transect). However, the location of the plots was random. The plots are 20 x 50 m (1000 m2), and subdivided in ten subplots of 10 x 10 m (100 m2). See Figure 5. The second measurement was carried out in January of 1996, and the third in October of 1997, and the last one in February of 1999.

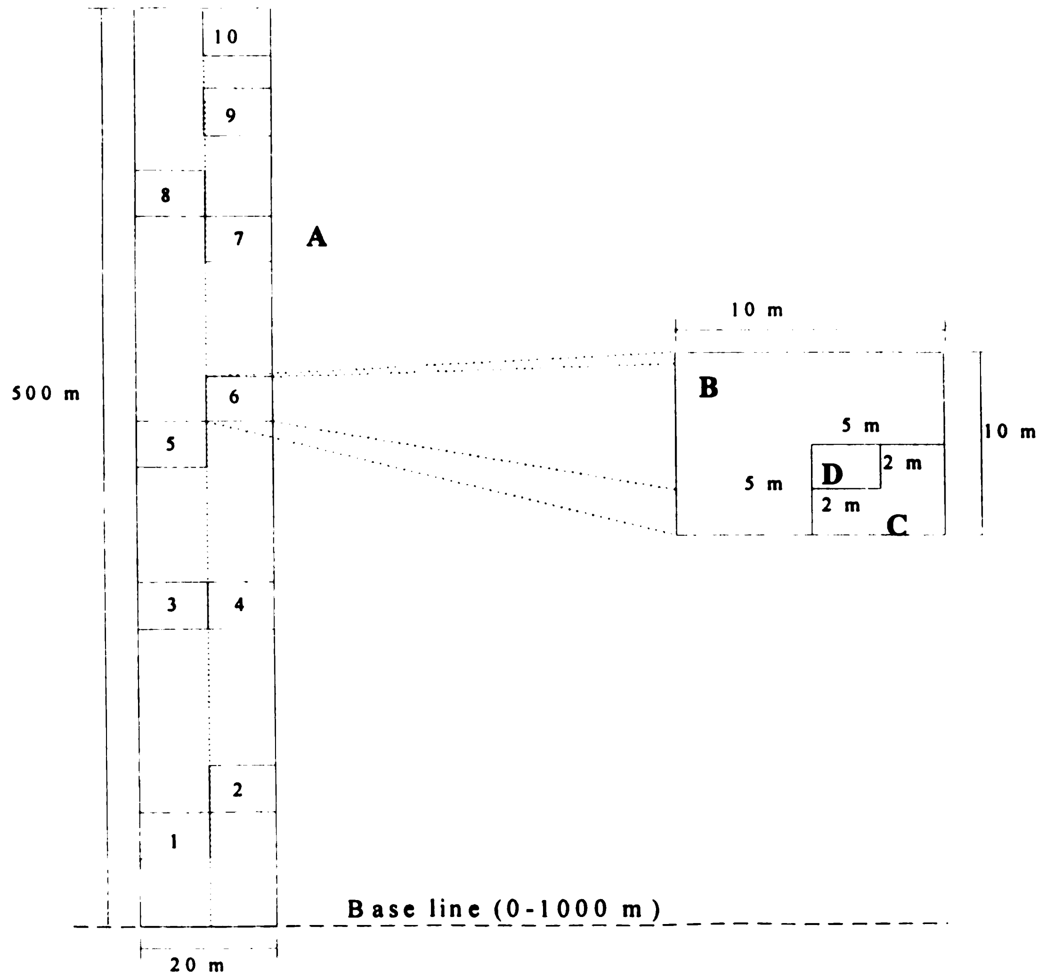

Figure 4: *Location and distribution of subplots in Chimanes*

Based on these data up to 1996, Valerio (1997) produced a report concerning growth and yield. Later, Valerio carried out a second analysis including the measurement of 1997, and an analysis of the available information of the two measurements at Chimanes.

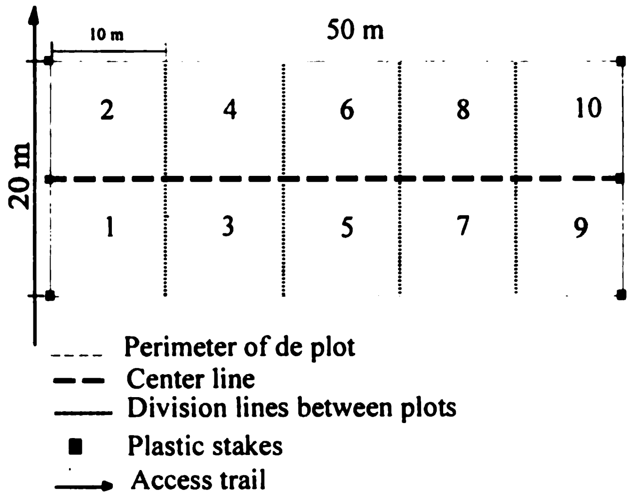

Figure 5: Schematic design of Las Trancas'94 plots

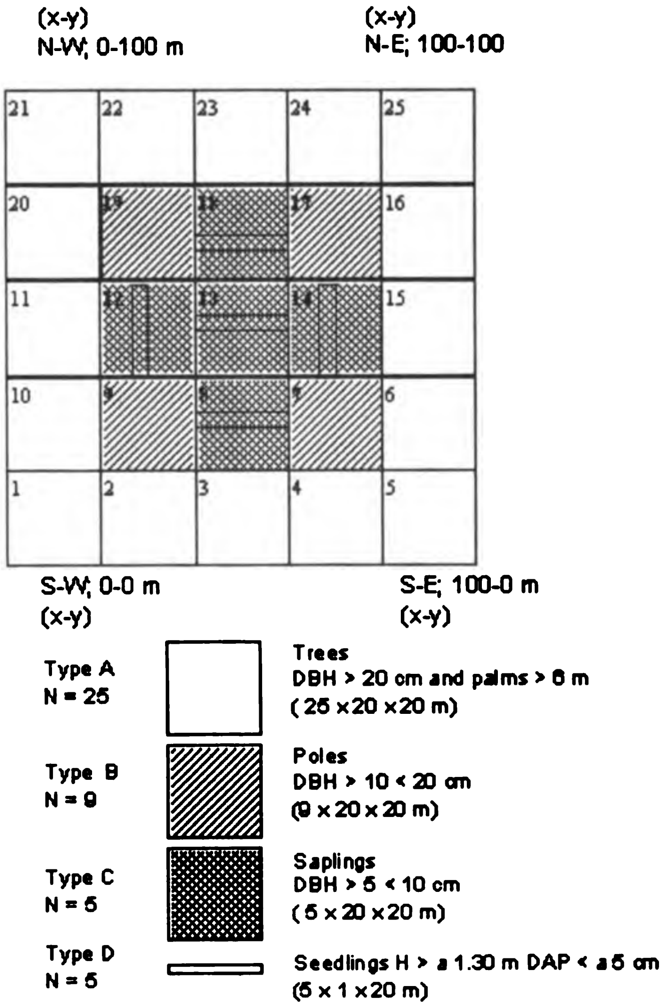

Figure 6: *Schematic design of Tarumá plots*

Tarumá

The Concession Tarumá is located in the Forest Reserve of the Bajo Paraguá, Velasco province of the Department of Santa Cruz. It is located approximately 600 km north of the city of Santa Cruz, with an altitude of 225 masl. The concession has a total area of 83,467 ha and is a subtropical Humid Forest.

The design of the subplots was adapted, so that for pole-sized trees there are 9 subplots. Also, the number of subplots for saplings was increased to 5 to permit estimates of variance. The Figure 6 shows the schematic design of the plots, and Figure 7 shows the location of the plots.

Amazonic

The forest property of 'Amazonic Sustainable Enterprises' is located in the province Ñuflo de Chávez of the Department of Santa Cruz 50 km east to Concepción. The total area is of 30,000 ha. The forest of the study area corresponds to the Semi-deciduous dry forest.

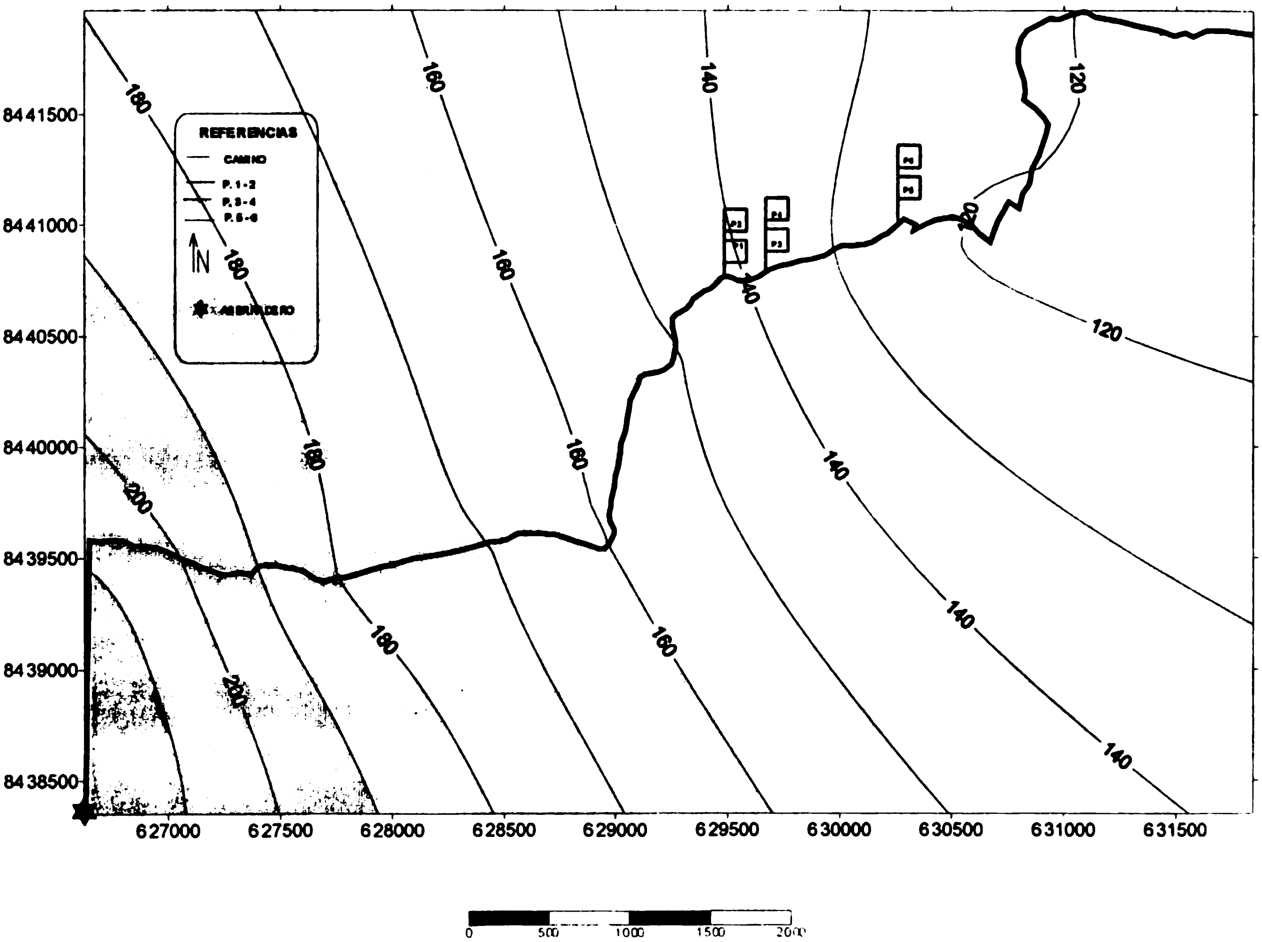

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Figure 7. *Locations of Tarumá plots*

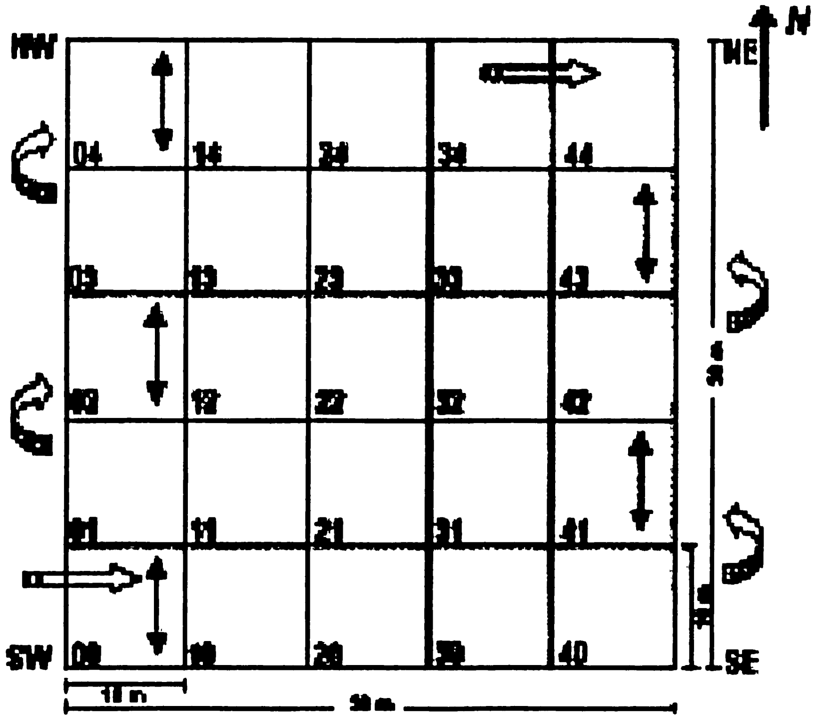


Figure 8: *Schematic design of Amazonic plots*

In July of 1998, 25 plots were installed in 5 census blocks, 5 per block, with each plot 50 x 50 m. Figure 8 shows the design of the plots. This form is included in the new Guide of Installation of Permanent Plots. Each side of the plot has a buffer area of 25 m.

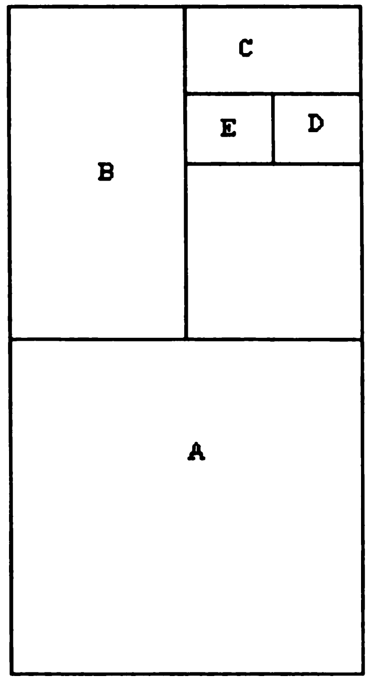
Other Locations

In another location of Lomerío (Las Trancas'95), Tim Killeen installed other plot totalling 10 ha. The design of these plots is shown in Figure 9. There have been 2 measurements of these plots, the most recent in 1998.

Also, in the region of Postrervalle in the province of Vallegrande, there are 6 ha of rectangular plots 120 x 80 m. A student of Bolfor is carrying out the analysis of the measurements.

In the El Choré forest were installed 100 x 100 m plots totalling 3 ha. A student of Bolfor also is carrying out the analysis of the two measurements.

In several other locations 1 ha square plots were also installed similar to those in Tarumá: a) Tiguipa ('Madel ABC'), in the chaco forest between the departments of Tarija and Chuquisaca are installed 6 100 x 100 m plots, b) in Tariquía, Tarija, a forest of the Tucumana-Bolivian formation are installed 6 plots, c) in the Botanical Garden of the city of Santa Cruz (tropical dry forest), are 3 square plots of 100 x 100 m.



Plot A: 30 x 50 m for DBH greater or equal than 20 cm
Plot B: 20 x 25 m for DBH greater or equal than 10 cm
Plot C: 10 x 10 m for DBH greater or equal than 5 cm
Plot D: 5 x 10 m for DBH less than 50 cm and height 1.5 m
Plot E: 5 x 5 m height greater or equal than 30 cm.

Figure 9: *Schematic design of Las Trancas'95 plots.*

FORESTRY STANDARDS

The Forest Law 1700, passed on July 12, 1996 establishes the beginning of a new regulation of our forests "[...] for the benefit of future and current generations, harmonizing the social, economic, and ecological interest of the country."

The Technical regulations 248/98 of October 26 1998 specify textually that "The responses of the forest to the interventions (harvest or silviculture treatments) will be evaluated by the company or organization by means of the installation, monitoring and analysis of permanent plots and regeneration sampling in the harvested sites". They establish relationship given in :

SISPERM

Based on our experience gained with the 'Sistema para el procesamiento de Inventarios Forestales' (Bolfor, 1997), Bolfor is developing two more systems for forest information processing: one for census processing and the other for processing permanent plots with SISPERM software.

System Description

The design of the system consider several components: a) definition of projects, plots, and subplots, b) processing of the field data corresponding to the different measurements, and c) analysis of data. At the moment, the system is in revision and some of its components are only in its first phase, including the graphical interface and the analysis of data.

Table 1: *Relationship between harvested area of the concession) and total area of permanent plots.*

Harvested area of the concession of property (ha)	Total area of permanent plots (ha)
200	1
1,000	2
5,000	4
10,000	6
20,000	10
30,000	15
50,000	17
100,000	20
150,000	25
200,000	30
300,000	40
500,000	50

Based on this, the guide for the installation of permanent plot sampling is more specific and indicates installation rules, measurement, and information processing for the plots.

