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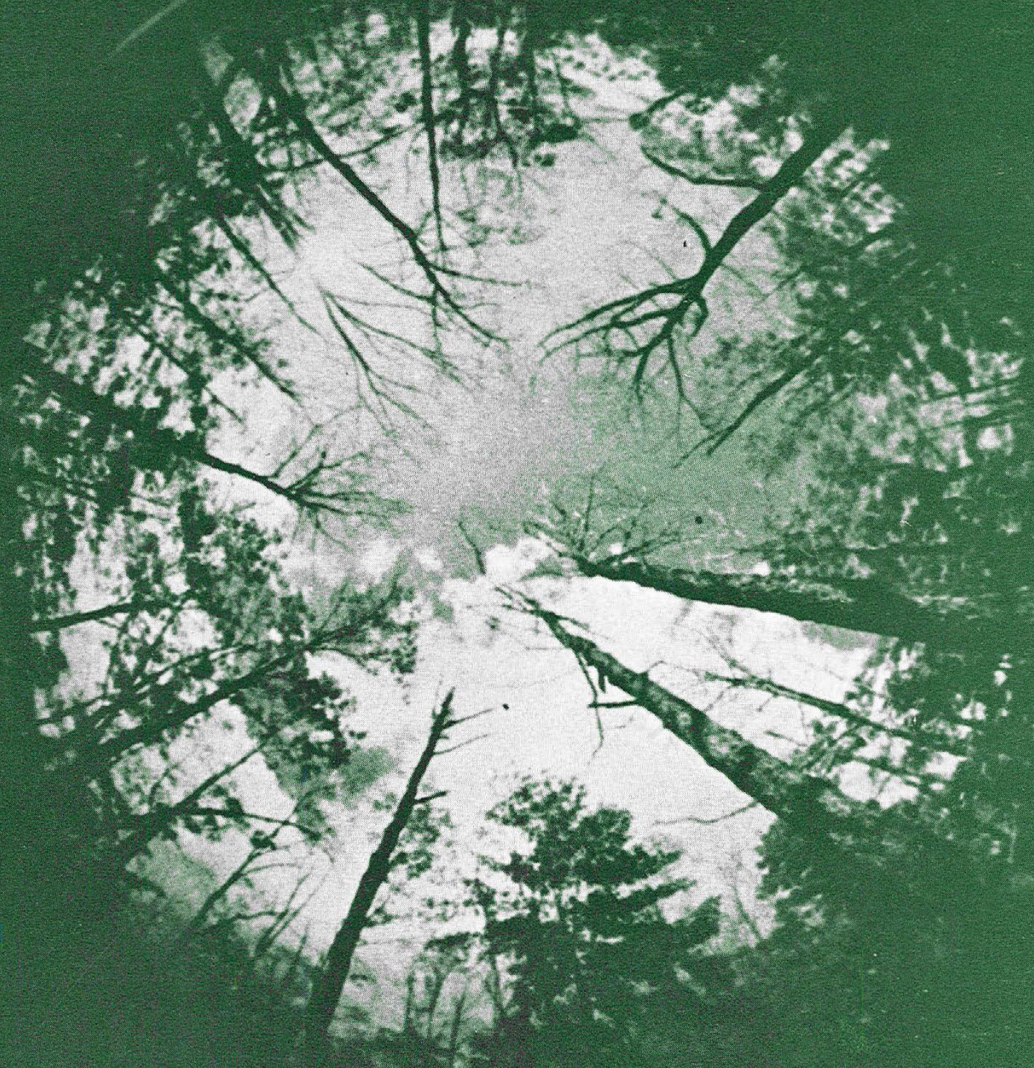
ENVIRONMENTAL INFLUENCES ON TREE AND STAND INCREMENT

Proceedings of the
Mensuration, Growth and Yield
Instruments and Methods in Forest Mensuration
Workshop



September 23-27, 1985
Durham, New Hampshire USA

Editors: Dale S. Solomon
Thomas B. Brann

ENVIRONMENTAL INFLUENCES ON TREE AND STAND INCREMENT

Proceedings of an International Conference

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Sponsored by

International Union of Forestry Research Organizations
S4:01-00 Mensuration, Growth and Yield
S4:01-06 Instruments and Methods in Forest Mensuration

U.S. Forest Service
Northeastern Forest Experiment Station

Ruth E. Farrington Forestry Fund
University of New Hampshire
Department of Forest Resources

Society of American Foresters
Biometrics Working Group

Editors:

Dale S. Solomon
Thomas B. Brann

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A special note of appreciation is extended to those who were cooperative to make the meeting a success.

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PREFACE

An international conference on Environmental Influences on Tree and Stand Increment was held at the University of New Hampshire, Durham, New Hampshire, USA between September 23 and 27, 1985. The meeting included recommendations from a previous I.U.F.R.O. meeting in Vienna, Austria.

Demands for forest resources are increasing but the forest land base is constantly decreasing. Timber supply can be increased by more effective management but it may also be decreased by insect and disease infestations or environmental influences (atmospheric deposition, drought, soil erosion, etc.). Due to the decreasing land base of this resource, any detrimental influence to timber supply compounds the reduction of the overall productivity of the forest. Techniques and methods for measuring the forest resource and projecting growth over time are important in order to determine the magnitude of this loss of productivity.

The objective of the conference and resulting proceedings was to provide a forum for the international exchange of research methodology by scientists working on the mensurational aspects of forest tree and stand increment. Understanding how to measure a tree and project its growth increment over time, in concert with other neighboring trees, is a formidable task. The conference was organized so that presentations would proceed from the basic "tree" to the complex "stand".

The conference included discussions by practicing mensurational and biometrical specialists concerning the techniques and methods of measuring tree and stand increment. It also included the use of these techniques in predicting future growth, and changes in that growth which occur as a result of external stress or changes in the environment.

DALE S. SOLOMON
Chairman IUFRO
Working Party S4.01-06

TABLE OF CONTENTS

Submitted Papers Not Presented

OPENING REMARKS

Denver Burns
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How important are measurements in today's society? A trip to the grocery store requires a person to scrutinize the labels to make sure they obtain the best buy in money per unit measure of a given product. Ask the person buying a car as they check the stickers for the miles per gallon figure for each model. As our products become more costly, the measurements of those products become more precise. Similarly, as our forest resources become more valuable, the ways we measure those resources must become more exacting.

Mensuration is defined as "the act of measuring". However measuring a living, growing organism presents an additional dimension. From a microscopic cell to a giant redwood, growing trees develop different parameters to measure volume and value. What or where is the best place to measure a tree? Root collar diameter, diameters at 1.3 meters, total height, foliar weights and biomass volumes are some of the measures presently used to measure tree growth. Since we take these measurements with a wide range of instruments and singly or in combination, the data from the "act of measuring" can be very overwhelming.

Why do we take all these measurements? One answer is to gain an insight as to the growth characteristics of trees within a forest stand. These growth characteristics then indicate directions for long term management decisions such as harvesting schedules, and regeneration needs. Measurements also indicate whether optimum growth is occurring on the site or whether thinning operations are needed to improve the rate of growth. As the world resource of trees becomes not only scarce but more valuable as a commercial product, mensurational data becomes the critical part of the decision making process.