Definitions of Projects, and Plots

The system needs to identify the data of the project, to create a project in the system, then to define the plots of that project. Also, the default project needs to be indicated. The system has procedures to validate data corresponding to this level.

Data Entry

One of the main problems found in the data of the permanent plots was the lack of consistency between the field data and the electronic data. Also, we found that the field forms were not very complete.

For the data entry, currently we have 2 field forms included in the Guide of PPMs (1999):

- FORM 1: PERMANENT MEASSUREMENT PLOTS, LOCATION, AND GENERAL INFORMATION
- FORM 2: TREE MEASUREMENT

The data entry programs provide help to correctly transcribe the data, and cross-validations among the interrelated data. Also, there is an option to indicate the ranges of some fields. To validate the data, special processes present the data in summarized form so that the user can view the data. It is also possible to obtain a report of all the data entered to the system, so that the user can compare them with the field data. It should be indicated that the data at the tree level are entered only once. Their modification is also allowed where errors have been made. The data of each measurement are the last level of detail of the information of the PPMs.

Tables, Data Exportation

It is possible with the system to obtain basal area and volume, for species or another selection that the user needs. It is also possible to obtain the abundance and dominance, and Importance value for species. In the same way, it is possible to have only the present species in the project, the plot, etc., either for trees and poles or regeneration.

All selections or groupings that the user wants to be carried out can be made through the system by means of an option in the utilities menu. Reports of indices of growth, and time duration within each class are also possible to obtain with the system.

All the queries and raw data of the reports are possible to export to the other formats: Excel, text delimited by tabulators, and other formats.

Graphical Interface, Surfer

The system allows creation of files that can be used in Surfer. Two files are exported to surfer: one for the lines of the plots and another for the location of the trees. Since Bolfor also has topographical contour information of the census areas, of inventory, and other areas; these two data sources can be combined to obtain a graph of the plots and of the trees. Currently, we are testing other routines that allow us to produce plots without Surfer. However, at the moment it is satisfactory to integrate with Surfer.

Analysis of growth

As mentioned before, Bolfor already carried out analysis of growth, through specific consultancies. Currently we are testing routines written in C and C++ that are of free access for incorporation in the next version. However, the analyses are carried out exporting the information of the plots. For this, the system has options that allow it to export specific queries or the whole database to a standard format as an electronic sheet or text delimited with tabulators. These are then processed in some statistical package such as SYSTAT or JMP, or if it was necessary in MATHEMATICA or MATLAB.

EXAMPLES OF CASES

Currently, we have transferred to the system the data of the PPMs of: a) Las Trancas'94, first three measurements (at the moment the fourth measurement is in transcription), b) The two measurements of Las Trancas'95, c) the two measurements of Chimanes, d) the Tarumá concession in its first measurement, e) the first measurement of Amazonic.

NEW PERMANENT PLOTS

According to the new effective norms, it is expected this year that at least ten more site installations. Also remeasurements will be in Amazonic, Tarumá, and the Botanical Garden.

ACKNOWLEDGMENT

This work would not have been possible without the collaboration of the colleagues of Bolfor, mainly Gilma Crespo who is programming the system in its database part. Valuable contributions from Juan Carlos Licona and Claudio Leaños were also provided pertaining to the measurement of PPMs. Todd Fredericksen helped to review the english version of this paper.

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GEOSTATISTICAL ANALYSIS OF LONG-TERM EXPERIMENTAL PLOTS

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ABSTRACT

The analysis of long term experiments in forest research is often based on statistical methods that provide statistical key parameters but do not address the spatial relationships within a stand. The spatial distribution of trees, the micro-heterogeneity of sites and management regimes will affect the interaction and growth of trees. In this paper the application of geo-statistical analysis for the investigation of the spatial pattern is shown for a forest stand in the Bernese Alps in Switzerland. It can be shown that the growth rates of individual trees show a pronounced spatial pattern.

Keywords: Geostatistics, long-term experiments, spatial pattern, tree growth

INTRODUCTION

Long term experiments are a well proven tool in forest research. The desire to discuss the planning and analysis of long term research plots was one of the main issues that led to the foundation of IUFRO in 1892. Early research plots were due to the lack of statistical theory not planned according to the rules of experimental designs. The analysis of long term research plots focuses mainly on the calculation of statistical key parameters or distributions. The spatial relation between trees is quantified by e.g. concurrence indices. There are few approaches to describe and map the spatial pattern of tree growth. It is, however, widely accepted that within-stand differences in soil conditions, micro-topography, management regimes or genetic diversity will affect single tree growth. In this paper geostatistical methods will be applied to a selective cut stand and the potential of this method for describing the spatial structure of growth patterns will be discussed.

Geostatistical methods were developed in the fields of mineralogy and prospecting, where they were first applied in the 1960's. Since then, geostatistics have been applied in many natural resource areas. The following remarks include a brief description of geostatistical methods and the problems in applying them to the analysis of long term experiments in forestry.

METHODS

Geostatistical methods are a direct extension of methods developed for analyzing time series (Ripley 1981). The basic methods of geostatistics were developed by two mining experts. G. Matheron (1965), working in France, evolved the theoretical formulation of spatial statistics, generally known as the theory of regionalized variables. D.G. Krige (1951, 1966), working in South Africa, developed geostatistical methods empirically and applied them to the location of gold deposits. Since then, several comprehensive studies have been published (e.g., Clark 1979, David 1977, Journel and Huijbregts 1978, Akin and Siemes 1988, Webster and Oliver 1990).

In classical sample-based inventories, it is assumed that individual sample elements, briefly, samples, are randomly selected from the population. In deducing the results for the sampled population, the spatial location of the samples is ignored. Nevertheless, it is clear from the start that samples that are close to each other show, on average, more similarity than samples that are far apart.

A set of random variables, $Z(x_i)$, determined from each point x_i on a plot or area, can be regarded as a realization of a sample from a random function $Z(x)$. The random variables are correlated according to the distance between and orientation of any two given points. One observation, $z(x_i)$ at point x_i, can thus be regarded as the realization of a random variable, and a set of observations, $z(x_1)$, $z(x_2)$, $z(x_3)$ ...., as the realization of a random vector $Z(x)$. Through this approach, locally dependent (regionalized) variables characterized by randomness and spatial dependence can be addressed.

The evolution of a formula for this relationship can be illustrated with a simple example of two sites of known distance from each other. The random variables $Z(x_1)$ and $Z(x_2)$ have value z_1 at the first location, and value z_2 at the second location. The relationship between the two values can be described with the difference $(z_1 - z_2)$ and with the variance:

$$s^2 = (z_1 - \overline{z})^2 + (z_2 - \overline{z})^2 = \frac{1}{2}(z_1 - z_2)^2 \quad (1)$$

where

$$\overline{z} = \frac{z_1 + z_2}{2}$$

Equation (1) can be extended for all possible pairs of locations by denoting the two locations as x and x+h, where x represents the position of one point, and h, termed lag, is a vector giving distance and orientation of the other point.

From equation (1) it follows that

$$s^2 = \frac{1}{2}\{z(x) - z(x+h)\}^2 \quad (2)$$

If the observation extends over m points, all separated by the vector h, it follows from equation (2) that we can estimate the mean $s^2(h)$ by:

$$\bar{s}^2 = \frac{1}{2m}\sum_{i=1}^{m}\{z(x_i) - z(x_i + h)\}^2 \quad (3)$$

In sample surveys, the practical application of geostatistical methods presents a similar problem. The observation x must be measured, where x is a realization of X. Similarly, where a random function Z(x) is considered, only the one observation of the random variable z(x) is known. In order to draw statistical inferences from z(x), assumptions regarding the stochastic model must be made.

The first homogeneity assumption is that the expectation of the random function is independent of the location x and is constant:

$$E[Z(x)] = \mu \qquad (4)$$

The second isotropy assumption concerns, $\frac{1}{2}s^2(h)$, the expected squared difference between the values for the location separated by the lag h,

$$E\left[\{Z(x) - Z(x+h)\}^2\right] = 2\gamma(h) \qquad (5)$$

This indicates that the variance of differences depends only on h. The semi-variance $\gamma(h)$ is the expected value of the variance s^2 for the lag h.

In linear geostatistics, only the first two moments are considered, so it suffices to limit the definition of stationarity to these two moments. What is termed the stationarity of order 2 is given when

- the statistical expectation, $E\{Z(x)\}$ exists and depends on the support point, and
- the covariance for each pair of random variables $Z(x),\ Z(x+h)\}$ is present and dependent on the vector h.

Where the spatial properties of Z(x) is invariant under translations, the random function displays strict stationarity. This indicates that the k-component vectorial random functions are identical for the two random functions $Z(x_1), \ldots \{Z(x_k)$ and $Z(x_1+h) \ldots, Z(x_k+h)$; and are independent of the size of the vector h.

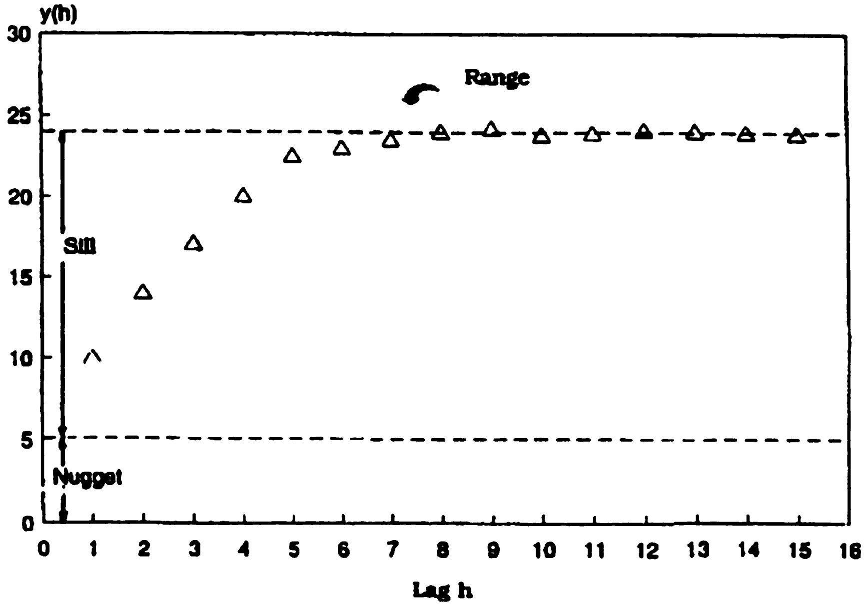
Thus, the presence of a covariance needed to formulate a hypothesis for stationarity of the second order demands a finite variance, $Var\{Z(x)\} = \gamma(0)$. According to Journel and Huijbregts (1978), the two assumptions on which equations (4) and (5) are based expresses the intrinsic hypothesis, although Matheron (1965) formulated it rather more broadly. The consequences resulting from failure to meet this hypothesis are discussed in detail by Akin and Siemes (1988, page 189 ff.).

Where the intrinsic hypothesis is valid, the measurements from several pairs of samples, n_h, with the distance of h can be used in equation (3) to estimate $\hat{\gamma}$. The semi-variance $\hat{\gamma}(h)$ can be computed for several lag vectors to produce a set of semi-variances $\hat{\gamma}(1)$, $\hat{\gamma}(2)$, $\hat{\gamma}(h)$, ... The basic equation for $\hat{\gamma}(h)$ is

$$\hat{\gamma}(h) = \frac{1}{2n_h}\sum_{i=1}^{n_h}\{z(i) - z(i+h)\}^2 \qquad (6)$$

This very general representation is only valid for one-dimensional problems, e.g., soil samples along a given line. For this discussion we must restrict ourselves to the above comments and refer those interested to the literature, as even one-dimensional problems illustrate the value of the variogram - the most valuable tool for describing a regional variable.

The semi-variogram is the plot of estimates $\hat{\gamma}(h)$ against lag h (sometimes termed a variogram). Figure 1 shows one possible version of such a variogram, aimed at illustrating general characteristics. The variance increases with increasing lag until it reaches a maximum, at which point the curve flattens out. This maximum point is termed the sill. The lag at which the sill is reached is termed the range and it denotes and shows the limits of the spatial dependence.



<u>Figure 1:</u> *Variogram*

Another aspect is reflected by the nugget-effect. Although the variance for lags tending toward zero also tends toward zero, there is often a considerable residual variance. This residual variance, or nugget variance, may stem from different causes, for instance, measurement errors. Frequently, the structures concerned are small in comparison with the lag and can only be resolved through additional, less widely spaced samples. This must be taken into account when interpreting variograms.

Naturally there are other variograms with different, more complex forms than shown in Figure 1. However, many of them, even those computed in this study, conform to that pattern.

Where variograms at one level are computed on the basis of the one-dimensional case, as discussed above, they can be constructed for various directions. Ideally, they are elaborated in four directions: the two directions parallel to the ordinate and abscissa and the two diagonals. If the variograms for the different directions match, it can be assumed that the variation is independent of direction. This circumstance is termed isotropy. Where variograms for the different directions exhibit the same sill but different ranges, the term geometric anisotropy is used. In a third case, termed zonal anisotropy, both the sill and the range differ.

A more advanced step in the application of geostatistical methods is to seek models to fit the sample values in a variogram. The elaboration of models for fitting and their parameters are essential for local estimation. Models are commonly fitted on the basis of least squares. There is a whole range of functions for fitting, for example, exponential, Gaussian, linear and spherical models. These functions are iteratively fitted to the points in the variogram, in a procedure analogous to that of "fit-by-eye." The ideal fitting of the functions is still the subject of debate. Webster and Oliver (1990, page 239 ff.) weigh the various approaches and arguments against each other.

Estimates for point or small unit areas (blocks) at one level are possible through the use of linear kriging, which can be regarded as an estimation procedure, in which a given number of samples, n, within a neighborhood are taken into account through the method of weighted means. The estimate for a block, B, is computed as follows:

$$\hat{z}(B) = \sum_{i=1}^{n} \lambda_i z(x_i) \tag{7}$$

Since $\Sigma\lambda_i = 1$ is valid, the estimate is unbiased. The variances of $\hat{z}(B)$, the krige variance, is given by

$$\hat{\sigma}^2(B) = \sum_{i=1}^{n} \lambda_i \bar{\gamma}(x_i, B) + \psi - \bar{\gamma}(B, B) \tag{8}$$

Here, $\bar{\gamma}(B,B)$ is the within-block variance, is the lag-range and $\bar{\gamma}(x_i,B)$ is the mean semi-variance between the block and the i^{th} sample point. The resulting estimates are unbiased and exhibit minimum variance. The semi-variances and λ_i included in Equation (7) are computed via the fitting functions of the variogram, which demonstrates the importance of the variograms for the krige procedure.

At this point, we must leave the discussion of geostatistical methods. Apart from the kriging approach described above, there is wide range of other procedures, e.g., punctual kriging, non-linear kriging, etc. These and other aspects, in particular the question of confidence levels, are discussed in the literature at considerable length.

APPLICATION OF GEOSTATISTICAL METHODS IN FORESTRY

Though the theory of regionalized variables has been widely applied in mineralogy, prospecting and soil science, it has so far been used comparatively little in forestry. Webster and Oliver (1985) employed geostatistical methods in soil mapping in the Wyre Forest, England. They showed that the greatest variation occurred between points 66 m apart. The variables correlated through this method corresponded with the occurrence of different soil types.

Payn and Clough (1988) presented an approach based on geostatistical methods for the mapping of plantations subjected to different fertilizer treatments. The spatial variability of heavy metals with a stand covering one hectare was described by computing variograms according to Wopereis et al. (1988).

Palmer (1988) employed a combination of ordination and geostatistical methods to describe the spatial pattern of plant associations. Using the results as a basis, he deduced various square plot sizes and distances between plots for phytosociological studies.

Ramirez-Maldonado (1988) discusses the theory and method of geostatistics in the context of forestry. Sample plots which are close to each other are often correlated, it is usually assumed that observations of the sample plots are independent in space. He then fitted the variogram of basal area measurement, constructed by means of point sampling, to a spherical model, and found that small gauge constants are to be recommended as being more efficient than large ones. He also used geostatistical methods for the analysis of the 10-point-cluster employed by the US Forest Service and for two-phase sampling. He presents a new theoretical approach to classic point-sampling in which point-sampling is regarded as a multinomial process.

Using growth in height of *Melia azederach* in Karnal, India, as an example, Samra et al. (1989) investigated the potentials of spatial interpolation by means of krige procedures for the mapping of forest inventory results. Within the study data, tree height varied both in relation to the lag h and the direction within a given stand (anisotropy). Over 70% of the heterogeneity of tree height in the northwest and southeast directions could be explained through age.

Working in a forest near Zurich, Mandallaz (1991) compared various estimation procedures based on geostatistical methods and reported on their suitability for stand and enterprise inventories. A new approach, termed double-kriging permits the use of auxilliary information such as aerial photographs or maps (Mandallaz, 1994).

Jost (1993) applied geostatistical methods for the estimation of standing volume. For her study she used 28 data sets from Germany and North-America ranging from 5 ha to 5000 ha in size. In 60% of the 28 data sets she found autocorrelative structures. The spherical and exponential model were sufficient to model semi-variograms. The lags ranged between 100 to 150 meter for stand data and 500 to 700 meter for larger forested areas. Anisotrophie was found only in rare cases. She applied geostatistical methods in order to calculate the sampling error in systematic sampling.

The potential of geostatistical methods for the analysis of forest decline surveys investigated Köhl and Gertner (1997). They analyzed a data set from the Swiss National Forest Health Monitoring Program and could show distinct spatial patterns of changes of forest condition.

AN EXAMPLE OF APPLICATION TO LONG-TERM GROWTH AND YIELD RESEARCH PLOTS

A permanent growth and yield research plot[2] of the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Birmensdorf, Switzerland, has been selected in order to evaluate the potential of geostatistical methods for the analysis of long-term experiments. The research plot is located in the Bernese Alps, Switzerland, and is stocked with a selective cut stand, i.e. an unevenaged mixture of spruce (*Picea abies* (L.) Karst.), fir (*Abies alba* Mill.) and beech (*Fagus sylvatica* L.). It is approximately 2.5 ha in size and is located in altitude of 1060m with a south exposition. The research plot is part of WSL's long term observation plots. It was first assessed in 1931 and remeasured in 1936, 1941, 1946, 1951, 1956, 1961, 1968, 1976, 1987 and 1995. For this study the data from 1976 and 1987 were made available. Since 1976 the coordinates of all trees standing on the research plot were recorded.

Table 1 presents the mean values and standard deviations as well as the number of observations for tree height and dbh measurement for the observations in 1976 and 1987. The differences between the two occasions were calculated based on paired observations of survivor trees. Do due the unevenaged structure and the fact that in selective cut stands mainly mature trees are harvested, mean heights and mean dbh do not change significantly during the observation period. Beech shows the lowest (0.2 cm a^{-1}), fir the highest (0.3 cm a^{-1}) dbh growth. As the rates for height growth are extremely low, only dbh-growth was considered for the geostatistical evaluation.

[2] Plot no. 02-047, Schallenberg - Rauchgrat, Röthenbach, Bern

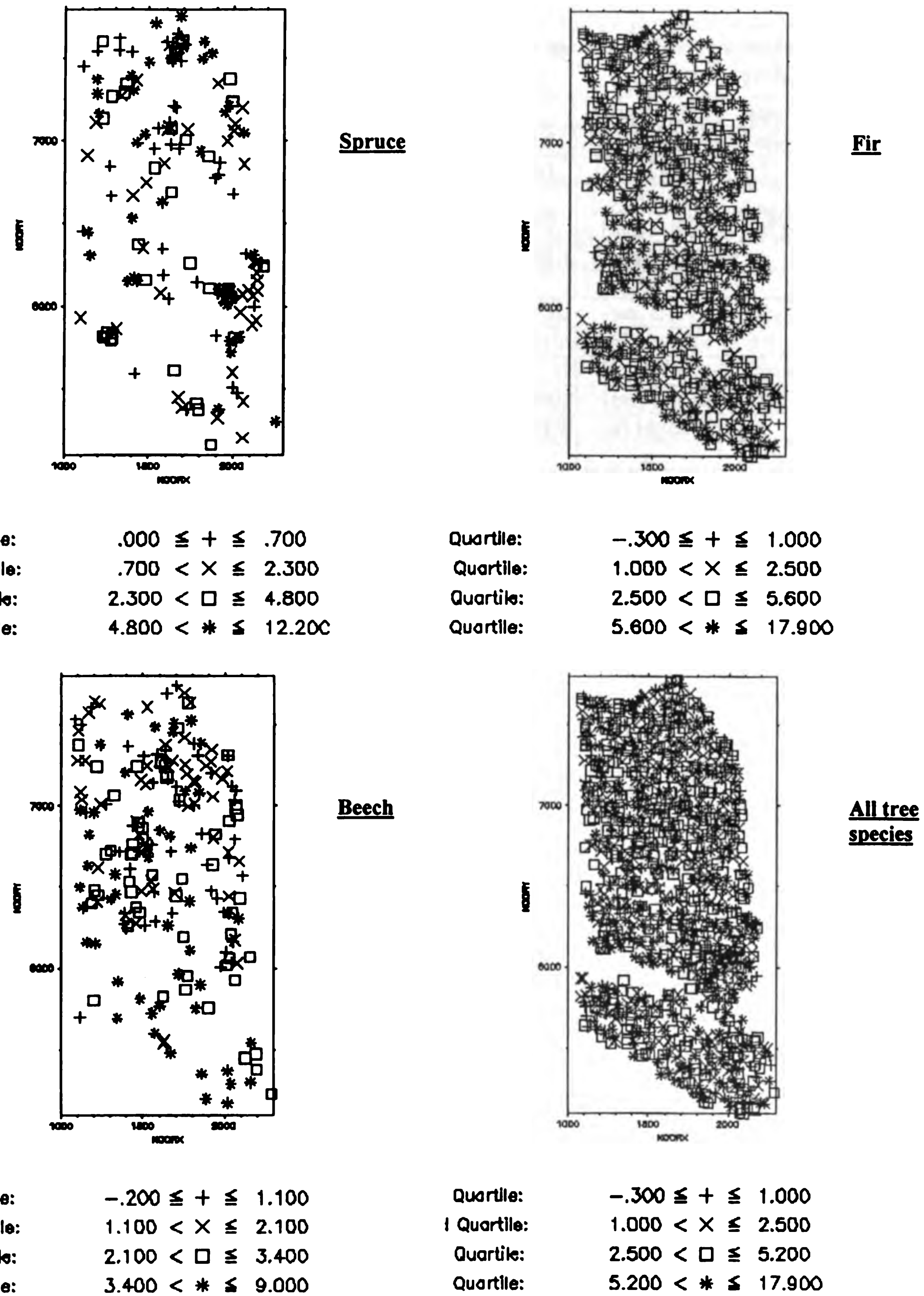
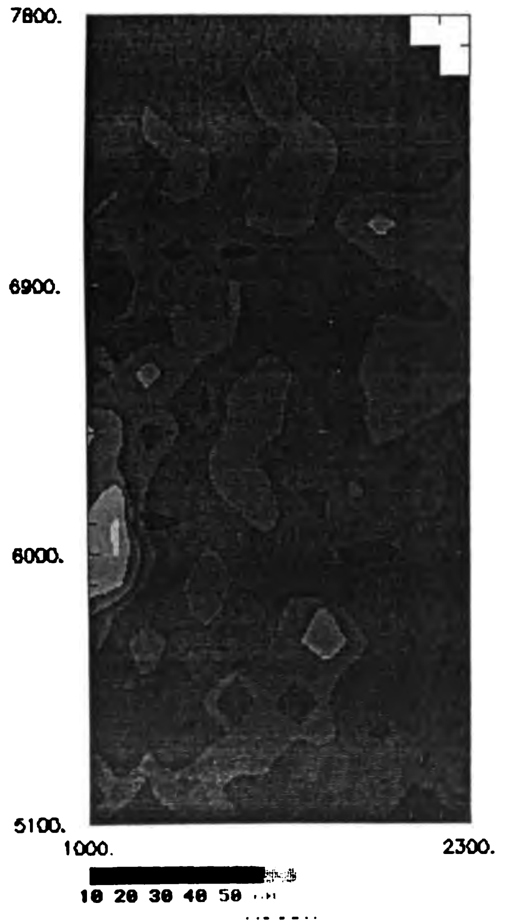


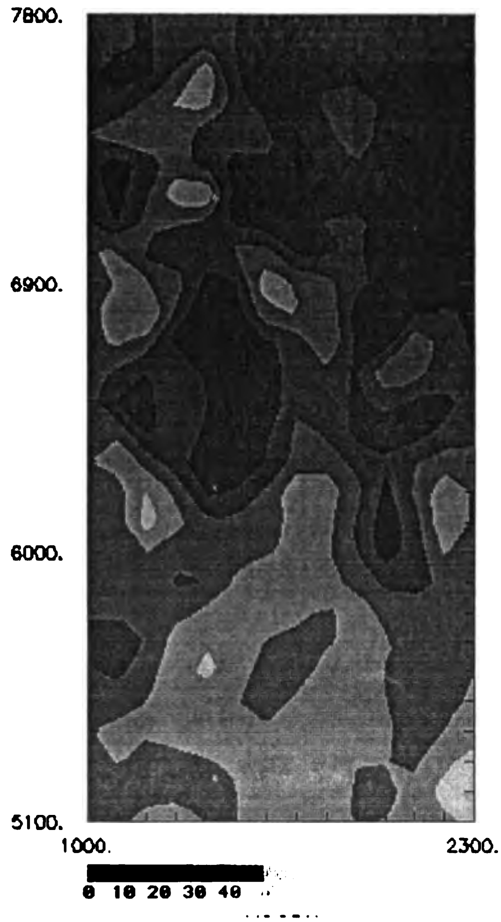
Figure 1: *Raw data (shown are tree locations and dbh-growth between 1976 and 1987)*

Table 1: *Mean values and standard deviations (in brackets) for growth and yield research plot Schallenberg-Rauchgrat*

Species	Attribute	1976	1987	Difference 1987-1976
Spruce	Dbh [cm]	20.0 (16.9)	22.2 (18.5)	3.1 (2.8)
	Height [m]	16.3 (10.6)	17.0 (11.0)	1.4 (1.8)
	n	168	172	160
Fir	Dbh [cm]	25.4 (19.9)	27.9 (20.6)	3.4 (3.1)
	Height [m]	19.8 (10.0)	19.8 (9.1)	0.3 (1.6)
	n	1011	961	945
Beech	Dbh [cm]	22.7 (18.2)	22.4 (18.2)	2.4 (1.7)
	Height [m]	18.3 (8.5)	18.3 (8.1)	1.5 (1.0)
	n	234	223	206
Total	Dbh [cm]	24.3 (19.4)	26.2 (20.1)	3.2 (2.9)
	Height [m]	19.1 (9.9)	19.2 (9.2)	0.6 (1.6)
	n	1413	1356	1311



Fir



Beech

Figure 2: *Dbh-distribution 1976*

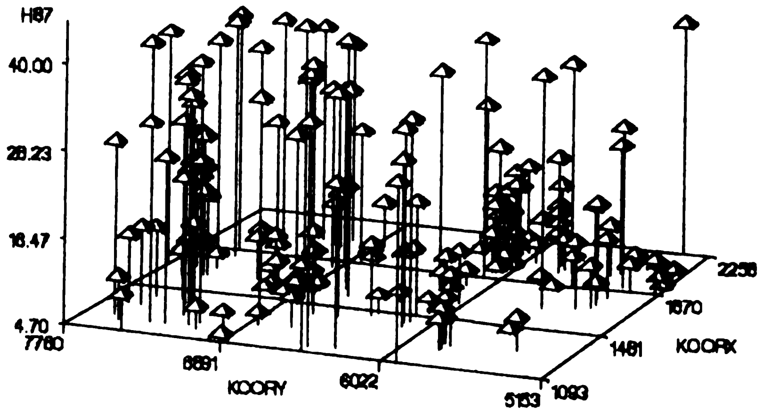
Figure 1 presents the locations of survivor trees that have been observed as well in the assessments in 1976 as in the assessment 1987. The symbols indicate the scale of dbh-growth. The plotted values do not indicate any spatial pattern of tree growth.

The raw data were analyzed by means of the Geostatistical Environmental Assessment Software (GEOEAS), which was developed by Englund and Sparks (1988). GEOEAS is a public domain software and runs under MS-DOS. GEOEAS was used to derive variograms, fit the models and to perform the Kriging procedures. The 1976 dbh - Kriging results for fir and beech are presented as contour maps in Fig. 2. Dark colors indicate low, bright colors high dbh-values. The contour maps represent clearly the typical heterogeneous spatial structure of selective cut stands.

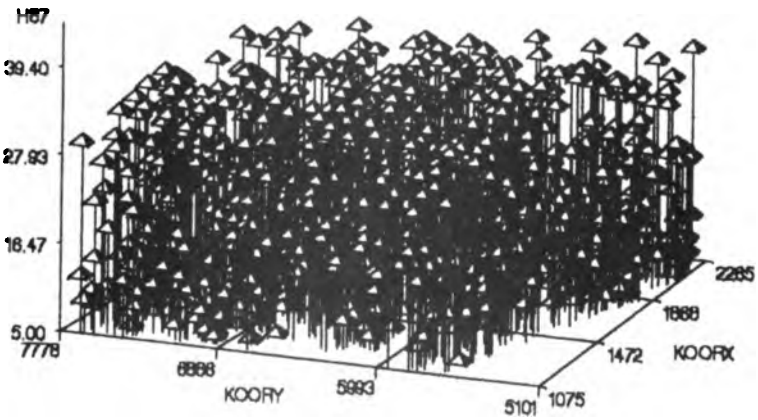
Total height and local position of all trees observed at both occasions are shown in Fig. 3. Spots can be identified for spruce and beech where trees show the same height. Selective cutting procedures with single tree utilization result in temporary gaps in the stands which are filled by natural regeneration. The clustered structure of trees with similar heights (and age) is an effect of the selective cut method and can be observed in natural forests as well.

For survivor trees, i.e. trees that were present on the plot in both years 1976 and 1987, the difference in dbh was calculated and used as input for the calculation of variograms. Variograms were calculated for each of the three tree species and the entity of all trees. The exponential variogram model was used for fitting the varograms. Fir shows compared to spruce and beech a relatively high nugget value, meaning that the clustered structure is not so obvious for fir than for the beech and spruce. Due to the large proportion of fir in the stand this nugget value affects the nugget value of the variogram calculated for all tree species. The lag was found to be slightly larger then 300 meters, which reflects the clustered structure of the trees in the stand. In the data set no anisotropic variance was found. The estimates were generated by ordinary Kriging and then converted to contour maps.

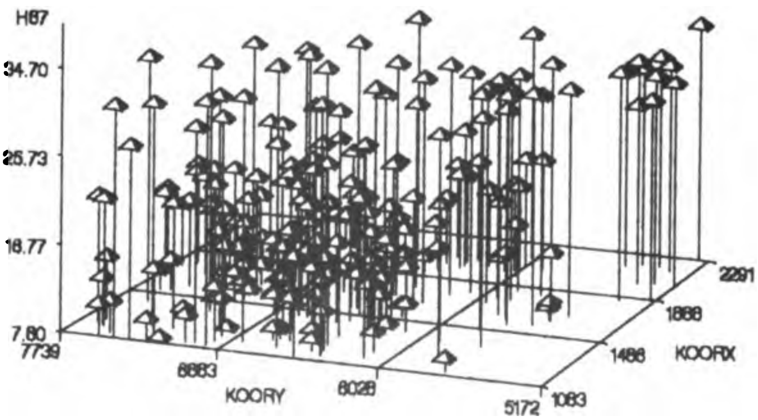
In Fig. 4 the contour maps for dbh growth between 1976 and 1987 are presented for spruce, fir, beech and all tree species together. The maps show the heterogeneous structure of the stands. In order to demonstrate the applicability of the contour maps the interpretation is restricted to the dashed rectangular shown in Figure 2 and 4. In Fig. 2 it can be seen that mainly firs belonging to the medium diameter classes are located in the rectangular. Spruce is abundant only in the upper part; beech is spread over the entire rectangular with individual trees having mainly small and medium diameters. Transferring the dbh-information to layers, fir and beech can be considered to belong mainly to the medium layer, which is in selective cut stands the proportion of the stand showing the largest growth dynamics. A concurrence situation between fir and beech is thus likely to occur in the considered rectangular. Close to the upper stand border spruce shows relatively high growth rates, which may be induced by the edge effect. On the left central part of the rectangular spruce dominates fir and beech, which results in high growth rates as well. In the remaining area of the rectangular spruce is dominated by beech and fir and shows only moderate or small growth rates. Fir dominates spruce and beech in most parts of the rectangular and thus shows the highest growth rates of the three species. Beech shows a high growth rate only in a very small part of the rectangular. This growth rate can mainly be contributed to two trees, which belong to the upper layer. The overall pattern is driven by the growth rates of fir. It can be seen that in the central part of the rectangular the growth rates are highest.