We attempt to measure and predict unhampered growth of a stand of trees over an "average" site, under "normal" weather conditions and with no distinguishable external factors such as fire, insect attack, disease epidemic, etc. However, we all know this may not always be true. In the past, white pine blister rust and chestnut blight have severely affected the composition of our forests in the East. Beech bark disease (<u>Nectria coccinea</u> var. <u>faginta</u>) and shoestring root rot (<u>Armillaria mellea</u>) are two other pathogens affecting our forests and where we have active ongoing research. Insect attacks have also impacted our eastern forests. Gypsy moth (<u>Lymantria dispar</u>) and spruce budworm (<u>Choristoneura fumiferana</u>) epidemics have been the subject of extensive research programs over the last ten years. CANUSA, a cooperative international research program between Canada and the USA has placed major emphasis on the field of mensuration--measuring the impact of the stress caused by these enemies of the forest.

Most recently, we are confronted with an insidious agent in atmospheric deposition. To measure the effects of atmospheric deposition one needs to be able to discriminate among the various causal agents involved. Large quantities of money are being expended by countries around the world to obtain data on how to measure the effect of this and other pollutions. The consequences of these answers have far-reaching economical and political implications world wide.

The era of the "crystal ball" approach or using the old field foresters "feel" for the situation in making management decisions has passed with time. From programmable calculators to huge computers, we now have the ability to assimilate billions of pieces of data in short periods of time. This capability is useless, however, if the data is improperly taken or if the cause and effect rationale behind the data is faulty. Multi-million dollar programs of research demand facts. The data behind these facts must be sound enough to use as a basis for decisions that have long term significance. Weak data equals poorly founded facts which, in turn, equal incompetent decisions.

Faulty management decisions made for such long periods of time can spell disaster for our natural resources. This is why the U.S. Forest Service has such as overwhelming interest in this field. We are committed through our own research people, through co-operative agreements with universities and private companies, and through joint work efforts with other federal agencies such as the Environmental Protection Agency, Soil Conservation Service (other agencies) to achieve reliable mensurational data on tree growth response.

International meetings such as this serve a valuable function in that they bring forth the research as well as the researchers from around the world to talk about this present research and latest results on ways of measuring one of our most valuable resources.

MENSURATION: THE FOUNDATION FOR INTERPRETING ENVIRONMENTAL RESPONSES

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Abstract--Forestry and Mensuration as one of its sub-sets, have over the years been highly subject to the pursuing of fashionable trends and fads. Using this idea, the author enumerates a number of developments in Forest Mensuration that have been caught up in faddism and have, as a result, fallen short of their potential. It is the thesis of the paper that before Mensuration can become "The Foundation For Interpreting Environmental Responses", changes will have to occur in the way problems are approached, the way new technology is promoted and in the way technical specialists are trained. The author approaches his title more as a question, than as a statement and using organizational analysis shows how the problem of over specialization leads to compartmentalized thinking and limited application of new technology. The paper concludes with a number of suggestions that the author believes will aid Mensuration in meeting its obligations and goals.

Keywords: Mensuration, biometry, education, organization.

INTRODUCTION

It is generally understood that the world's forests are under severe pressure. While the reasons vary from nation to nation, and while the outcomes have different implications, the solutions to the problems that are caused by the pressure must be founded in the knowledge we have about the forests in question.

Forests are not the only segment of the environment, however, that are under stress. Nearly all of the sub-systems of the environment are involved. We know a great deal about the nature of forests but there is much we don't know. Because of the unique nature of the forest, i.e., their long life, the fact that they accumulate responses to climate, pollution, depradations and other external characteristics, etc., the forests of the world could well be one of the keys to the understanding and interpretation of much of the environmental stress mentioned. If forest mensuration, as a body of science, had developed as the result of a rational plan, we would be of much more service to the rest of the scientific community than, I think, we presently are. Thus, I want to start by rephrasing my title so that it reads as a question, i.e., Is Mensuration the Foundation for Interpreting Environmental Responses?

Forestry, like many other fields of science has been highly subject to faddism. Mensuration, as a sub-set of forestry has shared in this fascination with fashion. It is my view that our preoccupation with such fads and fashion limit our scientific ability to contribute as we should, and as a result we fall short of our potential. The problem is one that centers around the idea that science is a highly rational system that operates in organizations that themselves are highly rationale. One might conclude from this, that the net result of the interactions between these two systems would be an orderly and progressive development. The fact is, that is not the case, and one of the major reasons that we, as mensurationists are not ready to take our place in the developing discoveries on environmental management is due to the fact that our efforts are so fractionated. It is going to be my thesis today that Forest Mensuration should be the foundation for interpreting environmental responses, but, before it can, we as technical specialists must rise above the tendency towards fads and fad promotion. We will have to avoid specialized and compartmentalized thinking and approach our tasks from a more wholistic or complete perspective.

In order to accomplish my task, I'm going to look at several factors that I think contribute to the present state of affairs and then make some suggestions that I think might help the profession in addressing these problems.

HOW WE DESCRIBE OUR ENTERPRISE

To begin with, we have over the years, been pretty sloppy with our definitions. As a teacher, I have always told my students that sloppy definitions were indicative of sloppy thinking. Perhaps the easiest place to demonstrate this is in the area of sampling. A quick review will indicate that the sampling system suggested by Walter Bitterlich is variously known as point sampling, horizontal point sampling, plotless sampling, variable plot sampling, angle gauging, Bitterlich sampling and some of my students even call it "pointless sampling", who can blame them, when we have allowed so many different terms to be used for the same concept?

Recently, while working with the Society of American Foresters/American National Metric Council's Forestry Sector Committee, we found that the terminology associated with the scaling practices, for example, in the United States was so variable, that it was deemed necessary to publish a set of definitions as a preamble to a standard scaling practices guide that we were developing. Inherent in the process of developing plans to convert from one measurements system to another is the chance to improve, somewhat, on the irregularities with which we have all grown so accustomed. The point here, is that until we, as measurements specialists, recognize that there are some basic problems with the way we describe things we can't expect to be seen as really competent scientists, or can our work be seen as a foundation.

The problem is not confined to the definition of terms either. The very name of our subject is undergoing subtle changes, which is not the product of any well thought out scheme, so far as I can determine. The result is, that at this very moment, I'm not sure if I'm communicating with you when I use the word mensuration. If one studies the college catalogues from the various schools around the country, it can be seen that there is a subtle change going on in the name of the subject that we are generally here to discuss. The traditional courses have had names like Mensuration I and or Measurements II. The content of those courses included qualitative and quantitative product measurements concepts, i.e., logs, poles, firewood, pulpwood, etc. Other items included in those courses were volume concepts, growth and yield, measuring and predicting, elementary surveying, state and plane coordinate systems, application of statistical decision making, etc. These courses were traditionally the place where beginning foresters learned their basic woodsmanship. The teachers were in the woods with them, nurturing them in the understanding of the particular characteristics that were being taught. Mensuration was a field oriented and tree based subject that included a great deal of the "smelling, touching and feeling" that has been so much a part of the "Art" of forestry.

I will never forget my mensuration teacher, Michel Afanasiev, (a Russian immigrant) who believed that to teach forest measurements one had to be in the forest. He would say to us when we asked him what we were going to do on a particular day, "Today bois (there were no females in those days) we ville go to the voods!" As I talked with foresters all over the world, I find that invariably, they make reference to their mensuration teacher and their experiences with the subject, when asked to reflect on their educational experiences. A careful analysis of those responses, however, shows that it wasn't the personality so much as it was that mensuration was the point at which their perceptions of career choice and reality began to come together. In other words, the basic role of mensuration has been more than the learning of how to measure trees and forests but has been the foundation for the beginning understanding of the nature of trees, forests and forestry.