Spruce



Fir



Beech

Figure 3: *Tree height and tree location in 1987*

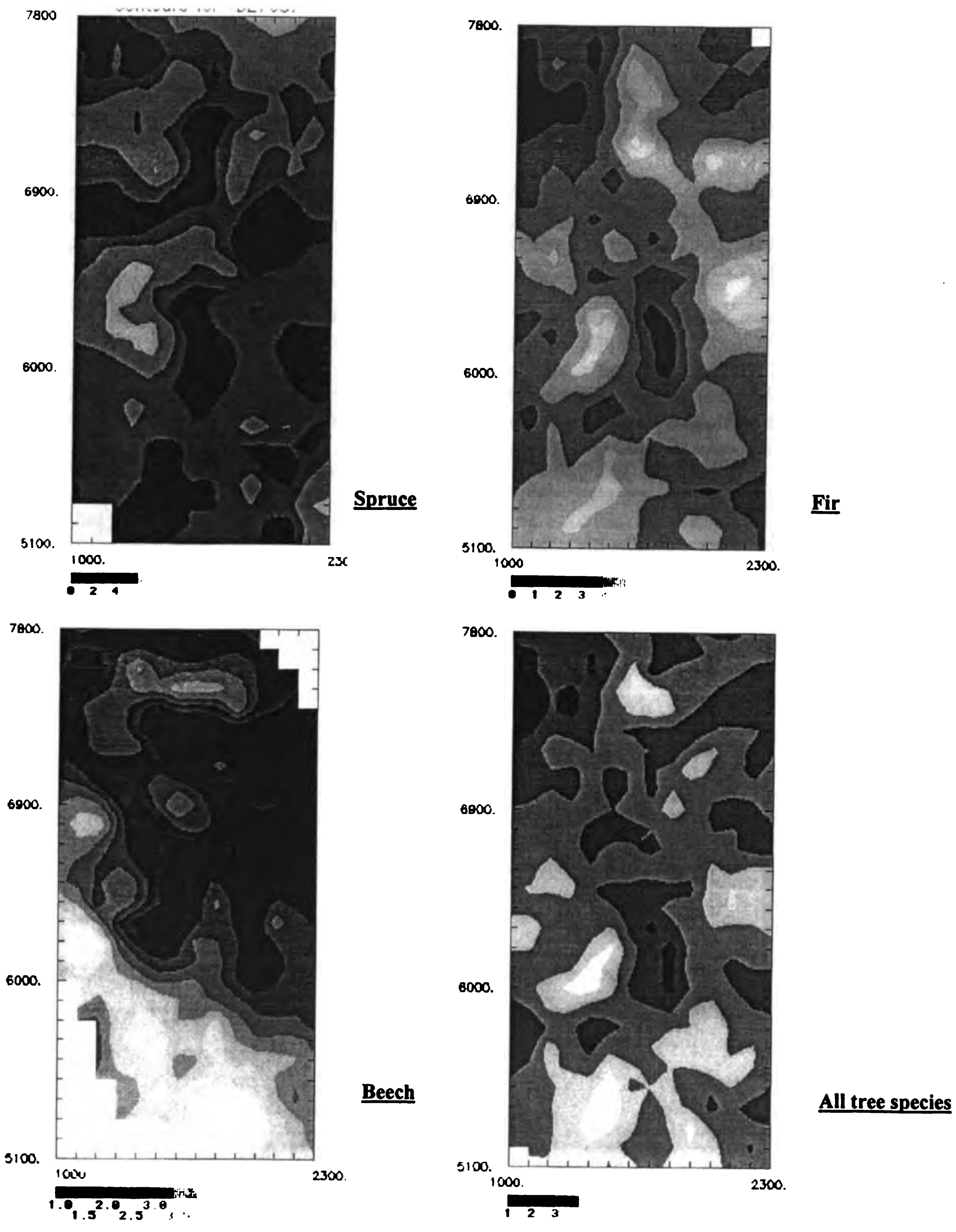


Figure 4: *Results of Kriging for dbh-growth between 1976 and 1987*

DISCUSSION

The maps show the heterogeneous structure of the stands. The spatial distributions presented here can only be properly interpreted if additional factors are taken into account. In every statistical estimation procedure, not only the estimated value but also the error of estimation must be considered. Especially in marginal areas and areas containing few trees, the sampling errors reach such levels that great caution should be exercised when interpreting the spatial distribution of growth patterns.

In the temperate region site productivity is expressed by the relation of age and height growth. As the growth patterns for single tree height were not very pronounced for the test data set, geostatistical analyses were only performed for dbh-growth. Further analyses will be extended to height growth and be based on tree height assessments over longer periods of time. These analyses may enable the extrapolation of the findings to site productivity.

They results obtained by Kriging do not allow to describe the concurrence situation in the stand. In selective cut and natural stands concurrence is not only a result of the horizontal distribution of trees, but of the vertical distribution as well. Therefore separate contour maps for individual tree layers are required to describe the concurrence situation of unevenaged stands with multiple layers.

This discussion is strictly based on the assumption that the computed variances and models are valid and consequently does not claim to be generally applicable. Rather, it aims at showing the basic possibilities and potentials of geostatistical methods in the interpretation of long-term experiments in forestry.

ACKNOWLEDGEMENT

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SESSION IV

"FOREST UTILIZATION AND GROWTH ASPECTS"

DETERMINATION OF THINNING INTENSITY OF *PINUS ELLIOTTII* ENGELM STANDS ON THE BASIS OF THE SPACING INDICES RELATIVE SPACING INDEX, STAND DENSITY INDEX AND WACHSRAUMZAHL

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ABSTRACT

Volume growth and spacing indices of trees of *Pinus elliottii* of plantation forest between the age of 7,5 and 24,5 years with different thinning intensities were studied on the basis of permanent observation plots. Losses of volume increment of thinning variants were calculated in comparison to the unthinned control. Spacing indices as Relative Spacing Index, Reinecke's Stand Density Index and Wachsraumzahl were calculated for different thinning intensities during the observation period. Values of spacing indices were adjusted on the basis of regression analysis. Analysis of covariance only showed equal inclination coefficients for stand density index. Simulation of spacing indices was carried out using different thinning intensities in dependence of expected losses in volume production.

Key words: *Pinus elliottii*, volume growth, spacing indices, simulation

INTRODUCTION

In the decades of 1960 and 70, Brazil experienced a great impulse in the area of reforestation due to the lack of forest raw material in various states of the federation. This activity was heavily influenced by governmental incentives/subsidies which were responsible for the formation of forests designated for the production of pulpwood and boards.

During decades the main objective of production of small timber with short rotations has been altered to the conduction of trees with larger dimensions in longer rotation periods as a means to aggregate more value in the forest and thus tending to increase its rentability. This tendency lead to the definition of new forms of stand management, including thinning and pruning with the objective to improve quality and dimensions of the stems produced. The silvicultural practices have also altered forest productivity which is directly related to age, stand productivity (site index) and stand density.

Within these factors, stand density has to be emphasized because it is directly related to diameter increment and, thus, to forest productivity. Thinning plays a major role within the regulation of stand density controling standing space a tree is requiring to establish regular crown and well developed root system, stable trees of bigger dimensions without, however, risking major losses in volume production.

In general, the intention of thinning is not to increase volume production but to concentrate it on fewer trees. Heavy thinnings can cause production losses but can lead to a higher production of more valuable assortments (Schneider *et al.*, 1991, Assmann, 1970, Reinstorf, 1970). However, the determination of thinning intensity has to balance expected losses in volume production and improvement of value production. The species of the present study, *Pinus elliottii* Engelm, although not native to Brazil, is the second planted tree species and is vastly spread over the country. It is a subtropical species with lightly colored wood which is used for the fabrication of furniture, boards and civil constructions. The reforestation in general is made with plant densities of between 1500 and 2500 trees per hectare. The wood outcoming of this plantations frequently is of low quality due to its small diameters, thus the cost/benefit ratio also is low. Various enterprises use 2-4 thinnings with clear cut after a rotation period of 20 (25) years.

Taking into account these facts, the following study has as main objectives to:

- determine losses in volume increment relating to thinning intensity;
- model density indices as Relative Spacing Index (S%), Reinecke's Stand Density Index (SDI) and the socalled Wachsraumzahl (WRZ, or modified Seebach-index) in relation to thinning intensity;
- simulate thinning regimes based on the indices studied in relation to expected losses in volume increment.

LITERATURE REVIEW

Factors influencing quantitative and qualitative production of forest stands are in their majority related to silvicultural treatments, site and to stand density. Managing forest stands has to consider all factors influencing increment in order to profit by site capacity as much as possible. In the same sense the potentiality of trees has to be considered relating to aspects as dimension and quality of the stems. If stand density is very low, it cannot be taken advantage of the entire site capacity in terms of light, nutrients and water supply. On the other hand, if density is very high, these elements, frequently, are not sufficiently available to guarantee optimal development of stand trees.

By thinnings, standing space for every tree is increased leading to an equilibrated development of the crown and root systems. However, heavy thinnings can lead to a disproportional increase of crown size and knots, thus reducing wood quality and volume production of the forest. But, thinnings applied with an adequate intensity and in the right time, allow an improvement of tree dimension and wood quality without significant losses of volume increment. So, thinning alows to direct productive potential of the site onto the most valuable trees and avoids their allocation on undesirable individuals or those with low value (Schultz, 1969).

Thinnings eleminate dead, injured or dominated trees. The remaining individuals are selected according to previously determined characteristics such as vitality, quality and distribution, focussing on the production goals of the stand (Abetz, 1975). A uniform distribution has not necessarily to be achieved, although wood quality is correlated significantly with regular distributed standing spaces.

In many cases thinnings, as partial cuts in stands beginning with crown closure, are controled by basal area. Although this quantity is largely applied in this sense, it is not able to describe the individual competition status of a tree, e.g. on sites with different production capacities.

Assmann (1970), analyzing the response of forest stands after thinning, noted that the remaining trees immediately increased increment due to a better utilization of environmental factors. He also observed that this effect, which has been called growth acceleration, depends on thinning severity and the period of thinning. The investigation of basal area in thinned and unthinned stands lead

Assmann (1970) to the definition of the following expressions: maximum basal area, which is established in unthinned stands or control plots, i.e. the number of trees of a specific dimension which can be nutrified and so maintained alive under specific site conditions; optimum basal area, which leads to the highest volume increment of the stand; and critical basal area, which allows to achieve 95% of the optimal volume increment.

Flotz *et al.* (1967) stated in their study with *Pinus* sp. that removing 35% or 40% of maximum basal area does not influence volume growth rate of a stand; however, removals of more than 40% of maximum basal area results in a clear decline of production. Glufke (1996) found a critical stocking index of 0,87 for *Pinus elliottii* and that thinnings removing 25%, 50% and 75% of maximum basal area lead to a reduction of about 9%, 20% and 54% of volume increment, respectively. Fishwick *apud* Bertoloti *et al.* (1983) stated that the increase in volume production of trees, in some cases, is not a result of applying drastical thinnings, as trees only have a limiting capacity to use standing space. Laar *apud* FAO (1981), investigating stands of *Eucalyptus grandis* in the region of Transvaal, South Africa, reported on losses in volume increment of about 15% in comparison to unthinned stands. However, increases in diameter increment twice as high as in an unthinned control have to be mentioned.

The effect of thinning on diameter increment is directly proportional to its intensity. With increasing thinning intensity, within certain limits, diameter increment of remaining trees also increases. All spacing indices used to quantify stand density also express the degree of competition between trees and their growth capacity. Thinning intensity, which means the beginning of thinning and thinning cycle (frequency of interventions) (Assmann, 1970), has to be defined according to technical and economical quantities, without losing sight of production goals in every phase of stand development (Schneider, 1993). In general it can be stated that the first and second thinnings determine the type, quantity and quality of wood to be obtained in the final cut (Alves, 1982).

Many methods to regulate stand density can be mentioned, among them the socalled English Method, where 70% of the medium annual increment is removed; the method of Abetz, which considers the h/d-ratio, executing thinning when h/d is superior to 1; the Mexican Method which also considers increment rate when determining thinning weight; Reinecke' s Stand Density Index (SDI) which takes into account the maximum number of trees when mean diameter of the stand is about 25 cm (10 inches); the Relative Spacing Index of Hart-Becking (S%) which determines tree number in function of the relation between standing space and dominant height; within other regulation procedures of growing space (Schneider, 1993).

Relative Spacing Index (or Hart-Becking method) is based on the concept that trees with a determined dimension need enough standing space to develop their crowns. Applying this method is quite simple: the number of trees to be removed in order to attain a pre-established S% for a given species. The use of dominant height in the determination of the index makes it independent from site quality, taking into consideration that dominant height, within certain limits, is independent from site and not affected from thinning from below.

In accordance with Assmann (1960) and Schober (1967) *apud* Kramer (1987), Relative Spacing Index has the disadvantage, even in unthinned stands, to variate (mostly decreasing) with increasing age. Fishwick (1975) used S% in thinning experiments of *Pinus elliottii* revealing that the production turns out a maximum if S% attains 21%, which is between the age of eight and nine years. When S% is declining to 16%, competition is very severe with increment losses of 25%. The author recommends the first thinning to be executed so that an S% of 21% will be achieved.

Reinecke's Stand Density Index (1933) is an expression of stand density in even-aged forests and valid only in fully-stocked stands. This index relates current density with maximum density of a stand with a mean diameter of 25cm (or 10 inches). Once the coefficients of the self-thinning line (mean diameter over tree number of a control plot) are established, the tree number of any treatment can be calculated in dependence of a pre-established SDI.

Inclination of SDI-curve in general is less with more tolerant tree species (Zeide 1987 *apud* Bredenkamp & Burkhart 1990). The so-called Seebach-index (Ausladungsverhältnis, *apud* Assmann, 1970) is an expression of a tree's standing space given by the relationship of crown width (b) and breast height diameter (d). The lower the value of b/d, the higher basal area or volume per hectare. Freist *apud* Sterba (1990) found a decline of the b/d-ratio with increasing crown surface; when analyzing this relationship within the sociological positions of Kraft an increase with increasing crown width can be noted. Thus, in order to obtain a small b/d-ratio it could be interesting to maximize dominant trees with small crowns. Spiecker (1994) applied a modification of Seebach's concept utilizing the ratio standing space and basal area (Wachsraumzahl, WRZ, or modified Seebach-index) as an index of quantifying competition.

MATERIAL AND METHODS

The data for the present study were collected at Fazenda Rio das Pedras in the central highlands region of the state of Santa Catarina, between 800 and 1200m above see level.

The soils of the region are predominantly leptosols (former lithosols) and cambisols (structured, more or less weathered humid acid brown soils). Climate is of type Cfb, after the classification of Koeppen. This means a mesothermical, sub-tropical humid climate without dry season (characterized by frosts of 15 and more days a year); mean annual precipitation around 1740 mm, falling on average during 108 days; mean annual temperature at 16.8°C (Mota *et al.*, 1971).

The natural vegetation in the experimental area belongs to the highlands of the Araucárias and is classified as Floresta Altimontana and Floresta Montana with *Araucaria angustifolia* in the upper storey and a high variety of broad-leaved tree species and shrubs in the lower storey.

Experimental design

The thinning experiment which delivered the data for the present study was installed by PRODEPEF (Programa de Desenvolvimento e Pesquisa Florestal) in a stand of *Pinus elliottii* at the age of 7,5 years between August and September of 1976. Initial spacing was 2,0 x 2,0m. The experimental design is a block design with 2 blocks randomly distributed with 4 plots of 800 m^2 and a border strip of 10 m, covering an area of about 1 ha. The treatments were controled with basal area (Table 1).

Table 1: *Thinnings applied in the experimental plots.*

TREATMENT	THINNING WEIGHT
t0	Control without thinning, complete density
t1	Light from below, removing the equivalent of 25% of basal area of t0
t2	Moderate from below, removing the equivalent of 50% of basal area of t0
t3	Heavy, removing the equivalent of 75% basal area of t0

In the present work, stand density was measured as is expressed in formula 1.

$$I = G / Gmax \quad (1)$$

Data collection

Tree heights and diameters were measured annually before and after thinning, which allows calculation of the respective basal areas. Eight dominant heights and 15 heights distributed around the medium tree were measured (Assmann, 1970), as well as heights of all thinned trees.

Preparation of data and calculation

For calculation purposes the statistical packages Excel and SAS were used. The estimation of heights not measured in the field was carried out with the h/d-ratio (model 2), which was developed for each thinning treatment and age by Glufke (1996).

$$d / \sqrt{(h-1,3)} = b_0 + b_1 d \quad (2)$$

Using the same procedure, volume was calculated with formula 3:

$$v = g.\ h.\ f \quad (3)$$

where: v = volume in m^3; g = basal area in m^2; h = height in m; f = artificial form factor

Artificial form factor was calculated using equation 4 (Schneider, 1984):

$$f = 0.2347 + 0.3719.(d_{0,5}/d)^2 + 0.2662.(d_{0,3}/d)^2 \quad (4)$$

and,

$$d_{0,3} = 10^{[-0.4619+0.3915.\log(d2.h)]} \quad (5)$$

$$d_{0,5} = 10^{[-0.1426-1.0068.\log(1/d)]} \quad (6)$$

where: f = form factor; $d_{0...}$ = diameter at 30% and 50% of total height of the tree, respectively; d = breast height diameter.

The total production per hectare for each treatment and age was calculated by summing up individual volumes. Thinned volume was obtained by the difference between the volume before and after thinning, and total volume (production) at every age was obtained by summing volume after thinning and the accumulated volumes of thinning at age t.

Annual current increment was calculated by the difference between volume before thinning of a given year and the volume after thinning the year before; periodic increment was calculated by the adjusted annual increments for periods of four years. The adjustment was made by regression analysis, using age and mean basal area over a period as independent variables (Glufke, 1996).

Relative Spacing Index (Hart/Becking, 1928) was calculated using equation 7:

$$S\% = \sqrt{[(10000 / N)]} / h * 100 \quad (7)$$

where: S% = Relative Spacing Index; N = number of trees; h = dominant height

Reinecke's Stand Density Index was obtained by equation 8.

$$SDI = N * (d_g / 25)^b \quad (8)$$

where: SDI = Stand Density Index; N = number of trees observed in the stand; d_g = diameter of the tree with mean basal area; b = angular coefficient

The modified Seebach-index (Wachsraumzahl, WRZ) used in the present study, is obtained by applying equation 9:

$$WRZ = ev / g \quad (9)$$

and,

$$ev = 10.000 / N \quad (10)$$

where: WRZ = Modified Seebach-index; ev = standing space of the tree; g = basal area; N = number of trees per ha.

RESULTS AND DISCUSSION

Response of stands to thinning treatments

G/Gmax-ratio is approximately constant for the treatments t1, t2 and t3, representing the respective thinning intensity between 7.5 and 25.5 years.

Volume production of the different treatments showed that the lower the ratio G/Gmax (or the higher thinning weight) the higher the losses in increment and, thus, production. In this sense, a major loss of increment is occurring in treatment 3 with 47.5% in comparison to the volume production of the control, measured between 7.5 and 19.5 years.

In the treatments t2 and t1 losses in increment of 19,5% and 9,5%, respectively, could be found, just in comparison to the unthinned control (Figure 1). It could also be shown that thinning response curves have different inclinations. The treatment with less thinning weight showed a slight reduction of increment with increasing age. On the other hand with treatment t2, volume increment expressed in percentage of maximum volume increment was approximately constant, while increasing with age in treatment t3. Unfortunately it was not possible to follow that tendency starting from the age of 16,5 years in treatment t3 as the experiment was interrupted at that time.

In general these results are compatible with those presented by Assmann (1970), Glufke (1996) and Schneider *et al.* (1991), which demonstrates losses in volume increment by the application of heavy thinnings.

The difference between periodic increment of thinning treatments and the unthinned control (i.e. increment losses) was adjusted by regression as a function of the relationship between mean basal area over a period of the treatments and maximum basal area calculated according to equation 11, which showed $r^2 = 0.96$ and $S_{yx} = 2.28$.

$$Y = 61.37 + 28.67.(G/Gmax)^3 - 0.29 / (G/Gmax) \quad (11)$$

where: Y = arcsen $\sqrt{(ipv\%)}$, G = basal area of thinning treatment in m^2/ha, and Gmax = maximum basal area of control plot in m^2/ha.

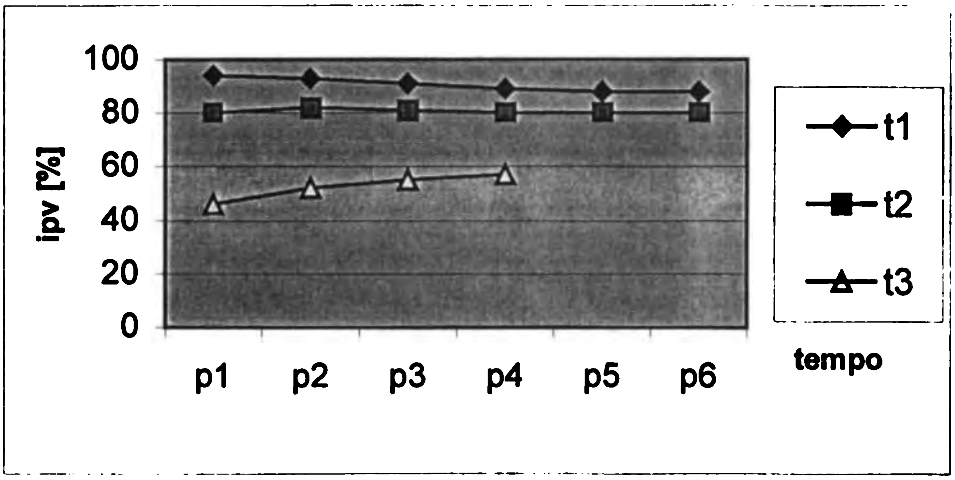

Figure 1: *Variation of the periodic volume increment (ipv%) of thinning treatments t1, t2 and t3, expressed as a percentage of increment of the unthinned control t0 (where: p1=7.5-10.5; p2=10.5-13.5; p3=13.5-16.5; p4=16.5-19.5; p5=19.5-22.5; p6=22.5-25.5 years).*

A drastic reduction of volume increment could be observed with increasing thinning weight (Figure 2), which indicates in general the possibility of controling losses of volume increment with the thinning weight applied. Removing of about 13% of basal area lead to volume increment losses of about 5 % (critical basal area) and removing 30% of basal area lead to losses in volume increment of 11%. On the other hand, thinning of 70% of basal area results in volume increment losses of 39% of the potential volume to be produced on the site.

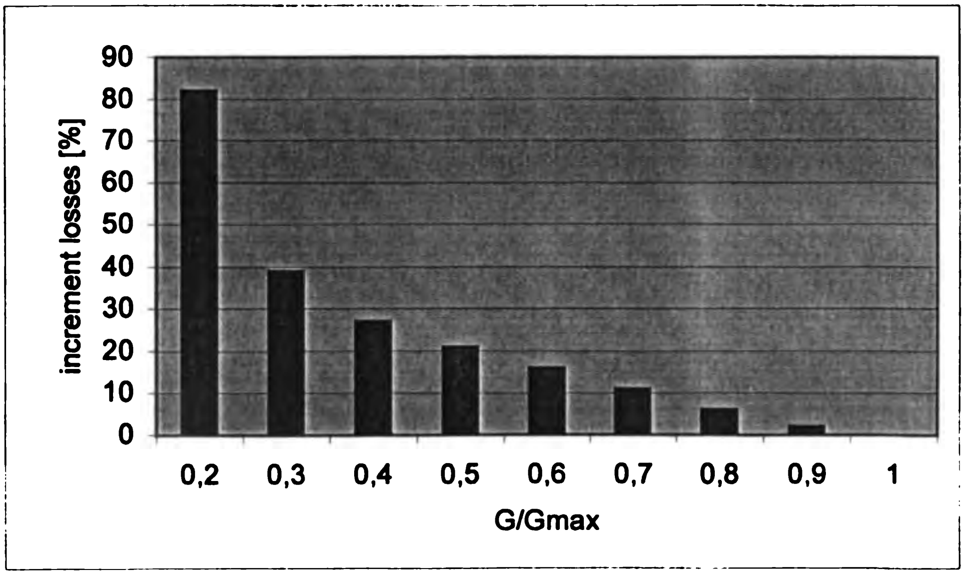

Figure 2: *Losses in volume increment in function of thinning weight, expressed by the ratio G/Gmax.*

Description of stand density

a) Relative Spacing Index – S%

Relative Spacing Index (S%), calculated with formula 7, is adjusted by equation 12 in the case of treatment t0, t1 and t2 and by equation 13 in the case of treatment t3, both regressions with a high precision as shown by table 2.

$$S\% = \exp^{(b_0 + b_1 / h)} \qquad (12)$$

$$S\% = b_0 + b_1 h^2 + b2\, h^3 \qquad (13)$$

where: S% = Relative Spacing Index, h = dominant height.

In treatment t3, with the most heavy thinning (75% of basal area), no thinnings were applied after the age of 16, leading to a different pattern of reduction of S% (Figure 3).

Covariance analysis applied on treatments t0, t1, t2 and t3 show a significant difference of F; (Pr > F = 0,0001), indicating a lack of parallelism between regression functions. Testing the differences between the means also indicates that there are different inclination coefficients. This result does not allow the investigation of the relationsship between the inclination coefficient as a function of mean basal area over a period.

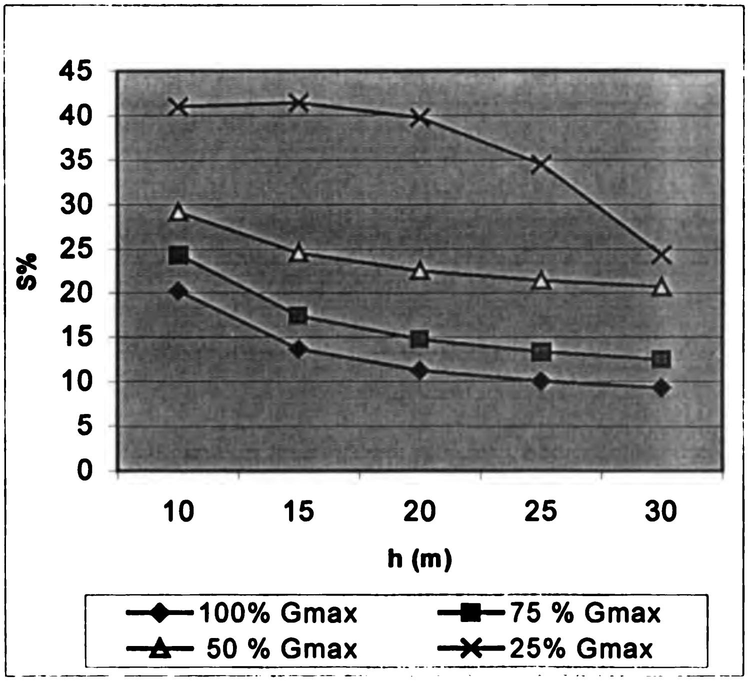

Figure 3: *Values of S% above dominant height (h), adjusted with equation 12 for the treatments t0 (100% Gmax), t1 (75% Gmax) and t2 (50% Gmax) and with equation 13 for treatment t3 (25% Gmax).*

Table 2: *Coefficients of regression (equation 12), describing the relationship between dominant height and Relative Spacing Index for treatments t0, t1, t2 and with equation 13 for treatment t3.*

TREATMENT	COEFFICIENTS			r^2	$S_{yx}\%$
	b_0	b_1	b_2		
t0	1.837109	11.683828	-	0.98502	0.9599
t1	2.178673	10.268424	-	0.96014	1.2837
t2	2.855854	5.161713	-	0.75145	1.6859
t3	38.943130	0.038502	-0.001826	0.90385	2.7690

b) Stand Density Index - SDI

The regression function for the calculation of tree number and mean diameter results in the figures described in table 3.

For the unthinned control, intercept and coefficient of inclination show values of 11.622394 and –1.337677, respectively. The coefficient of determination r^2 and $S_{yx}\%$ (0.9298 and 0.6803, respectively) indicate a good adjustment of the model to the data observed.

The same function applied to the data of the thinned plots show similar intercept and coefficient of inclination, indicating good adjustment to the data too (r^2 and low $S_{yx}\%$) (Table 3 and Figure 4).

Table 3: *Regression coefficients to describe the relationship between the number of trees in function of mean diameter of the treatments t0, t1, t2 and t3.*

TREATMENT	*COEFFICIENTS*		r^2	$S_{yx}\%$
	b_0	B_1		
t0	11.62239	-1.337677	0.9298	0.6803
t1	11.30814	-1.361114	0.9042	0.9042
t2	11.60193	-1.605667	0.9827	0.8970
t3	10.37192	-1.456471	0.9795	1.2729

Covariance analysis applied to the regression functions obtained (t1-t3) do not show significant differences in F; ($Pr > F = 0.12$), indicating parallelism between regressions. The whole model for all treatments reveals an inclination coefficient equal to –1.4560 with $r^2 = 0.9964$ and $S_{yx} = 0.9641\%$.

In order to describe the level of the regression function, the relationship between intercept and mean basal area over a period after thinning was tested, resulting in equation 14 with the following statistical characteristics: $r^2 = 0.5948$ and $S_{yx} = 4.0772\%$.

$$b_0 = 10.318679 + 0.022381.g_{mop} \quad (14)$$

where: b0 = intercept, g_{mop} = mean basal area over a period.

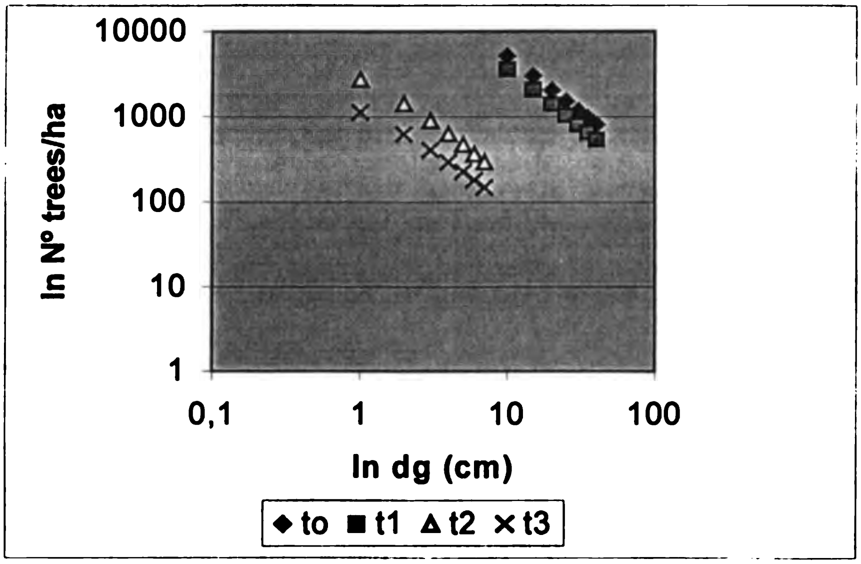

Figure 4: *Tree number of treatments over mean diameter (dg).*

In Figure 5 the small variation of SDI values with increasing dominant height is evident. This could be explained by the difference of annual tree numbers after thinning which does not reflect exactly standing space of each treatment, resulting in a slight decline of SDI lines.

Modeling this index was executed with the procedure stepwise using as independent variables h, h^2, 1/h and $1/h^2$. The results are shown in equation 15, respectively for the treatments t0, t1 t2 and t3:

$$I_{SDI} = b_0 + b_1 h \qquad (15)$$

where: I_{SDI} = Reinecke's Stand Density Index, h = dominant height.

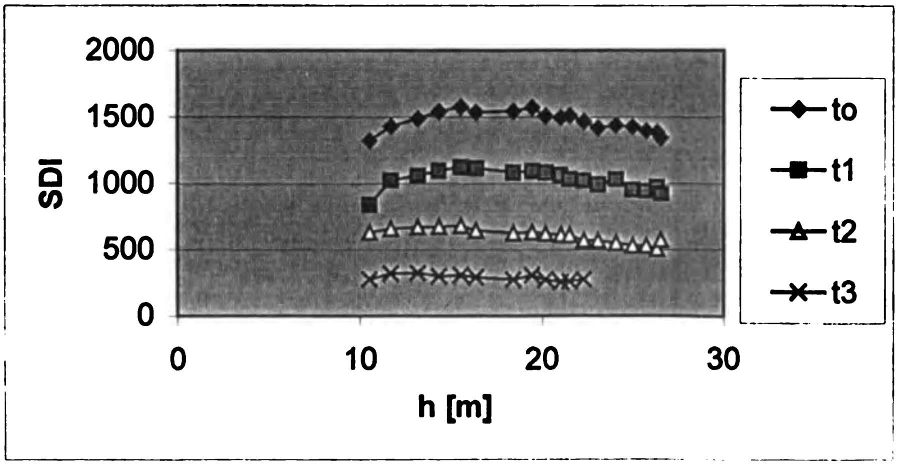

Figure 5: *Stand Density Index (SDI) for different thinning intensities (treatments t0-3) in dependence of dominant height (h).*

c) Modified Seebach-index - WRZ

The Modified Seebach-index (WRZ) shows the relationship between standing space available for each tree and mean diameter.

The evidence of diminuishing WRZ in function of dominant height is highlighted by Figure 6.

The regression function for adjustment of this relationship can be expressed as shown by equation 12 (statistics in table 4).

As regression curves show lack of parallelism, modeling of intercept in function of thinning grade (expressed by g_{mop}) is impossible.

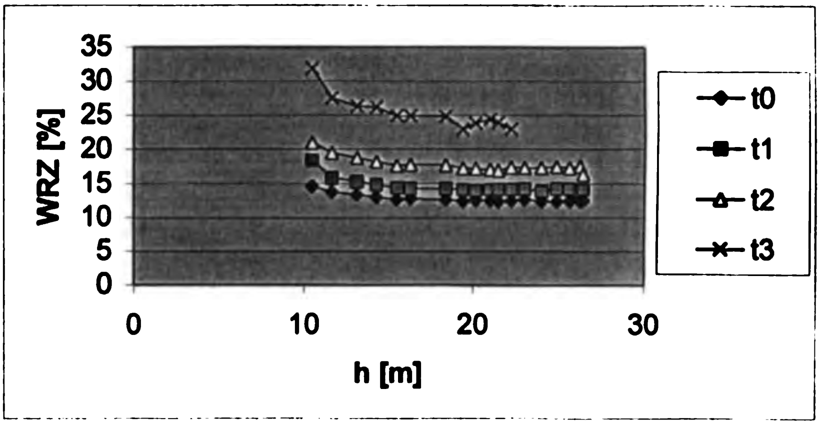

Figure 6: *Modified Seebach-index (WRZ) of different thinning intensities (treatments t0-3) over dominant height (h).*

Table 4: *Coefficients of regression to describe the relationship between WZR and dominant height of the treatments studied.*

TREATMENT	COEFFICIENTS		r^2	$S_{yx}\%$
	b_0	b_1		
t0	11.62239	-1.337677	0.9298	0.6803
t1	11.30814	-1.361114	0.9042	0.9042
t2	11.60193	-1.605667	0.9827	0.8970
t3	10.37192	-1.456471	0.9795	1.2729

Simulation example of S%, SDI and WRZ with different thinning weights, expressed as G/Gmax

With the equations established, density indices were simulated in function of pre-established thinning weights, expressed as G/Gmax (Table 5). For calculation of S%, tree number of the respective thinning weight and mean height of all treatments involved, for SDI and WRZ tree number and the respective diameters of the desired thinning weight were used.

Estimation of breast height diameter (dap) at different thinning weights was conducted with the aid of regression analysis, using the equation $b_{dap} = -0.18 + 0.704.G/Gmax$ ($r^2 = 0.99$; $S_{yx} = 0.10\%$).

Table 5 shows an example of simulation with a thinning weight of 50% of basal area remaining after treatment. With a mean basal area over a period of 50% and the corresponding diameter for this variant, tree number was calculated (T0.5N). Simulation of density indices was based on this tree number. S% is attaining a value of about 20 and WRZ of 17. SDI is decreasing slightly during the whole simulation period (from 810 to 540).

The tree number to be thinned on the basis of Relative Spacing Index is calculated with the formula $N=10000/EMD^2*0.866$, assuming hexagonal spacing after thinning. The medium distance between the trees (EMD) results in: EMD = h100*S%/100, with h100 = dominant height in m. The difference between the trees before and after thinning define the quantity of trees to be removed and allow to finally calculate thinning volume in a specific period with a volume table.

Fishwick (1975) suggested an S% of 21 for *Pinus elliottii* stands without considering the variation of S% with increasing age. According to him, an S% of 16 leads to losses in volume increment up to 25%.

Van Laar (1973) obtained values of S% of *Pinus radiata* between 20 and 22%. On the contrary, using the yield table of Assmann/Franz, he found Relative Spacing Indices lower than 20, showing a higher density in thinned stands of *Picea abies* in Germany, when comparing with South African *Pinus*.