Today the fad is Biometrics. Mensuration courses are having their names changed to Biometry I, Biometrics and Growth and Yield, etc. If you study the vacancy advertisements in the trade journals you will see that the measurement positions at the American universities are for Biometrists not Mensurationists. I've not talked with a teacher of graduate students in the measurements field for years who says he/she is teaching Mensurationists. They are teaching Biometricians.

One might conclude that these are the tirades of an old timer who hates to see the "grand old profession" change. I don't think so. Let me explain.

One of the oldest definitions that I have found for Forest Mensuration is a combined definition and scope statement in Belyea (1931). Forest Measurements is:

> "the branch of forestry which considers the measurement of forest products ... and is defined as the science which deals with the determination of the volume of trees, and stands. It thus concerns itself not only with the probabilities of the present exploitation but also with the possibilities of the future utilization."

This definition was approved by the SAF and stood as its definition for the subject from about 1919. In 1971, the SAF document on terminology defined forest measurements as:

"that branch of forestry, concerned with the determination of the dimensions, form, increment, and age of trees, individually or collectively, and of the dimensions of their products, particularly logs and sawn timber." (Ford-Robertson 1971).

One can see that while these definitions are pretty consistent, considering the time involved, they certainly are not inclusive of what most persons would consider should be included in the subject today. Sampling, as a subject is only suggested for an example. On the other hand, the courses and the text books over the years have included those subjects.

The term biometrics or biometry is a relatively new one on the scene. As our field became more sophisticated, as labor intensive systems became less attractive, and as we plugged into the explosion of graduate education, more and more of us beeame enamoured with what we could do with the increased applications of the statistical sciences and with computers. As more and more of us gained training in the statistical and computer sciences, some way somehow we coined a new name. In simple terms, it was the application of advanced statistical procedures to our particular set of interests. While it is difficult to find an authorative and widely accepted definition, the following definition given for biostatistics will suffice:

"The application of statistical methods to the solution of biological problems." (Sokal and Rohlf 1973)

In their new book for entry level forestry Nyland, et al. (1983) discuss the general situation and confine biometry to the subject that "deals more with mathematical models, statistical analyses and probabilities, and computer simulation to represent forest conditions and to suggest how these change over time." It seems to me that this is an expression of understanding. The problem remains, however, is biometry also mensuration? The key to the issue is that if mensuration is to be the foundation, etc., then it is really important that the measurements aspects and the statistical applications aspects don't subvert each other. I am suggesting here that they are inadvertantly doing just that, as we try to come off as a sophisticated science. When we concentrate the training of the next generation in small segments of the total field, there is no way for the field to retain its breadth. Without that breadth there is no way, in my opinion, for the field, whatever we call it, to ever attain its potential as the foundation for interpreting environmental responses. I will predict, that if we don't make a major concentrated effort to retain the breadth implied in the 1971 definition of mensuration, that within a few years, foresters will learn all of their woodsmanship in the office, at the keyboard to a computer and will perhaps not realize that the basic parameters deal with trees. While there may be many among this audience that think forestry and forest mensuration need to take off their boots, I, for one, would think that a pity.

THE WAY WE PROMOTE OUR IDEAS

Another area that contributes to the field's inability to attain the goal of foundation for interpreting environmental responses, is the way we promote the ideas we develop through research. I will identify a couple of historical examples and then later discuss the reason for the reactions that occur. Let me focus on an idea that was quite popular some thirty years ago. I'm sure some of you remember the development of the Lake States Continuous Forest Inventory (CFI) System. It was developed in Wisconsin, primarily for Lake States Hardwoods by the USFS. The project developed a procedure, based on European practice, modified for the Lake States. As the system became more and more popular, the development team published a newsletter that was designed to promote the use of the procedure and a mailing list that was national in scope. The Lake States CFI system became rationalized and before long the newletter was suggesting that if the inventory system did not follow the exact procedures as proposed then it was not CFI. The system had certain characteristics that were, in my view, short sighted, such as fixed radius plots, plots that were painted with numbers on every tree, and painted routes to those plots, etc.

At one point in my career, I had the task of designing an inventory for a major industrial ownership in the south and I wrote the Lake States team of the USFS to ask about some variations that I was considering. One variation was to use concealed horizontal points and the other was to make use of a dendrometer on individual trees, in order to cut down on the number of sample points established. The answer I received was that while those things might work in my situation, I would not have a CFI system and implied in the response was an overtone that it would not work, since I was not going to follow the approved and promoted system. After a number of years the newsletter began to carry procedures on how to set up additional samples to be used to determine if the base plots had received prejudicial treatment. What that meant of course, was that the readily identified plots were being treated in a non-representative way and in my view at least, this could have been prevented with concealed plots.

The major point that I want to deal with in this example is that while the design group had a brilliant idea that had the making of a major contribution to mensuration as the foundation for interpreting environmental responses, rigid applications of rules and regulations killed it! Industries all over the eastern U.S. had established the "CFI" system as promoted, with little real understanding of what they were doing. Managers began to extrapilate inferences to their forests that the system was not designed to allow for and when they found that their results were not verifiable, rather than to modify the system, they abandoned it. This particular problem was caused by the fact that in most cases the managers were not current in inventory design and were mesmerized by the flashy reports that were generated by the computer. The managers really did not understand what they purchased when they paid for the new inventory system.

It is my belief that the mensuration folks were guilty here of overpromoting a system that was good, from our point-of-view, but we were short in our understanding of what the manager's needs really were. Had we not promoted the CFI system the way we did the chances of it falling into disuse so rapidly would have been less. It is mind boggling to think about what kind of data base would now be available had all those CFI systems been maintained. Think of the contribution that could be made to the present problems of acid rain monitoring, pollution impact, etc., with a twenty five year data base that had been made up of remeasurement data on five or ten year intervals over several hundred ownerships in the eastern U.S.

Another example that we are all familiar with, that demonstrates the promotional problem in forest measurements, is that of dendrometry and the STX computer program developed at the USFS Southern Station and promoted by the USFS Division of State and Private. About the time the Lake States CFI system was going well, Grosenbaugh and Wheeler were colleagues at the Southern Forest Experiment Station. Each of them devoted a great deal of time to the development of a dendrometer. Wheeler worked on the penta-prism while Grosenbaugh developed the Barr and Stroud short base rangefinder. The Barr and Stroud was and is a marvelous instrument, but, it has several limitations due to the complexity of the theory associated with its operation. Forestry organizations all over the country rushed out and purchased instruments in order to be caught up in the then current fad. I have no way of estimating how many instruments were purchased but the one I have is number 324. If one were able to determine how many of these instruments were currently being used, I believe they would find that there were an awfully large number of them that are simply occupying shelf space now.

It could be concluded, that because the dendrometers are not now in use that there was little place for them in modern forest measurements but I'm sure you would agree that is not a logical conclusion. The problem was that because there was such a high investment in the development of the instrument and the associated STX program that to justify the expense there had to be a major effort to expand their use beyond the rather limited objective for which they were designed. Once folks got into the system, like the Lake States CFI, they found that the information they got out was not what they needed and as a result they dropped the use. This is a pity because there are many situations in the forest inventory task where single tree dendrometry is a very desirable solution to a problem.