Table 5: *Simulation of S%, SDI and WRZ for a G/Gmax ratio of 0.5, which represents losses in volume production of about 21% in relation to control. hm = mean height of thinning treatments; g = basal area; dg = mean diameter of control plot; T0N = tree number of control plot; T0,5N = tree number calculated with 50% of basal area remaining after thinning; S% = Relative Spacing Index; SDI = Stand Density Index; WRZ = Wachsraumzahl.*

year	hm	g	dg	T0N	T0,5N	S%	SDI	WRZ
1976	10,51	0,007967	15,00	2450	1599	24	810	18,8
1977	11,67	0,008623	15,61	2450	1366	23	769	18,8
1978	13,17	0,009306	16,21	2431	1180	22	732	18,8
1979	14,32	0,010015	16,82	2419	1122	21	762	18,0
1980	15,51	0,010749	17,42	2362	988	21	730	18,0
1981	16,34	0,01151	18,03	2281	876	21	701	18,0
1982	18,41	0,012297	18,64	2200	819	19	706	17,6
1983	19,42	0,01311	19,24	2150	736	19	681	17,6
1984	20,18	0,013948	19,85	2019	665	19	658	17,6
1985	21,02	0,014813	20,45	1938	620	19	655	17,4
1986	21,52	0,015704	21,06	1901	565	19	635	17,4
1987	22,28	0,016621	21,67	1819	518	20	616	17,4
1988	23,05	0,017563	22,27	1713	482	20	607	17,3
1989	24,05	0,018532	22,88	1663	445	20	591	17,3
1990	24,94	0,019527	23,48	1607	411	20	576	17,3
1991	25,70	0,020548	24,09	1538	385	20	566	17,2
1992	26,31	0,021594	24,70	1482	358	20	553	17,2
1993	26,50	0,022667	25,30	1413	334	20	540	17,2

In his study in Passo Fundo (Rio Grande do Sul, Brasil), Schneider (1984) estimated S% of *Pinus elliotti* through the equation: S%=180.040+0.0649.h100, where: h100 = dominant height (m).

According to Bredenkamp & Burkhart (1990), S% and SDI of *Eucalyptus grandis* showed a significant decline with increasing age. The values of SDI in general can be used in density management diagrams, thus allowing to establish thinning programs.

The socalled modified Seebach-index or Wachsraumzahl (WRZ) can also be utilized to develop thinning rules. Spiecker (1994) calculated a WRZ of 25 in order to quantify thinning of cherry *(Prunus avium)* in Germany. By multiplying diameter with the value of 25, the distance between two future crop trees in a thinning period can be obtained.

CONCLUSIONS

The following conclusions can be drawn from this work:

- Losses in volume production totalize 5% with a thinning weight (G/Gmax) of 0.87 up to 39% with a thinning weight of 0.3.
- The relationship between the density indices tested and the different thinning weights can be adjusted by regression functions. Covariance analysis only revealed equal inclination coefficients with the SDI index.
- Simulation of density indices is a possibilty to quantify density regulation of a stand. With thinning weights of 0.5, S% is attaining a value of 20 and WRZ one of 17; SDI falls constantly in the period observed.

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GROWTH DYNAMICS OF THE GMELINA ARBOREA PLANTATIONS OF STON FORESTAL, SOUTHWEST PACIFIC COSTA RICA

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ABSTRACT

The volume and basal area growths, as determined by the analysis of permanent plot data, of the pre and post 1993 Ston Forestal plantations are presented and discussed.The pre 1993 tree farms sampled are now 7 to 8 years old. The post-1993 farms sampled are now 2 to 3 years old. After 8 years, the pre-1993 farms produced total chip volumes of 385, 372, 319, 225 and 173 m^3/ha (approximately 77, 74, 64, 45, and35 cords/acre) on Class IA, 1, 2, 3, and 4 Sites, respectively. The corresponding volumes of saw wood on the same Sites were, after 8 years, 183, 170, 156, 129 and 78 m^3/ha. After three years, post-1993 Class 1A and 1 Sites have produced twice the amount of saw wood as did the same site classes in the pre-1993 plantations.Graphical analysis of basal area growth rates demonstrate that the trees on Class IA and 1 sites, planted with improved seed and advanced management practices, are producing increased basal area growths, with respect to those of the pre-1993 plantations. Although thinned, the Site 2 and 3 post-1993 plantations, after 3 years,have achieved basal area growth rates similar to those of the pre-1993 plantations.

RESUMEN

Se presentó y discutió los resultados del análisis de los datos del crecimiento en volumen y área basal obtenidos de las parcelas permanentes ubicadas en las pre,-1993y post-1993 plantaciones de Ston Forestal. Las pre-1993 plantaciones ya tienen entre7 y 8 años. Las post-1993 plantaciones estan entre 2 y 3 años. Después de 8 años, las plantaciones establecidas antes de 1993 han producidos volumenes comerciales totales de astillas de 385, 372, 319, 225 y 173 m^3/ha (aproximadamente 77, 74, 64, 45 y 35cords/acre), respectivamente en Sitios de Clase IA, 1, 2, 3 y 4. Los volumenes de madera para aserrio en las mismas Clases de Sitios, después de los 8 años, eran: 183,170, 156, 129 y 78 m^3/ha. Los Sitios de Clase IA y 1, plantados después de 1993, han producido dos veces mayor volumen de madera para aserío que las mismas clases de sitio plantados antes de 1993. Las melinas plantadas después de 1993 en Clases de Sitios IA y 1, utilizando semilla mejorada y prácticas silviculturales avanzadas, tienen tasas de crecimiento en Area basal mayores que las melinas plantadas antes de 1993 enlas mismas clases de sitios. Las plantaciones post-1993 en Clases de Sitios 2 y 3, que han sido raleadas, han logrado crecimientos en área basal similares a los de las plantaciones pre-1993 no raleadas.

INTRODUCTION

The data basis of this study are consecutive annual measurements of two to eight year old melina trees on 75 - 400 m^2 circular permanent sample plots established on Ston Forestal tree farms, planted using common comercial seed obtained in Costa Rica, and on 13 -400 m^2 permanent plots established on two lo three year old tree farms, planted using seed from the Ston Forestal XA seed orchard. In addition lo the use of improved seed, the tree farmns planted since 1994 had been planted using three lo four week old nursery stock in paper tubes with the use of herbicidas and fertilizers, and were pre commercially thinned,at age 1.5 lo 2 years, at intensities which varied in aecordance lo site class. The seven and eight year old farms had all been established using pseudostumps, cut from 6 month old nursery stock, planted with no, or limited use of, herbicidas and fertilizers and have not bcen thinned. The permanent plots are not a plantation inventory device. However, permanent plots were stratified and represent the best and worst third of the melina plantation on each farm. The results of permanent plot analyses can be used to estimate the general productivity of given Ston Forestal tree farms, once the total areas of each site class on each farm have been measured or estimated.

The permanent plot data was grouped according to the year 5 mean annual increments of commercial volume (MAI V_{com}):

Class 1A	60 to 69.9 m^3/ha/yr
Class 1	50 to 59.9 m^3/ha/yr
Class 2	40 to 49.9 m^3/ha/yr
Class 3	30 to 39.9 m^3/ha/yr
Class 4	20 to 29.9 m^3/ha/yr

To generate tables and graphs of the data, the growth mean data from the 5 site class groups of permanent plots were fitted to polynomial equations of the form:

$$y = ax^2 + bx + e$$

COMMERCIAL VOLUME GROWTH

Volume mean annual increments

Total commercial chip volume is the tree underbark volume up to a diameter of 7 centimeters and is calculated using the formula:

m^3 =0.011392(DBH) - 0.00037431(DBH) ^{2} + 0.000029317(DBH)^2(total ht.)- 0.09224(where DBH = diameter at breast height; n = 507; R^2 = 0.099; standard error = 0.020;significance = $p < 0.0000$)

Saw wood volume, in this report, is the tree overbark volume, calculated by determining the large and small end diameters of 1 meter segments along the stem, to either a small end diameter of 18 centimeters or a total height of 8 meters, using taper equations of the form:

diameter (x) = (a)DBH + (b)DBH - c.

The constants (a, b, c, ect.) for the diameters at x number of one meter increments along the stem were calculated by applying linear regression to field data from 250 melina trees,which had been felled and measured at one meter increments. Intrasegment diameters were estimated by linear interpolation. The volumes of each segment were calculated using Smalian's equation (**M^3 = (B + b)/2)1**, where B and b are the cross sectional areas of the large and small ends of each log of length 1). Total log volume is the sum of the overbark volume of each segment up to that of a 1.2 meter bolt having a minimum small end diameter of 18 cm.

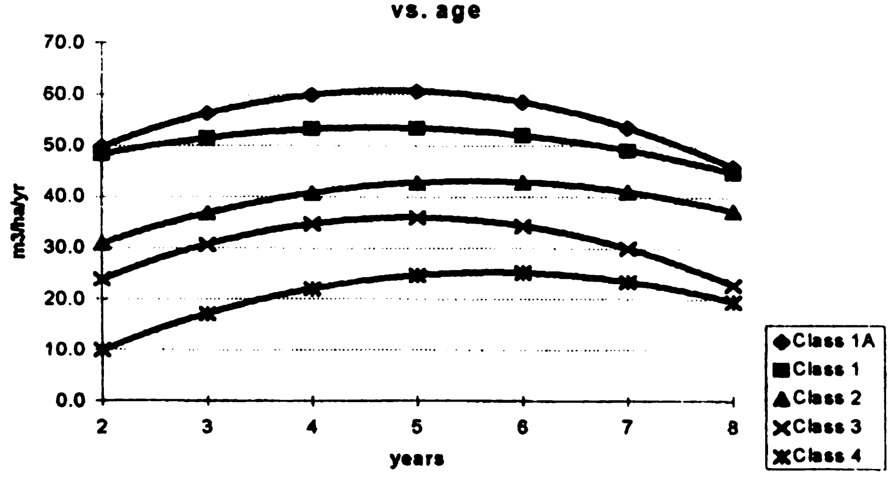
Table 1 and Graph 1 demonstrate the fact that the mean annual increment of commercial chip volume peaked on all five site classes between ages four and 7. Volume growth rates on Class IA sites peaked at 5 years, Class 1, 2 and 3, around 5 years and Class 4, after 6 years of age.

The mean annual volume increments (MAI_{vol}) of Sites IA and 1 converge after 7 years.The MAI_{vol} of Sites 3 and 4 tend to converge after year 8. This effect can be attributed mostly to the reduction of basal area growth in the unthinned pre-1994 melina plantations which effect tended to he more prominent on the better classes of soils.

Table 1: Mean Annual Increment of Commercial Volume for Site Classes 1A to 4

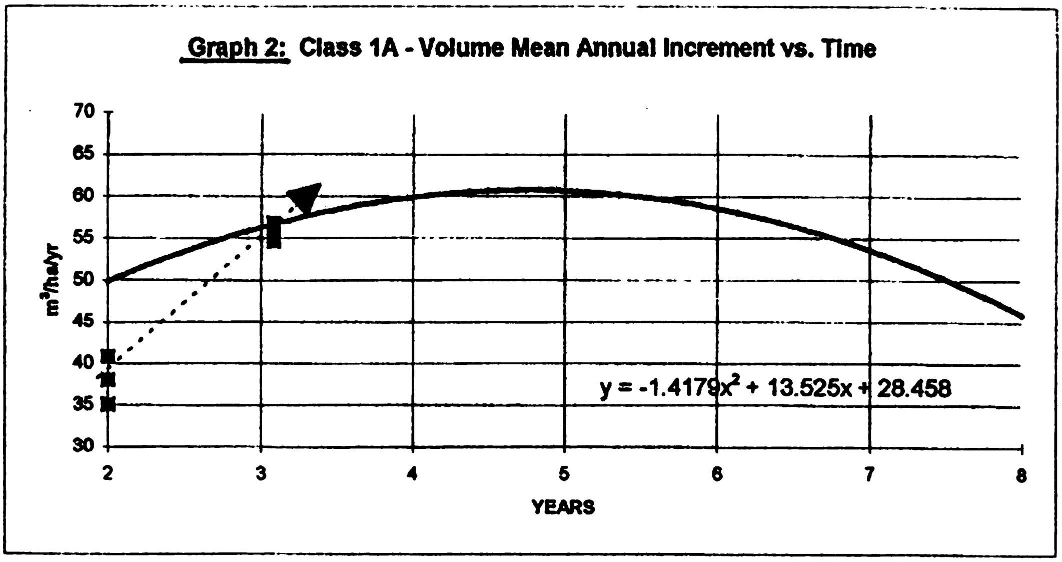
Age (yrs)	Class 1A $m^3/ha/yr$	Class 1 $m^3/ha/yr$	Class 2 $m^3/ha/yr$	Class 3 $m^3/ha/yr$	Class 4 $m^3/ha/yr$
2	49.8	48.3	30.8	23.9	10.0
3	56.3	51.5	36.8	30.7	17.1
4	59.9	53.2	40.8	34.7	22.0
5	60.6	53.4	42.8	35.9	24.7
6	58.6	52.1	42.9	34.3	25.2
7	53.7	49.2	41.1	30.0	23.5
8	45.9	44.9	37.2	22.9	19.6

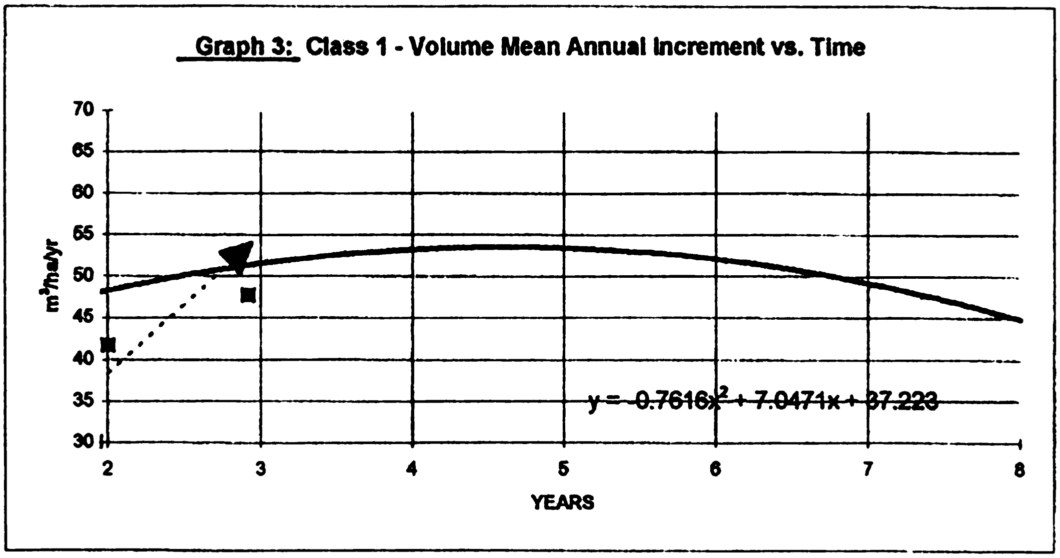
Graph 1: Mean annual commercial volume increments vs. age



Volume MAI for pre and post-1993 plantations on Class IA and 1 Sites are compared on Graphs 2 and 3. On both graphs, the commercial MAI for the age 2 and 3 permanent plots on post 1993 farms are marked by filled squares.

Multiple year trend lines can not be developed with few points, but the approximate 2 to 3 year + trend, for the post 1993 data, is indicated by a dotted line. The post-1993 plantations were thinned down to 650 to 750 stems/ha before year 2, while the unthinned pre- 1993 plantatiens were stocked with, approximately, 900 +/- trees/ha; it can be observed that the year 3 rate of MAI increase, on Class 1 A and 1 Sites, in the post- 1993 plantations,was dramatic. The XA orchard seed produces trees which have a higher rate of diameter growth, than those planted using common commercial seed, when planted on fertile soils in a tropical wet climate. The caray thinning of these plantations eliminated the characteristically aggressive between-tree competition which develops before year 3, whenmelina is planted on high quality sites.





COMMERCIAL VOLUME PRODUCTIVITY BY SITE CLASS

The yearly accumulative total of commercial chip volumes for each of five site classes, on pre-1993 Ston tree farms, is presentes in Table 2. Table 3 contains the corresponding over bark total volumes of saw logs down to a minimum diameter of 18 cm over bark.

The chip and saw wood volumes in the post-1993 melina plantations are illustrated onTable 4, using 2 and 3 year data from the listed permanent plots.

Comparing the productivity between the old and new tree farms, it can be seen that the total standing volume in the Class IA permanent plots in the post-1993 plantations, after 3 years, is the same as that of the pre-1993 plantations. Recall that the former plantations have on the order of 40% fewer trees per hectare. There is only one Class 1 plot represented in the post-1993 group, therefore generalizations are tenuous. When comparing the volume of standing saw timber between the pre and post 1993 plantations,the combined impacts of the use of improved seed, herbicidas and fertilizers and early thinning are made evident. The volume of standing timber, at the end of year 3, in the post 1993 plantations was double of that in the pre 1993 plantations; a marked improvement inplantation quality.

Table 2: Total Commercial Chip Volume for Site Classes 1A to 4

Age (yrs)	Class 1A m^3/ha	Class 1 m^3/ha	Class 2 m^3/ha	Class 3 m^3/ha	Class 4 m^3/ha
2	89	94	61	46	13
3	175	159	115	97	56
4	246	215	165	140	93
5	303	265	210	174	123
6	345	308	251	200	146
7	372	344	287	217	163
8	385	372	319	225	173

Table 3: Commercial Saw Wood Volume for Site Classes 1A to 4 *

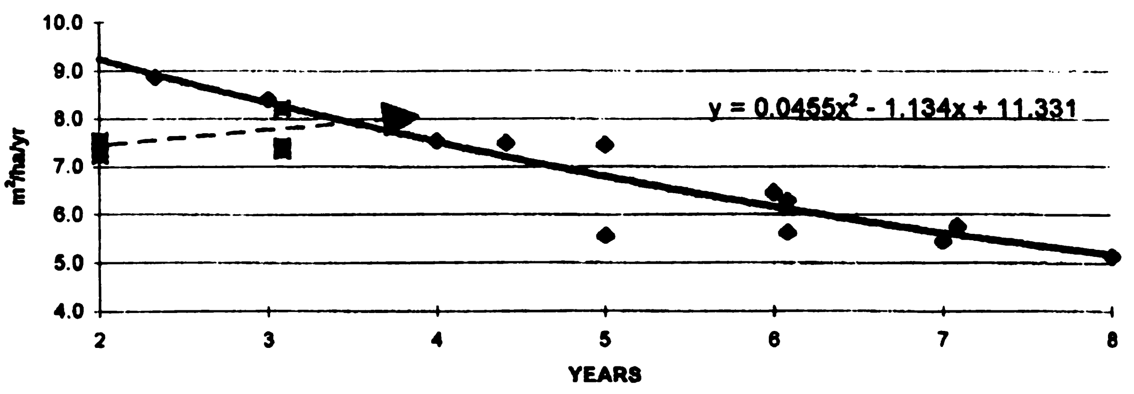
Age (yrs)	Class 1A m^3/ha	Class 1 m^3/ha	Class 2 m^3/ha	Class 3 m^3/ha	Class 4 m^3/ha
2	0	0	0	0	0
3	29	19	13	6	1
4	62	52	35	20	11
5	93	83	60	40	23
6	124	113	89	64	38
7	154	142	121	94	57
8	183	170	156	129	78

* volume from base to 18 cm underbark or 8 m of height

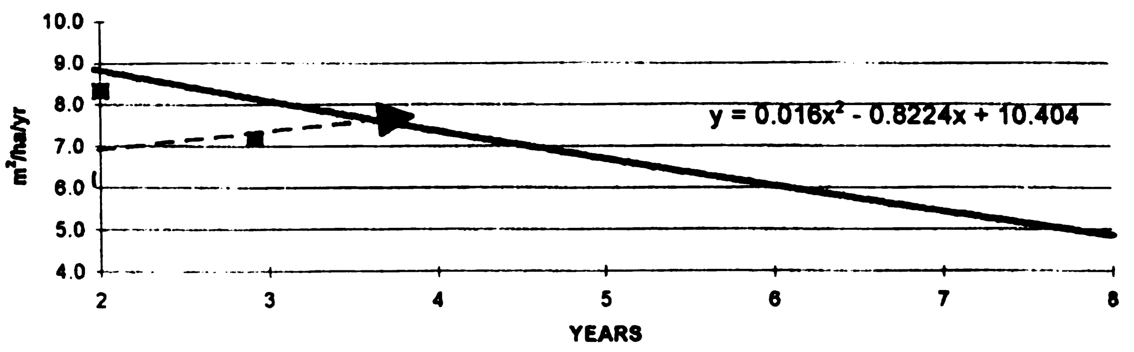
Table 4: Total Commercial Chip and Saw Wood Volumes for Site Classes 1A and 1; post-1993 plantations

Age (yrs)	-------- total chip volume (m^3)----------		---- total saw wood volume (m3)----	
	Class 1A Farms EH,EJ,PL	Class 1 Farm EK	Class 1A Farms EH,EJ,PL	Class 1 Farm EK
2	64	57	1	2
3	171	139	71	42
	Class 2 Farms EK,SU,PL,EN	Class 3 Farms EH,EJ,EL,RF	Class 2 Farms EK,SU,PL,EN	Class 3 Farms EH,EJ,EL,RF
2	54	38	2	0
3	98	77	15	1

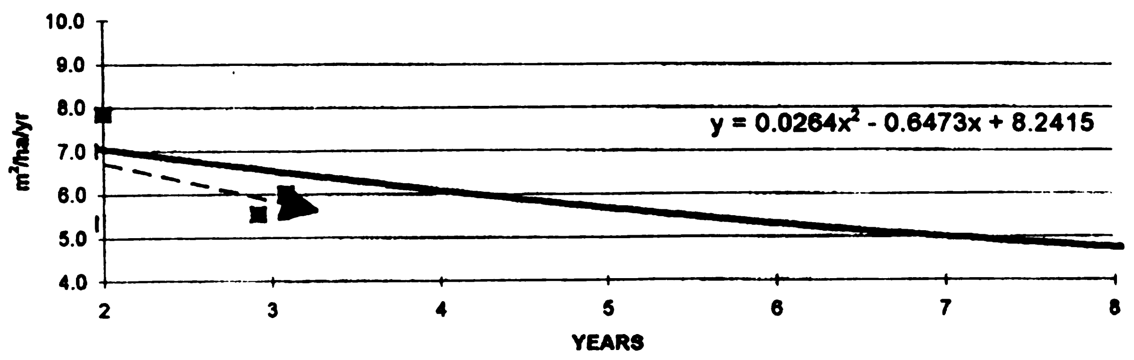
Graph 4: Class 1A Basal Area Mean Annual Increvent vs. Time

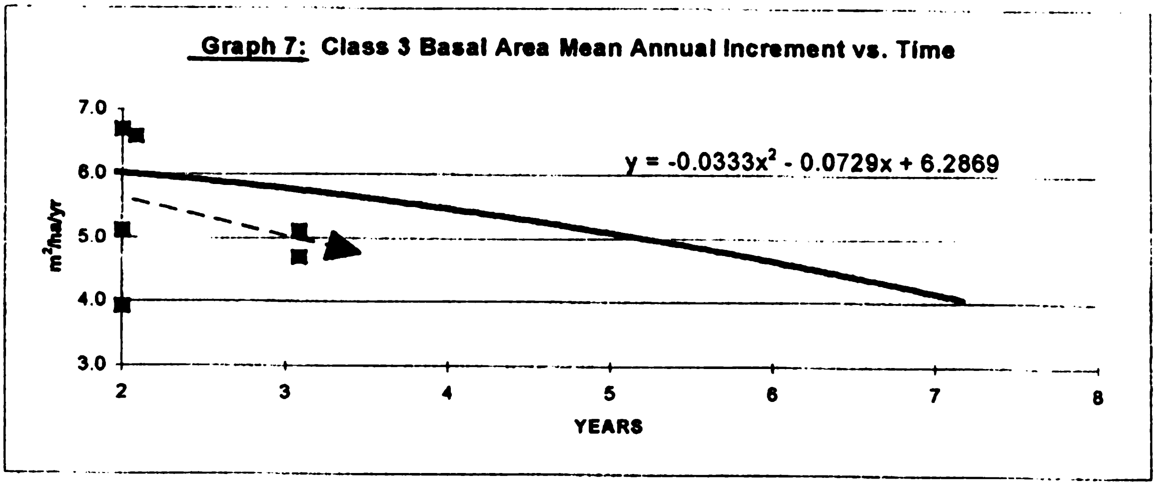


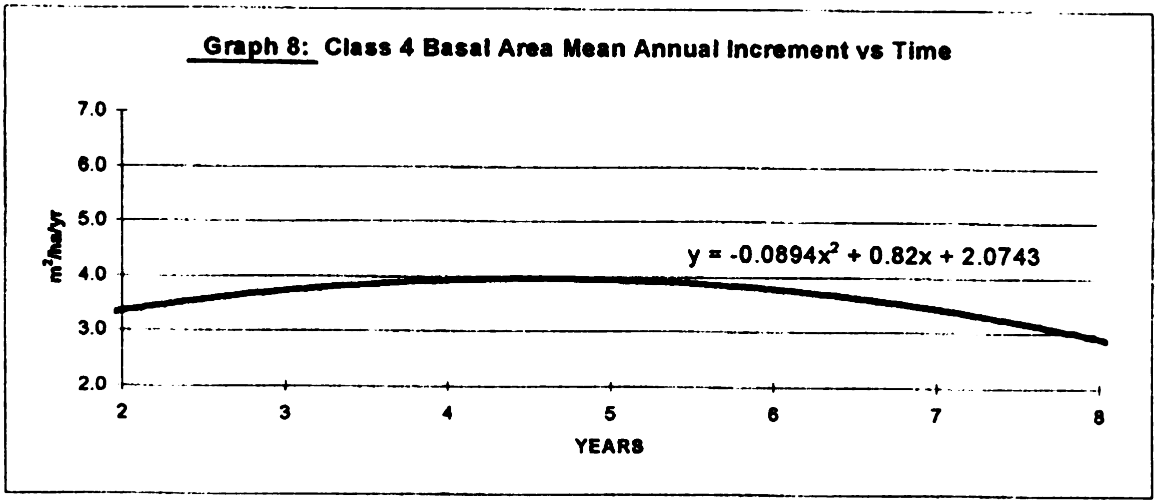
Graph 5: Class 1 Basal Area Mean Annual Increment vs. Time



Graph 6: Class 2 Basal Area Mean Annual Increment vs. Time







Year 3 total chip volumes, for the post 1993 Class 2 and 3 melina plantations, lags behind the expected volumes as per the pre 1993 plantations. Total saw wood volumes for the same site classes were equal to those of the pre 1993 plantations. This preliminary result should be rectified by the end of year 4 and reflects a response lag due to thinning melina stands on lower class sites.

MELINA PLANTATION BASAL AREA GROWTH

Through the use of improved seed, improved planting and maintenance practices and early thinning in the post 1993 plantations, the decline of the rate of basal area growth between years 2 and 3 was altered on the better sites. The filled squares represent the permanent plot data for the post 1993 plantations. The dotted arrows plot the approximate one year trend of the post 1993 data points. On Class IA and 1 sites, the rate of basal area growth increased slightly between year 2 and 3. On Class 2 and 3 Sites, the rate of basal area growth increase on the post 1993 was similar to that of the pre-1993 plantations. At this time Ston Forestal is not thinning Class 3 and 4 plantations. Graph 8 clearly shows that,given the low growth rates on Class 4 sites, basal area growth is relatively unimpeded until after year 5, in that the crowns of these stands do not close for more than 2 years after planting.

The following graphs illustrate site class trends of basal area growths in pre and post 1993 plantations. Graphs 4, 5 and 6 demonstrate the magnitude of the yearly decline in the annual rate of basal area growth per hectare in the unthinned pre-1993 melina plantations.The decline is more pronounced on the better sites, given that the trees enter into competition for crown space at an earlier age. The year 8 MAIs of basal areas were 56%,56%, 68%, 75% and 85% respectively of the year 2 MAIs on Class 1 A, 1, 2, 3, and 4 Sites.

Table 5 presents the total basal areas, by Site Class, after .8 years, of the pre 1993 plantations. The actual R&D and silviculturas management objective is to achieve at least, 42, 40, 34 and 32 m^2 of total basal area on Class IA, 1, 2 and 3 Sites, on those farms planted after 1993, through genetic and silvicultural improvements.

Table 5 : Total Basal Areas for Site Classes 1A to 4

Age (yrs)	Class 1A m^2	Class 1 m^2	Class 2 m^2	Class 3 m^2	Class 4 m^2
2	18	18	14	13	7
3	25	24	20	19	11
4	30	29	24	24	16
5	34	33	28	29	20
6	37	36	32	33	23
7	39	38	35	36	24
8	41	39	38	38	23

Table 6 : Total Basal Areas for Site Classes 1A to 4

Age (yrs)	Class 1A m^2	Class 1 m^2	Class 2 m^2	Class 3 m^2	Class 4 m^2
2	14	14	13	11	11
3	24	21	17	15	

The basal areas in the post-1993 plantations in Table 6, reflect the thinning applied on Class IA, 1, 2 and 3 Sites before year 2. As Indicated previously, the rates of basal area growth increments were accelerated, particularly on Class IA and 1 sites, therefore on these sites similar total basal areas were achieved by year 3, in spite lower stocking.

MEASUREMENTS OF TREE GROWTH IN VENEZUELA

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ABSTRACT

Aware of tree growth significance in forest management, the Forest Management Course of the Forestry Engineering School (University of Los Andes) initiated the establishment of permanent plots of growth control in 1956 (42 years ago). Since then, a total amount of 60 plots were established in different types of forests in the country (9 Life Zones, according to Holdridge); which have periodically been measured. Collected informations have been used, not only for growth determination of these forests and its relative potential productivity, but as well for growth calculation and individual tree growth and harvest rotation corresponding to minimal cutting diameters established in the country. Most recently, these values have been useful as a base for studies related to Carbon cycle and climate change, in which researchers from the University of Illinois (USA) and from The Institute of Tropical Forestry of Puerto Rico, have been working. Several publications from national and international origins give testimony of this. In the present paper, reference of these publications and main results achieved in previous papers is made.

Key words: Growth, natural forests, harvest rotations, climate change.

RESUMEN

Consciente de la importancia del crecimiento de los árboles en el manejo de los bosques, la Cátedra de Ordenación Forestal de la Escuela de Ingeniería Forestal (Universidad de los Andes. Mérida, Venezuela) inició en 1956 (hace 42 años) el establecimiento de parcelas permanentes de control de crecimiento. Un total de más de 60 parcelas fueron establecidas desde entonces en distintos tipos de bosques del país (9 Zonas de Vida, según Holdridge); las cuales se han venido midiendo periódicamente. Las informaciones recogidas están siendo utilizadas no sólo para la determinación del crecimiento de estos bosques y su productividad potencial relativa, sino también para el cálculo del crecimiento y edad de los árboles individuales y de los turnos de explotación correspondientes a los diámetros mínimos de cortabilidad establecidos en el país. Más recientemente estos valores han servido de base para estudios relacionados con el ciclo del carbono y el cambio climático en los cuales vienen trabajando investigadores de la Universidad de Illinois (USA) y del Instituto de Dasonomía Tropical de Pto Rico. Varias publicaciones científicas de origen y nivel nacional e internacional dan testimonio de ello. En el presente trabajo se hace referencia de algunas de estas publicaciones y de los principales resultados alcanzados en los primeros trabajos.

Palabras Claves: Crecimiento, Bosques Naturales, Turnos, Cambio Climático.

INTRODUCCION

El crecimiento o incremento de los árboles es una de las informaciones básicas más importantes en el manejo y aprovechamiento racional de los bosques, sean éstos naturales o plantados; pues está íntimamente ligado al principio del rendimiento sostenible y a la cuota de explotación anual o periódica. El manejo sustentable de un bosque impone una regulación en la Cuota de explotación (o Posibilidad). La cantidad de madera que puede extraerse periódicamente, en forma regular, es función del volumen de la Masa Boscosa existente y del Crecimiento de la misma. También es función del Crecimiento, la edad a la cual los árboles alcanzan su respectiva madurez económica y pueden ser cortados y aprovechados (Turno o Rotación y Ciclo de Corta).

En general, el crecimiento de los bosques depende de los factores bióticos, climáticos y edáficos. Los elementos bióticos comprenden por si mismos, la composición florística, estructura, edad, competencia, ecología, etc.; en sí las características de las comunidades forestales. Los elementos climáticos, en particular la precipitación y la temperatura, tienen mayor influencia sobre el crecimiento de los árboles. Los edáficos comprenden el suelo, con sus propiedades físicas y químicas, la profundidad, humedad edáfica y movimiento del agua en el suelo, topografía y exposición, que también influyen sobre el crecimiento de los árboles.

Existen dos grandes grupos de métodos para calcular el crecimiento:

- Por medición de anillos anuales de crecimiento; y
- Por comparación de inventarios sucesivos.

En las zonas donde los árboles crecen regularmente durante una época del año y en otra interrumpen su crecimiento (o disminuyen su ritmo de vida), se forman anillos diferenciados en la madera del tronco, que pueden ser apreciados, contados y medidos en su espesor. En base a estas mediciones es posible conocer la vida de los árboles (su historia), su edad y su ritmo de crecimiento. Este es el caso de casi todos los árboles de la zona templada y algunos pocos de la zona tropical.

Cuando no existe interrupción en el crecimiento, los anillos no se hacen visibles y no es posible medir el crecimiento de los árboles en forma inmediata. Para conocer el crecimiento hay que establecer parcelas permanentes y comparar mediciones sucesivas de los árboles durante un período más o menos largo. Es lo que generalmente se hace en nuestros bosques naturales tropicales y en plantaciones en esta zona.

ANTECEDENTES

El crecimiento de los bosques venezolanos ha sido objeto de estudio por la Sección de Ordenación del Instituto de Silvicultura de la Universidad de Los Andes (ULA), bajo la responsabilidad del Profesor J. P. Veillon y un equipo de colaboradores entre los cuales están Ingenieros y Peritos Forestales. A partir de 1955 se iniciaron los estudios de dinamismo de los bosques de Venezuela, comenzando con mediciones de árboles individuales; a principios de 1956 se procedió a la instalación de las primeras parcelas de crecimiento, las cuales han sido medidas anualmente desde entonces en 9 Zonas de Vida del País.

En total, Veillon y colaboradores establecieron 62 parcelas dinámicas de forma cuadrada o rectángular, con superficies de 625 m2 a 10.000 m2 (La mayoría de 50 x 50 m). En cada parcela se han medido los árboles a partir de 10 cm DAP., y se han realizado observaciones sobre la topografía, el suelo, el clima y las eventuales influencias humanas.