Because of the bad experience with the Barr and Stroud and the STX system, few folks consider dendrometry as an option in inventory planning today. Think of the data base that might have been available had the system not been oversold and thus lost. I am familiar with one situation in the South where they have maintained a dendrometer based inventory now for over twenty-five years that includes diameter outside the bark measurements for over 3000 trees, at each of four locations along the stem. They not only know how their increment at DBH has changed but they can describe the diameter performance (taper) at the top of the first log, at the original sawlog merchantable top, at the original pulpwood merchantable top, etc. With that sort of information on a wide scale, think how we could have helped to address the problems or monitoring long term environmental changes, how we could validate our present day empirical taper models, and think how we could have helped our managers make decisions on how best to allocate the cubic volume of the standing inventory? In the Southeastern U.S. where the U.S. Forest Survey has developed a dendrometer based inventory system, they have been able to generate many more documents that relate to the changing technology and management demands of the present day, than have the others. The recent round of publications on biomass, species taper equations, etc., are but an example of how flexible such a system can be. I chose historical examples because I believe it is easier to evaluate from that perspective. We are still doing it, however, think of how many standardized growth models are being promoted as "your answer".

ROLE OF ORGANIZATION

Let me turn now to focus on what I consider to be some of the major contributing factors to the problems I have tried to identify. Foresters in general, work in large bureaucratic organizations. Most of us, in the mensurational sciences, are employed in public bureaucracies at that. While these various big organizations differ in size, product, age, and tradition, they all are quite similar in form, procedure and the claims they make upon members for loyalty and consistency. Generally, they are large, specialized, and are arranged in a hierarchy. They create status anxiety amongst their members, they are run by a few (oligarchy), they use co-option (i.e., the selection of successors by a few) and they promote efficiency and rationality. These big organizations provide a distinctive psychological climate in which authority and status are nicely differentiated. Ideally, there is very little ambiguity in a bureaucratic organization.

What does all this mean for our current discussion? Social scientists have established that as societies increase in size, density and urbanization, the division of labor increases rapidly. This is due to an intense competition between participants. By structuring the world around us into smaller segments we are better able to cope with that competition. Our organizations support this trend in specialization by assigning more status to the specialist. As the process of specialization develops, there is an increasingly higher amount of alienation because the skill demands for each job are reduced through routinization. Efforts to reduce alienation result in organizational behavior.

Hierarchy is a system for ranking positions along descending scales from higher to lower. According to Weber (1953), hierarchy has its roots in the routinization of Charismatic authority. The process brings with it rules and regulations that limit the discretion of each succeeding official. Since the positions in the organizations are scaled according to the hierarchal arrangement, participants respond to that organization in predictable ways. The so called "publish or perish" syndrome in the research universities is derived from this arrangement. I dare say that nearly every one of us here can relate to these ideas at one level or another. Another organizational response has to do with the establishing of accountability systems. As the organization we work for, strives more and more for an equitable, accountability system, they force us into behaviors that are essentially not part of the goal system. The easiest example of this can be seen in the oft times quote of the college professor who says "This would be a great place to work if it weren't for the students".

It is because of these organizational patterns that the ideas of fads and fashion take hold in our enterprise. The rules and regulations that are designed to make us comply also cause us to behave in an organizational way. We wind up promoting ideas for organizational reasons rather than for reasons of science or equity. Our very ideas become routinized and we have difficulty in developing adaptations for applications outside of our experience, rather we attempt to structure the outside situation to our unique and limited understanding. Such behavior, limits the ability of the mensuration specialist to provide the breadth of knowledge that is inherent to the field.

Recently, Virgil Baldwin (1983) in an address to the Southern Forest Biomass Working Group Workshop, made an interesting analysis of how changes in education of foresters in the area of biomass studies have taken place. He studied section titles in the most popular mensuration textbooks over the last twenty-five years and concluded that the subject had received increasing attention over the years. I have done the same thing but with a different focus. I've been concerned with how much has been left out as our technology has grown. My conclusion is that we are forgetting that the basic parameter that we work with is the tree. Tree measuring and product measuring are giving way to taper models and mathematical assumptions, growth measuring is shifting to growth modeling. The cause of this is specialization, routinization and the other organization imperatives. It is my contention that if forest mensuration is to become the foundation for interpreting environmental responses, we are going to have to be more careful in how we allow ourselves to fall into the trap of specialization and into the processes of fad promotion.

SUGGESTIONS

Simply to criticize the system without suggestions for remedies is of course, not responsible. Let me conclude my remarks by making a few suggestions that I believe will help forest measurement specialists realize their potential in becoming the foundation for interpreting environmental responses.

First of all we need to recognize and articulate the problems. We need to become more philosophical. Then, we need to work diligently at the task of improving the way we describe our technology. It seems to me, that there is sufficient reason to have a standing committee on mensuration terminology, probably at the international level. That group could also work at maintaining a working definition of the subject as a whole, so that we don't inadvertently change the nature of our business. Please note the use of the word inadvertent. I am not at all opposed to seeing the subject as defined, change with changing times. What concerns me, is that the changes should be the result of rational and intentional design, rather than a response to organizational behavior. The changes should be in the best interests of the forests, not of the forestry organizations or the status of the foresters in the organizations.

Secondly, it seems to me that we should establish some form of an association between those persons that teach the undergraduate level courses in forest measurements. Through that association, the teachers could interchange ideas about the balance between technical and theoretical information. Through such a group the young, highly but narrowly trained teacher could have the opportunity of interacting with the less specialized more practical older teacher. It is important to note that these relationships are relative over time. Such opportunities for mutual benefit would do a lot to interrupt some of the narrowness that is seeping into the field. It would also help the elder folks in the business too, in that it would help them focus on the changes that they are too often reluctant to consider. The major point is, however, that the emphasis of the group would be on the exchange of ideas related to teaching mensuration rather than on research. In this way, they would be working continuously at defining the field, and to my way of thinking, this would help to prevent the inadvertent changes. It would also ensure that generations of future foresters still have the opportunity to relate theory with reality by helping to bring those divergent ideas together.

I am not naive, and recognize that such a suggestion runs counter to the organizations for which we work. In general, matters related to qualitative teaching contributions are relegated to a pretty low priority since they do not produce peer evaluated publications, the hallmark of the research organization. If we want the result we will have to dare to challenge the organizational environments in which we work. This is of course the key. To do this we must become students of organization.

Another more radical idea would be for the SAF to impose non-academic work experience requirements for the faculties of accredited schools. This, in and of itself, would not solve all of the problems but it would be a start. Another idea that may have less political appeal but that would certainly impact the nature of our enterprise would be to eliminate undergraduate instruction at all but about twenty-five or thirty schools. In so doing the "chosen" schools could have a sufficient critical mass of both students and <u>balanced</u> general interest faculty so that the operatives of over-specialization would not be so critical. These few schools would become specialty houses in undergraduate instruction and would provide a more uniform and more broadly based product to the research institutions. While I might hesitate to make such a suggestion in the environment of my own institution, I think here and in this role it is all right.

Another thing that can be done with little or no organizational implications, is to assume the responsibility as trainers of new persons entering the field, to see that our programs include opportunities for neophytes to learn how to evaluate research needs prior to turning them loose in society. Much of the problem comes from the fact that the reward system places high priority on publications. Young faculty and researchers, in general, can produce a larger number of quick publications if their work relates to their dissertation area regardless of its relative importance. The results are obvious. Frequently the right questions are never asked, in developing research programs so our people simply go further down the specialized road.

A final area for improving the breadth characteristics of the field, lies in the area of research administration. Too frequently, research administrators are not too effective in transmitting the organizational goals and objectives. There is a tendency to let new researchers, and old ones for that matter, do what they want to do, rather than to help guide them towards the highest priorities. We need to see that our research administrators are given every opportunity to broaden their own understanding and skill in the administrative sciences. They must be taught how to administer research programs.

As technical specialists, primarily providing information on a wide variety of resource data for a wide variety of owner objectives, etc., we need to become much more understanding about the nature of the enterprises we are servicing. Mensuration and the sciences associated with it really have no intrinsic value, hard as that is to say and to accept. Yet, we must realize that fact, and remember that the decisions being made about the future of the forests of the world depend on the quality of information we provide. It is my view at least, that the responsibility for the quality, quantity, and form of information available lies with those of us that call ourselves mensurationists. We will either promote our fads and pursue the fashions of the day that are the product of organizational behavior or we will rise above all that, broaden our understanding and become the true Foundation for Interpreting Environmental Responses. At that time we will be true professionals rather than organizational, driven technicians. Thank you for your patience.

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METHODS FOR MODELING WHOLE STEM INCREMENT[1]

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Abstract--Models for whole stem increment were constructed from both stem profile models and a biological hypothesis of the increment's vertical distribution on a tree stem. Both modeling approaches appear to provide reasonable results. The models based on Pressler's hypothesis provided better diameter increment estimates than the stem - profile - model - compatible increment models.

Keywords: Taper, tree increment, mensuration.

INTRODUCTION

Almost all individual tree stem diameter or cross-sectional area increment models have been concerned with modeling increment at breast height. While these models have proven useful, they are not complete since growth occurs at all points along a tree stem. This omission becomes more critical, from a modeling and management standpoint, as the increment at breast height provides less information about the increment along the rest of the bole. A more complete and potentially more reliable modeling approach would estimate diameter or cross-sectional area increment along the entire tree stem.

Mitchell (1975), working with Douglas-fir, estimated total bole increment as a function of foliar volume. Once the total volume increment was estimated, its allocation to the bole followed Pressler's growth hypothesis (Larson 1963). Pressler's hypothesis states that

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[1]The authors wish to thank the Weyerhauser Company for their support in this study.

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cross-sectional area increment at any location on the tree stem is proportional to the amount of foliage above that location.

The concept of model compatibility has gained wide acceptance in forestry. Two or more models are said to be compatible if they provide numerically equivalent results using different approaches. This compatibility concept can be used to construct whole stem diameter or cross-sectional area increment models from existing stem profile or taper models.

The objectives of this study were to construct stem-profile-model-compatible whole stem diameter or cross-sectional area increment models and compare them to increment models based on Pressler's hypothesis.

METHODS

Data

The felled tree data used in this analysis were provided by the Weyerhauser Company from their Alikchi loblolly pine (*Pinus taeda* L.) plantation study area in southeastern Oklahoma. Approximately 2150 trees were planted per hectare. The average site index base-age 25 was 18.3 meters. Fifty 14-year-old sample trees were selected from two previously unthinned 0.08 hectare plots.

After diameter at breast height (dbh) was measured to the nearest mm, the trees were felled and total tree height and height to the base of the live crown were measured to the nearest 3.0 cm. The trees were bucked into 1.2 meter sections, an approximately 2.5 cm thick disk was cut from the bottom of each section, and the height (to the nearest 3.0 cm) of the disk was recorded.

In the laboratory the number of rings on each disk and the width of each ring (nearest mm) were determined.

Compatible Models

A stem profile model is compatible with a whole stem diameter or cross-sectional area increment model if the stem diameters determined by the profile model are the same as the diameters determined by the increment model through accumulating the growth increments. This concept suggests that annual whole stem diameter or cross-sectional area increment can be modeled as the annual difference in diameter or cross-sectional area at a given height on a tree stem as determined by a stem profile model. Using this definition, whole stem diameter or cross-sectional area increment models can be expressed as

$$\begin{aligned} \Delta d_h &= d_{h,t+1} && H_t \leq h \leq H_{t+1} \\ &= d_{h,t+1} - d_{h,t} && 0 \leq h < H_t \\ \Delta ca_h &= ca_{h,t+1} && H_t \leq h \leq H_{t+1} \end{aligned} \tag{1}$$

$$= ca_{h,t+1} - ca_{h,t} \qquad 0 \leq h < H_t$$

where Δd_h = annual diameter increment at height h,

$d_{h,t+1}$ = stem diameter at height h in year t+1,

$d_{h,t}$ = stem diameter at height h in year t,

Δca_h = annual cross-sectional area increment at height h,

$ca_{h,t+1}$ = stem cross-sectional area at height h in year t+1,

$ca_{h,t}$ = stem cross-sectional area at height h in year t,

H_{t+1} = total tree height in year t+1,

H_t = total tree height in year t.

The difference form of the growth model was chosen over the differential form for two reasons. First, growth, as it was considered here, is the annual difference in diameter or cross-sectional area along the entire stem. The stem growth which accounts for this difference is not continuous throughout the year. Therefore, the difference equation appeared to be more appropriate. Second, most stem profile models are constrained such that $d_{h,t} = 0$ when $h = H_t$. This constraint is passed along to the differential growth model in the form of $\partial d_{h,t}/\partial t = 0$ when $h = H_t$ which seems biologically unreasonable.

Several stem profile models were chosen from the literature for this study. These models covered the one-equation, segmented and total-volume compatible categories. The one-equation models were Kozak and others (1969), Ormerod (1973), and Amidon (1984). The segment models were Max and Burkhart (1976) and Cao and others (1980). The compatible models were Goulding and Murray (1976) and Cao and others (1980).

Pressler's Hypothesis Models

The second method for modeling whole stem diameter or cross-sectional area increment was based on Pressler's hypothesis. Models based on Pressler's hypothesis can be expressed in the following general form:

$$\begin{aligned} \Delta ca_h &= Q & 0 \leq h \leq CH \\ &= Q\ (THT-h/THT-CH)^{\beta} & CH < h \leq THT \end{aligned} \qquad (2)$$

where Q = annual cross-sectional area growth between ground level and crown height,

THT = height on the tree stem where $\Delta ca_h = 0$ when h = THT,

CH = height to the live crown,

β = model parameter ($\beta > 0$).

This general model form accounts for the main components of Pressler's hypothesis. Cross-sectional area growth is constant below the crown. Within the crown, cross-sectional area growth decreases from the bottom to the top. Cross-sectional area growth is equal to zero at the top of the tree and below crown growth (Q) at the base of the crown. The model parameter allows the cross-sectional area increment to increase at an increasing, decreasing, or constant rate from the top of the tree to the base of the crown.

Based on this general form, two increment models were evaluated in this study. The first model is from Mitchell (1975). The second model based on Pressler's hypothesis has the form:

$$\begin{aligned} \Delta ca_h &= \Delta BA & 0 \leq h \leq BCH \\ &= \Delta BA\ (H_{t+1}-h/H_{t+1}-BCH) & BCH < h \leq H_{t+1} \end{aligned} \tag{3}$$

where ΔBA = annual basal area growth,

BCH = height to the base of the live crown.

This model differs from Mitchell's version of Pressler's hypothesis in several ways.