Además, recientemente el MARNR – Dirección de Recursos Naturales (hoy Servicio Autónomo Forestal Venezolano) exigió a las Empresas Concesionarias de Bosques, el establecimiento y medición de parcelas de control de crecimiento en las áreas intervenidas de sus respectivas Unidades de Manejo; y el propio organismo oficial (SEFORVEN) ha establecido estas parcelas permanentes para estudiar el dinamismo de la vegetación arbórea y el efecto de las explotaciones forestales sobre ella.

También existen algunos registros útiles sobre el crecimiento de las plantaciones forestales establecidas en el país en años recientes.

En 1958 el Prof. Veillon publicó los primeros resultados de las mediciones sobre parcelas establecidas en la Región de Los Andes y Llanos Occidentales y en 1985 publicó un nuevo informe con el título de: "El Crecimiento de Algunos Bosques Naturales de Venezuela en Relación con los Parámetros del Medio Ambiente" y está publicando resultados actualizados, en Capítulos separados, sobre los bosques en las distintas Zonas de Vida de Venezuela.

En 1992, Aníbal Luna Lugo y Judith Petit publicaron en la Revista Forestal Latinoamericana N° 10/92: "Tendencias en el Crecimiento de los Bosques Naturales Venezolanos" basado en estos trabajos del Prof, Veillon.

En 1993, el Instituto Forestal Latinoamericano (IFLA) publicó también el trabajo: "Estudio sobre el Crecimiento y Edad de 20 Especies Forestales Comerciales de los Bosques Naturales Venezolanos", del Prof. Aníbal Luna.

Por su parte los Drs. Sandra Brown (Universidad de Illinois) y Ariel Lugo (Instituto Forestal Tropical de Río Piedras, Pto Rico) han venido usando estos mismos datos recogidos y aportados por Veillon y asistentes, para trabajos relacionados con productividad de los bosques tropicales y estudios del ciclo del carbono. Recientemente ambas instituciones firmaron acuerdo con la Facultad de Ciencias Forestales y Ambientales de Mérida para continuar las mediciones e intercambiar informaciones.

OBJETIVOS

Dada la importancia que reviste el tema de la Conservación y el Crecimiento de los Bosques en los actuales momentos en Venezuela y el Mundo, en relación con el Ciclo de Carbono, el Efecto Invernadero y el Cambio Global del Clima, hemos creído conveniente llamar la atención de los forestales y ecólogos sobre la existencia de estos trabajos que, a nuestro parecer, son casi pioneros en América Latina y representan un extraordinario esfuerzo continuo y sostenido de más de 40 años de investigaciones de campo, nada cómodas, por cierto.

Además, se comentan algunos de los aspectos generales más relevantes de los resultados obtenidos, haciendo referencia al crecimiento relativo de los distintos tipos de bosques y especies forestales individuales, edad y turnos de explotación de algunas de ellas.

RECOPILACION Y PROCESAMIENTO DE LA INFORMACIÓN

Recopilación de Datos

La información básica para el presente trabajo fue aportada por el Instituto de Silvicultura (Sección de Ordenación), de la Facultad de Ciencias Forestales y Ambientales (Universidad de Los Andes, Mérida). Consistió en los datos de las mediciones de crecimiento de árboles en las parcelas permanentes establecidas por el Prof. J. P. Veillon y que han venido siendo recabados y registrados por él y sus colaboradores de la mencionada Sección, a lo largo de unos 40 años de trabajo constante y tesonero. Se trata de parcelas de bosques poco o nada intervenidos.

Los métodos y procedimientos empleados en la recolección de los datos, así como las diferentes mediciones hechas en el terreno aparecen en la Bibliografía. También se señalan allí algunas de las precauciones y previsiones tomadas para reducir a un mínimo los inevitables errores de medición. Sin embargo, es importante destacar acá que en cada parcela no sólo se midieron cuidadosamente los árboles marcados y numerados, sino también se llevó control de los "ingresos" y los "egresos".

Procesamiento de la Información

Los datos de los registros fueron procesados por el Per. For. Julio Serrano, de la mencionada Sección, mediante Programa Fortran elaborado por el Dr. Noel Ogaya, ex-profesor de la Cátedra de Programación y Computación de la Escuela de Ingeniería Forestal. En el caso de ciertas especies, y dado que en algunas Categorías Diamétricas no se tenían representantes, se asumió el promedio de crecimiento en diámetro de las categorías más próximas. (superior e inferior).

Para el Cálculo del Volumen de los Arboles en la determinación del Crecimiento Volumétrico se usó la fórmula desarrollada por el Prof. V. Konrad, de la misma Sección de Ordenación ($V = b_0 + b_1 d^2$). El cálculo del Crecimiento de los árboles en Volumen (m3) se hizo mediante la fórmula: $C = V' - V + E - I$, que toma en cuenta los Egresos (E) y los Ingresos (I) habidos entre mediciones (período). El crecimiento relativo (en %) se calculó con la fórmula de Pressler:

$$C(\%) = \frac{V' - V}{V' + V} \frac{200}{n}$$

Los Diámetros Mínimos de Cortabilidad (para el cálculo del Turno de Explotación) fueron los establecidos oficialmente en Venezuela: 30, 58 y 63 cm DAP, para Maderas Duras, Blandas y Finas, respectivamente. Para el cálculo de los "Turnos Legales" se aplicó el procedimiento de los "tiempos de paso", o números de años a los cuales las distintas especies van alcanzando las diferentes clases de grosor.

ALGUNOS RESULTADOS OBTENIDOS

Crecimiento de Bosques (Veillon, 1985)

Entre las valiosas informaciones aportadas por el trabajo del Prof. Veillon nos han parecido más relevantes las contenidas en el Cuadro-Resumen y los Diagramas N° 1 y 2 del texto original, que copiamos a continuación.

Como puede apreciarse fácilmente de estos documentos, existe una marcada relación entre la precipitación anual y el crecimiento de los árboles y bosques, tanto en diámetro como en área basal y volumen. Es así como el Bosque Espinoso Tropical refleja los menores crecimientos en contraposición con el Bosque Húmedo Tropical, que tiene los máximos valores, en general. Ello puede deberse tanto al total de la precipitación anual, en las respectivas Zonas de Vida, como al número de meses secos al año, según observa el autor.

Análogamente, resulta evidente la relación entre altitud o piso climático (más propiamente la temperatura media anual) y el ritmo de crecimiento de los árboles. De tal forma que en la región montañosa de Los Andes, el de menor crecimiento es el Bosque Húmedo Subalpino y el de máximo crecimiento el Bosque Húmedo Premontano; este último con valores muy cercanos a los del bosque Húmedo Tropical. Estas tendencias generales pueden ser también observadas en las gráficas siguientes, preparadas a partir de los valores del Cuadro Resumen.

Cuadro 1: *Características dasométricas según zona de vida*

DATOS POR HECTAREA - Arboles con DAP superiores a 10cm								
Ecosistema o Zona de Vida, según L. Holdrige	Masa Forestal		Productividad. Volumen fustes (m^3/año)				Crecimiento medio anual DAP (cm)	Clase Productividad JPV
	AB m2	Vol. Fustes m^3	Min	Máx	Medio	Porcen-taje %		
Bosque Espinoso Tropical	10	25	0	1	0.5	1	0.1	IV
Bosque muy seco Tropical	15	80	1	3	2	2	0.25	III
Bosque seco Tropical	25	150	2	6	4	2	0.35	II
Bosque Húmedo Tropical	30	300	4	12	8	2.5	0.45	HI
Bosque Húmedo Premontano	35	400	4	10	7	1.7	0.25	HI
Bosque Húmedo Montano Bajo	35	300	2	6	4	1.4	0.20	II
Bosque Húmedo Montano	40	300	2	5	3.5	1.5	0.22	II
Bosque Húmedo Subalpino	20	50	0.3	1.3	0.8	0.8	0.20	I

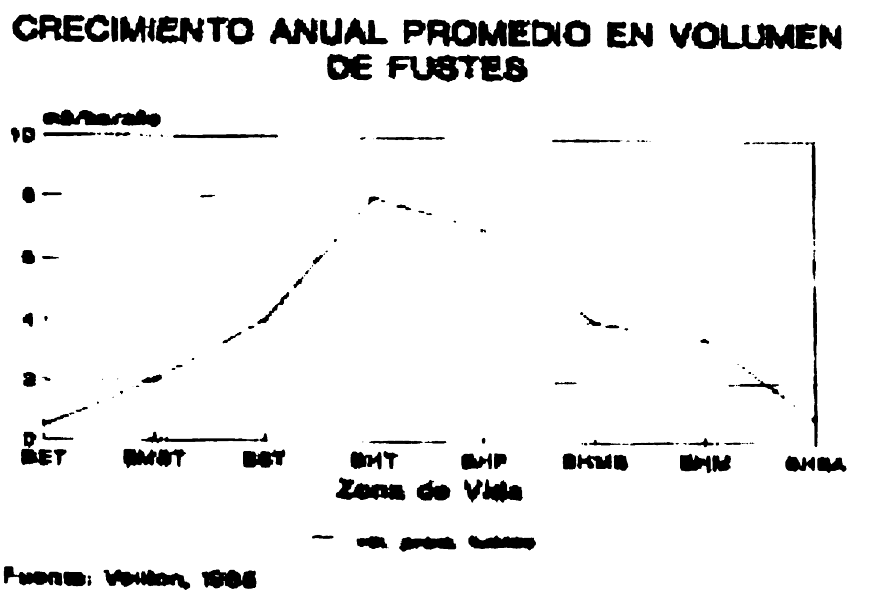

Figura 1: *Crecimiento anual promedio en volumen de fustes según zona de vida.*

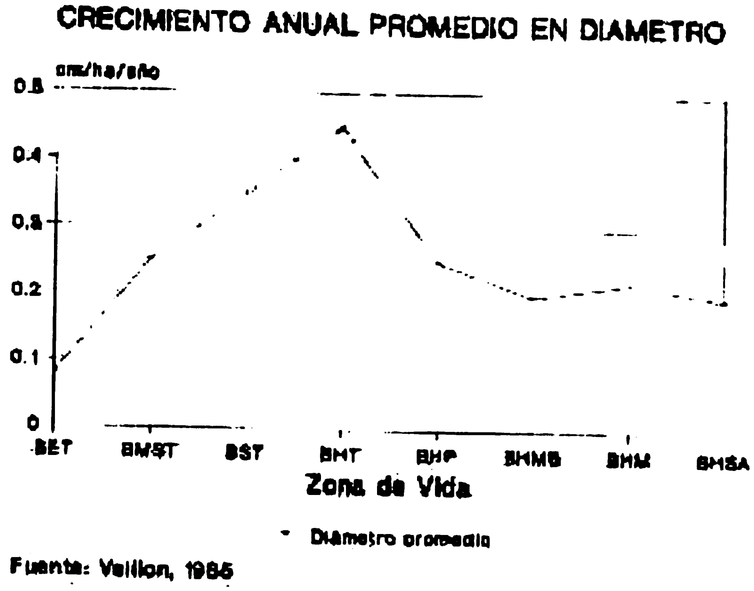

Figura 2: *Crecimiento anual promedio en volumen de fustes según zona de vida*

Cuadro 2: *Crecimiento volumétrico por especies*

ESPECIES ESTUDIADA NOMBRE VULGAR	NOMBRE CIENTIFICO	GRUPO DE MADERA	DMC (cms)	TURNO (años)	CMA PRESSLER (%/AÑO)
Amarillón	Terminalia obovata	D	30	25	5,27
Apamate	Tabebuia rosea	B	58	70	2,41
Balso	Ochroma piramidale	B	58	30	3,95
Baramán	Catostemma commune	D	30	160	0,92
Caoba	Swietenia macrophyla	F	63	110	1,45
Cedro (1)	Cedrela montana	F	63	90	---
Cedro (2)	Cedrela odorata	F	63	55	2,57
Cedro (3)	Cedrela angustifolia*	F	63	60	---
Charo	Brosimum alicastrum	B	58	85	1,95
Chupón	Chrysophyllum caracasanum	D	30	25	4,42
Drago	Pterocarpus acapulcensi	B	58	100	1,50
Gateado	Astronium graveolens	D	30	100	1,72
Guayabón	Terminalia guyanensis	D	30	20	6,29
Jabillo	Hura crepitans	B	58	150	1,17
Jobo	Spondias mombim	B	58	140	0,77
Mora	Mora gonggrijpii	D	30	90	1,53
Pardillo Negro	Cordia thaistiana	F	63	70	2,38
Perhuetamo	Mouriri barinensis	D	30	70	2,34
Saqui Saqui	Bombacopsis quinata	B	58	75	2,76
Vera	Bulnesia arborea.	D	30	100	1,76

CRECIMIENTO DE ÁRBOLES (LUNA, 1993)

Con escasas excepciones, las especies de maderas duras crecen más lentamente que las blandas y las finas. Un resultado que era de esperarse. Aunque hay especies que alcanzan su mayor vigor de crecimiento a edad avanzada, la mayoría la alcanza a edad temprana. Al comparar el crecimiento de cada especie en las distintas clases de grosor, se constata que la categoría I (10-20 cm DAP) es generalmente la de mayor crecimiento.

En general, los "Turnos Legales" en Venezuela (correspondientes a los Diámetros Mínimos de Cortabilidad en el país) van desde 20 a 120 años en bosques poco o nada intervenidos. Aunque la mayoría de las especies estudiadas a estos efectos (20) arrojaron Turnos que están por encima del promedio asumido hasta ahora en los Planes de Ordenación y Manejo (60 años), cuatro de ellas resultan con Turnos muy inferiores a dicho valor (20-30 años). De todos modos es de esperarse que en bosques bajo manejo, estos Turnos puedan reducirse por disminución de la competencia y los consiguientes estímulos al crecimiento.

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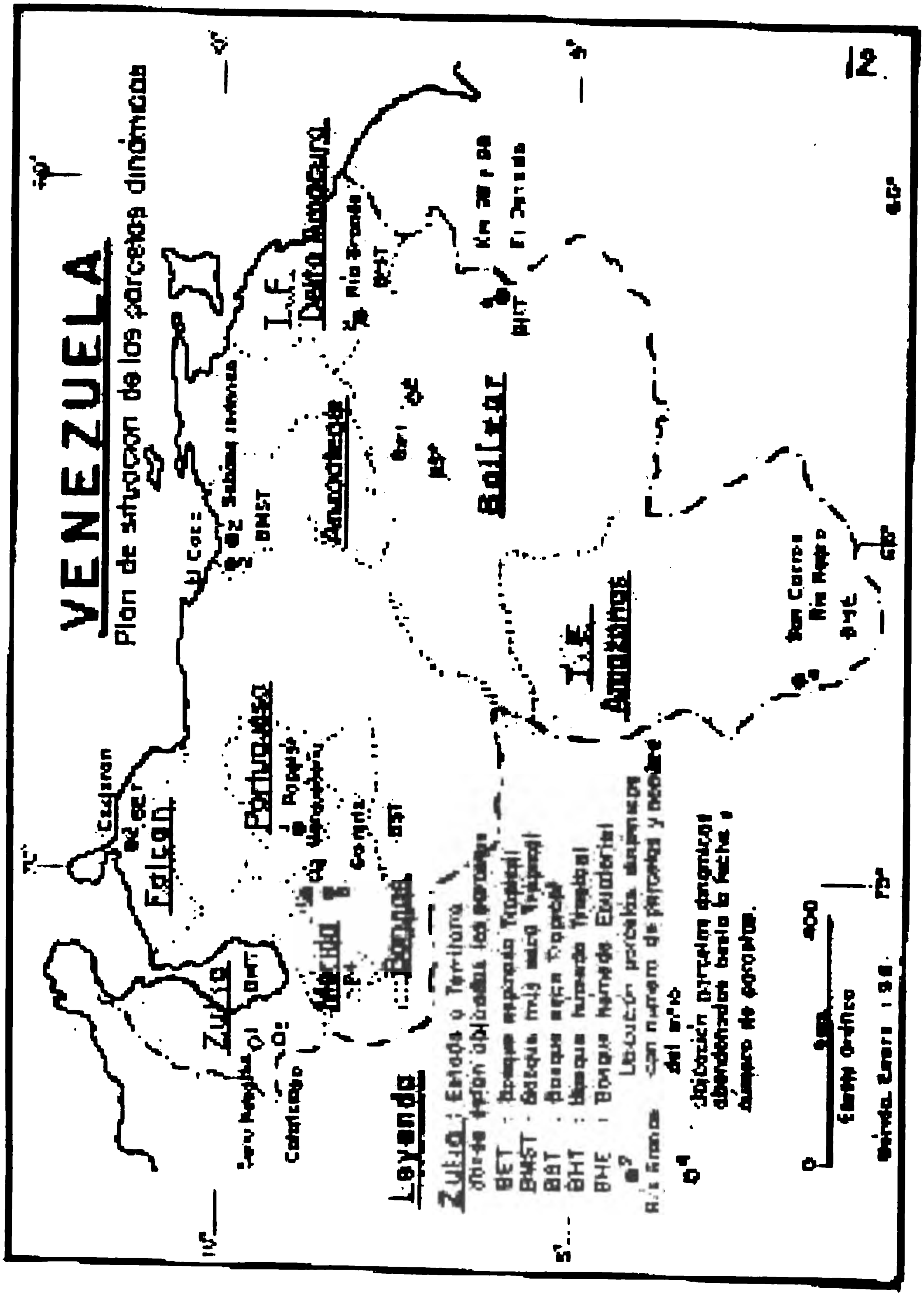
ANNEXO: MAPA VEGETAL DE VENEZUELA



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