Mitchell specified the below-crown increment so that it was compatible with a tree's total bole volume increment. Model (3) uses basal area increment as an estimate of below-crown increment. If cross-sectional area growth is constant below the live crown, then the increment at any point along the bole below the crown should be indicative of that growth. Since diameter at 1.37 m is commonly measured, basal area increment was selected as a second estimate of cross-sectional increment below the crown. This assumes that crown height is above 1.37 m and butt swell does not significantly affect increment at breast height.

Mitchell contended that cross-sectional area increment over most of the terminal leader is negligible, therefore, increment was not specified over the entire stem. He used $H_t + (H_{t+1}-H_t)/3$ as the height on the stem above which $\Delta ca_h = 0$. We decided to use total height at the end of the annual growth period (H_{t+1}) since there is some cross-sectional area above Mitchell's height albeit quite small.

Mitchell assumed that $\beta = 1$, implying the increment increases at a constant rate. The assumption of $\beta = 1$ was necessary to make the total bole increment constraint easier to incorporate into his model. With basal area increment as the below-crown increment estimator, we tested the hypothesis that $\beta = 1$ vs. $\beta \neq 1$ and concluded that $\beta = 1$ ($\alpha = 0.05$).

Model Fitting and Evaluation

All whole stem increment models were fitted to the stem-analyzed data using either linear or non-linear least squares. The last annual increment prior to tree felling was used in this analysis since crown information was gathered at tree felling.

These same data were used to compare predicted diameter increment with observed diameter increment for all increment models reported in this study.

The models were compared in terms of average bias and mean absolute deviation (MAD).

RESULTS AND DISCUSSION

Table 1 shows the results of the error comparisons made on each whole stem increment model in this study.

The whole stem increment models based on Pressler's hypothesis have less total error (MAD) than do the compatible stem increment models. Two reasons probably account for most of these differences. First, there is no mechanism in the compatible increment models for relating tree stem growth to a tree's crown. Since the pattern of growth within the crown appears to be quite different from the pattern of growth below the crown, some mechanism should be present to delineate the separate patterns. Current stem profile models and their compatible increment models contain no explicit crown information, and consequently cannot distinguish between the two patterns of growth. Second, current stem profile models do not allow tree form to change with changing growing conditions (Newberry and Burkhart 1986). If predicted tree form remains constant from year to year, or tree to tree, then the implied pattern of growth cannot be flexible enough to fully describe the actual pattern of stem growth.

The increment models based on bole volume increment generally provided better results than those models based on dbh or basal area increment. The whole stem increment models based on the stem profile models of Goulding and Murray (1976) and Cao and others (1980) as well as Mitchell's version of Pressler's hypothesis utilize bole volume increments. Total bole volume increment implicitly accounts for growth along the whole stem. Therefore, it seems reasonable that models based on total bole volume increment will estimate diameter increment better than the models based on dbh or basal area increment.

The segmented stem profile models of Max and Burkhart (1976) and Cao and others (1980) did not provide whole stem increment models that were any better than the simpler increment models. The segmented increment models presented here were derived from stem profile models with one join point. The fitting procedures used in this study never converged in the two join point case. With a larger data base and the more complicated model form, the results could change. In addition, the join points obtained for these two segmented models were approximately five percent of tree height and, therefore, had only minor impacts on increment

Table 1. Error analyses for predicting inside-bark whole stem diameter increment for 50 trees from the Alikchi study area. Increment models were derived from Pressler's hypothesis and stem profile models.

Model	N	Bias	MAD
Pressler (Mitchell 1975)	422	0.04	0.13
Pressler (Eq. 3)	422	0.07	0.16
Kozak and others 1969	422	0.03	0.22
Ormerod 1973	422	0.02	0.19
Amidon 1984	422	0.02	0.19
Goulding and Murray 1976	422	0.05	0.18
Max and Burkhart 1976	422	0.04	0.22
Cao and others 1980	422	0.05	0.22

$$\text{Bias} = \sum_{i=1}^{N} (O_i - P_i)/N$$

$$\text{MAD} = \sum_{i=1}^{N} |O_i - P_i|/N$$

where O_i = ith observed diameter increment (cm)
P_i = ith predicted diameter increment (cm)
N = number of observations

prediction. Finally, it must also be remembered that while most of these models were fit to cross-sectional increment, the model evaluation is on diameter increment. Therefore, a small reduction in error sum of squares for cross-sectional area increment may not be seen in a diameter increment evaluation.

CONCLUSIONS

Models for whole stem diameter or cross-sectional area increment were constructed from both stem profile models and a biological hypothesis of the increment's vertical distribution on a tree stem. Both modeling approaches appear to reasonably estimate stem diameter increment.

The simpler models, those based on Pressler's hypothesis, provided better diameter increment estimates than the compatible increment models. The Pressler's hypothesis-based models are particularly valuable in that no model parameters need be estimated by statistical techniques once dbh or volume and total height increments are established.

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MEASURING DIAMETER INCREMENT CHANGE CAUSED BY WESTERN SPRUCE BUDWORM DEFOLIATION IN BRITISH COLUMBIA

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Abstract--Stand surveys to determine diameter loss in Douglas-fir caused by western spruce budworm defoliation are reported. The number of reduced rings and the diameter loss per tree averaged 4.4 rings and 0.8 cm, respectively. Both were positively correlated with the pre-infestation growth rates and with the defoliation level, and were negatively correlated with tree age. Since the standard deviation of the mean diameter loss for the stand was correlated with the mean loss, which in turn was correlated to the tree growth rates, more samples are required to estimate diameter growth loss in faster rather than in slower growing stands.

Keywords: Diameter increment, spruce budworm, defoliation.

INTRODUCTION

The western spruce budworm, _Choristoneura occidentalis_ Freeman, is a recurrent defoliator of Douglas-fir, _Pseudotsuga menziesii_ (Mirb.) Franco in British Columbia (B.C.) (Harris _et al_. 1985). Infestations extend over vast areas and last from 1 to 13 years in a locality before declining.

Effects of defoliation on Douglas-fir are severe. Commencing in the second year of defoliation, annual diameter growth is progressively reduced as tree defoliation intensifies with each additional feeding season (Alfaro _et al_. 1982). Diameter growth remains depressed for several years following the population collapse. Repeated defoliation also reduces or eliminates height growth for several years, often resulting in crown top-kill or dieback (Van Sickle _et al_. 1983). Stem recovery after severe top-kill can lead to stem deformities or defects which increase cull (Thomson _et al_. 1982). Tree mortality due to defoliation is usually below 10% of the infested trees but occasionally rises above 50% in particular stands. Mortality is higher among intermediate and suppressed trees (Alfaro _et al_. 1982).

In 1981 and 1982 surveys were conducted to quantify the diameter and volume reduction in a sample of 30 stands defoliated by budworm in the 1970s in B.C. This report summarizes the diameter change sustained by the defoliated trees and discusses its variability.

EXPERIMENTAL METHODS

The current budworm infestation in the Province began in 1967, reached its maximum spread (226,000 ha) in 1976 and declined thereafter. In 1981 and 1982, thirty stands were selected in areas that had sustained defoliation in the 1970s but that exhibited an apparent complete foliage recovery by 1981. Stand selection was designed to include stands over the entire infestation area and was constrained by accessibility. The number of years of defoliation that affected each stand was determined by studying the Forest Insect and Disease Survey (FIDS) maps and aerial photography of the period. The stands were mature and immature, on medium and poor sites with Douglas-fir as the dominant species and varied in area from 20 to 200 ha.

The stands were sampled by establishing a transect line as close to the centre of the stand as possible. Then, all trees in ten variable radius plots (BAF = 5 in most cases), establishd 80 m apart along the transect, were selected and diameter (DBH) recorded. One tree in each plot (two in 1982) was sampled with an increment borer for growth and loss determination. A total of 514 trees were cored in all stands. Cores were obtained from the north side of the tree.

Each increment core was dated and a graph of growth by year prepared. The years of reduced increment were recorded. For each tree, diameter loss (inside bark) was obtained by comparing the actual tree diameter with the "theoretical" diameter the tree would have reached if the infestation had not occurred. Theoretical diameter was obtained by resetting annual diameter growth, for the depressed growth period, to the average of the 5 years preceding the infestation (Fig. 1) and then summing the increments (Thomson and Van Sickle 1980). An average stand diameter loss was obtained by averaging the diameter loss of all cored trees in the stand.

RESULTS

The average number of years of defoliation per stand was 5.6 (standard deviation, S.D., 1.4, range 1 to 7). Increments from cores of defoliated trees showed the typical pattern of growth decline and recovery described for Douglas-fir by Alfaro et al. (1982) and Brubaker and Greene (1979) (Fig. 1). However, on average, only 85% of the trees in defoliated stands (range 29-100%) showed detectable radial increment reduction. Some trees escaped defoliation, particularly when stand defoliation was rated as light or moderate by aerial observers. The average number of reduced rings per tree (based on all trees sampled) averaged 4.4 (S.D. 3.1, range 0-14).

The number of reduced rings per tree as well as the absolute diameter loss and percentage diameter loss per tree were significantly correlated (positive correlation) to the pre-infestation growth rates (average radial increment of the 5 years preceding the infestation) and to the level of defoliation sustained by the tree. The same variables were negatively correlated to tree age. Thus, for a given defoliation level, fast growing young trees had a greater number of reduced rings and sustained a greater relative loss than slow growing, old, trees. Very

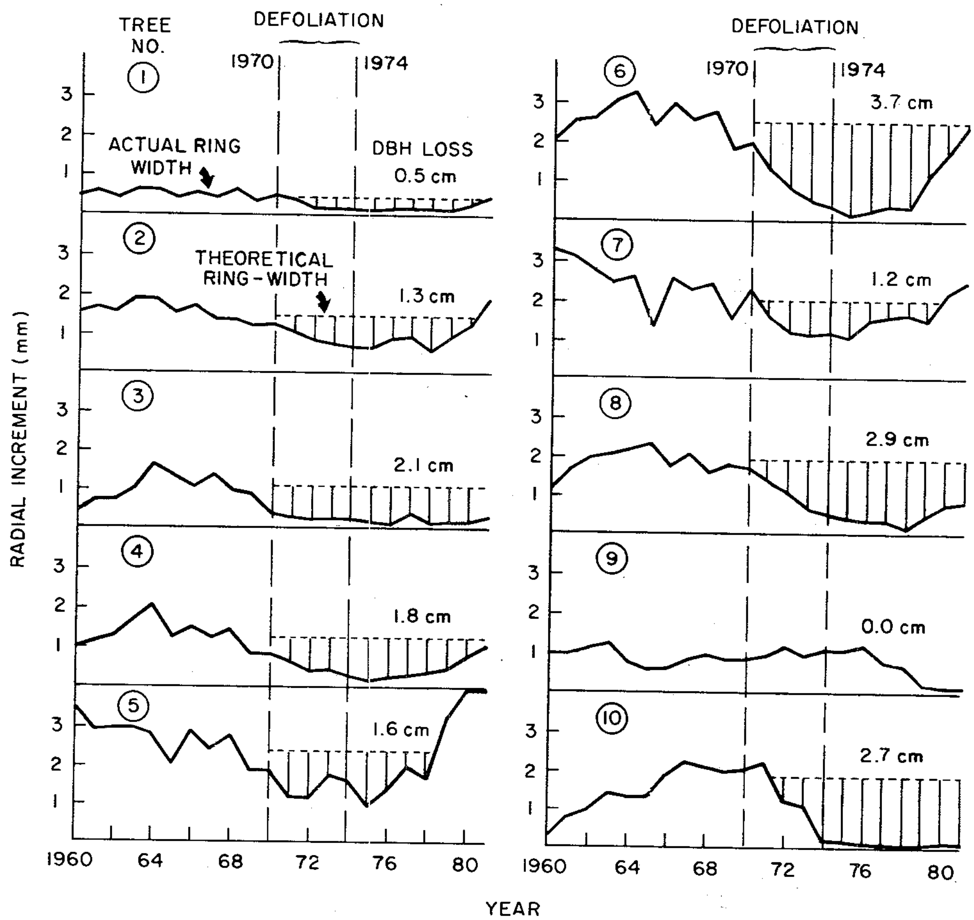

Figure 1. Actual and theoretical annual radial growth in 10 trees selected from a Douglas-fir stand defoliated by the western spruce budworm.

$$\text{Mean diameter loss} = \frac{\Sigma \text{DBH loss for each tree}}{10} = 1.8 \text{ cm (S.D.} = 1.1 \text{ cm)}$$

old trees (250+ years old) often did not show any appreciable reduction in their already narrow rings.

The stand diameter loss (average increment loss of the cored trees in the stand) averaged 0.8 cm over all stands sampled but varied considerably from stand to stand (range 0.0 to 4.9 cm) with factors such as diameter distribution, tree ages and defoliation intensity. The standard deviation of the average stand diameter loss was highly correlated with the mean (Fig. 2) and ranged from 0.1 to 1.4 cm. The coefficient of variation ranged from 55 to 249%.

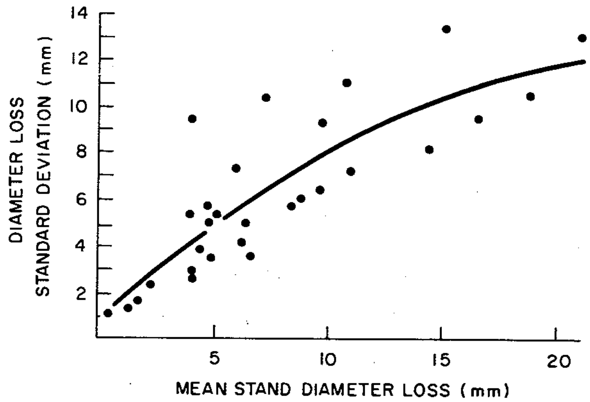

Figure 2. Relationship between mean diameter loss for a stand and its standard deviation.

DISCUSSION

Tree diameter loss was calculated by assuming the growth rates during the years of reduced increment equal to the mean increment of the 5 years preceding the infestation. This method is satisfactory for trees with approximately constant radial growth over time, but is probably inaccurate in trees with rapidly changing growth rates such as the rapid growth increases after thinning. Alternative methods to estimate theoretical growth include the use of regression equations based on pre-infestation growth (Thomson and Van Sickle 1980, Archambault and Beaulieu 1985) or estimation of theoretical growth by comparison of growth on defoliated trees with non-defoliated host or non-host trees. These methods have difficulties as well (Alfaro 1986). Model selection in the regression approach is critical. For example, a linear model based on the pre-infestation growth will yield acceptable loss results for most trees in Figure 1, but will overestimate the loss in Figure 1, tree 10.

Use of non-defoliated host as controls is the most desirable method. However, because budworm infestations are extensive, non-defoliated host is often available only on distant locations which may vary in site index, exposure or other variables. The use of non-host trees for growth comparisons with defoliated host in the stand is not valid if above normal growth occurs in the non-host as a consequence of the reduction in competition from the defoliated host.

Alfaro *et al.* (1982) found that defoliation level per tree was independent of tree size. The positive correlation between diameter loss and average pre-infestation growth and the negative correlation with tree age indicate that, for a given defoliation level, fast growing trees (young, dominant and co-dominant trees) are more severely impacted than slow-growing trees. This result suggests that sampling to determine the average diameter loss caused by budworm should consider stratification by tree diameter, crown class or age. Also, because the variability in diameter loss increased with the mean loss (Fig. 2), more samples will be required to determine the loss to a given precision in fast than in slow growing stands.

An average loss of 0.8 cm per tree over the extent of the loss period may not seem of practical significance. However, when the loss in the other tree dimensions, basal area and height, are converted into volume loss figures, losses of up to 30% of the theoretical volume were recorded for individual trees. On average, 10% of the trees (range 0-74%) in the stands surveyed sustained a loss of 2.1 m of their existing crowns to top-kill. In addition to the growth deficit in the surviving trees, total stand losses caused by budworm include mortality and increased cull due to defect formation in the top-killed stems.

Western spruce budworm is a native, recurrent pest in British Columbia with up to 4 infestations documented in parts of the Province. The additive effect of these repeated infestations is of great concern to foresters.

CONCLUSION

Western spruce budworm causes measurable diameter increment reduction in Douglas-fir in British Columbia. However, because of the high variability of the loss, future loss surveys should stress stratification by diameter, crown class or age.

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COMPATIBLE INDIVIDUAL TREE TAPER, VOLUME, AND WHOLE STEM PROFILE INCREMENT EQUATIONS

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Abstract--Simultaneous estimation of tree taper, total volume, merchantable volume to height and diameter limits, and whole stem profile increment insures mathematical compatibility between component equations. Equations were calibrated and compared using red pine data from Upper Michigan. A system based on the segmented taper curve given by Max and Burkhart (1976) gave the best performance on these data.

Keywords: Stem taper, volume, compatibility, increment.

INTRODUCTION

Selection of optimal forest management alternatives may depend on accurate models of an individual tree's volume and dimension. A system of compatible equations can be used to predict total and merchantable volume to any merchantability limit, diameter at any height, height at any diameter, and tree profile increment along the stem. Four systems of five equations estimating tree taper, total cubic volume, merchantable cubic volume to any height and diameter limit, and whole stem diameter or cross-sectional area increment are examined. The four systems of equations are based on the form factor and Schumacher's (Spurr, 1952) total volume equations and on segmented taper equations given by Cao and others (1980) and Max and Burkhart (1976).

Such systems of equations should be compatible or mathematically related such that volumes estimated through integration of the taper curve are identical to the volumes calculated from the total volume or the appropriate volume ratio equation (Demaerschalk, 1972). Estimation systems are compatible when the coefficients of the derived volume and stem profile models are written in terms of the taper equation coefficients. Compatible total volume and taper equations have been derived by Demaerschalk (1972) and Goulding and Murray (1976) and compatible volume ratio and taper equations have been derived by Clutter (1980), Martin (1981), Reed and Green (1984) and Byrne (1985).

To date no such system of equations has included a compatible whole stem diameter or cross-sectional area increment model. This paper will bring together several compatible taper and volume equation systems with associated stem profile increment models (Newberry, 1984) and each will be evaluated using red pine (*Pinus resinosa*) data from Upper Michigan.

EXPERIMENTAL METHODS

Data and Estimation

Data used in this study were taken from 36 red pine trees felled in the William Payne LaCroix plantation located in the western portion of the Upper Peninsula of Michigan. Information collected from these trees included:

1) total tree height (m) for each of the years 1971-1983
2) inside bark dbh (cm) for each of the years 1971-1983
3) outside bark dbh (cm) for 1983
4) inside bark diameter (cm) at stump height (0.3 m) and every 1.3 meters starting at dbh for years 1971, 1974, 1977, 1980, 1983.

Height, diameter, and dbh increments were calculated on a yearly basis. Cubic volume (m^3) was estimated using Smalian's formula.

Each observation in the study consisted of a partial height (m), dbh (cm), dbh increment (cm/yr), total height (m), total height increment (m/yr), diameter (cm), diameter increment (cm/yr), total volume (m^3), and cumulative volume (from the ground to the height of the observation) (m^3). This produced a total of 1062 observations. Approximately 55 percent or 592 observations were randomly chosen to estimate the coefficients of the systems and 45 percent or 470 observations were used to test the final equations; the 470 observations were not used in the estimation process. A summary of the data can be found in Table 1.

Compatible taper and volume estimation systems based on the form factor and Schumacher's total volume equation are given by Reed and Green (1984). Martin (1981) gave a similar system based on the taper curve of Max and Burkhart (1976). Byrne (1985) developed a system based on the taper equation of Cao and others (1980).

To derive a whole stem diameter or cross-sectional area increment model one could use the difference form or the differential form. Green and Reed (1984) illustrate the differentiation method where $\Delta d_h = \partial d/\partial t$. All results reported in this study are derived from the difference method and are expressed in the form discussed by Newberry (1984). When models derived from the differentiation method were fit to the data poorer fits

Table 1. Summary of the developmental and validation data.

	Developmental Data (592 observations)				Validation Data (470 observations)			
	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum
D[a]	18.165	4.042	10.700	29.500	18.252	2.915	13.200	24.600
H	12.494	2.093	7.320	16.030	12.598	2.113	8.080	16.220
TV	0.185	0.100	0.046	0.534	0.181	0.077	0.068	0.383

[a] Notation:

D = Diameter at Breast Height (cm)
H = Total Height (m)
TV = Total Volume (m^3)

resulted (percent variation explained < 0.40). Newberry suggested that annual stem growth is not a continuous process throughout the year, but can be viewed as a difference from year to year; secondly stem profile models are constrained such that d=0 when h=H and thus in the differential model $\partial d/\partial t = 0$ when $h = H_t$, which is biologically unreasonable. Based on this reasoning and the fact that the differential model yielded poorer fits, the difference method was used in developing final equations.

Coefficient estimation for each system of equations was accomplished by minimizing total system squared error (TSSE) which is defined by a loss function (Burkhart and Sprinz, 1984; Reed and Green, 1984). Total sum of squared error for this study was defined by

$$TSSE = \sum_{j=1}^{J} \sum_{i=1}^{N} \frac{(X_{ij} - \hat{X}_{ij})^2}{\sigma^2_{x_j}}$$

where X_{ij}, $\hat{X}_{ij}$ are the observed and predicted values for the ith observation of the jth dependent variable, $\sigma^2_{x_j}$ is the mean squared error of the least squares fit of the jth dependent variable, N is the number of observations, and J is the number of component equations.

Determination of Accuracy and Precision

Comparisons between each system's performance with final estimated coefficients were made on both the developmental and the validation data. These comparisons were based on three criteria: average residual (bias), standard deviation of the residuals (precision), and percent variation explained (PVE). Residuals were defined as observed minus predicted values and PVE is given by:

$$PVE = \frac{\sum_{i=1}^{N} (X_i - \bar{X})^2 - \sum_{i=1}^{N} (X_i - \hat{X}_i)^2}{\sum_{i=1}^{N} (X_i - \bar{X})^2} (100)$$

where X_i and $\hat{X}_i$ are the observed and predicted values, $\bar{X}$ is the average observed value, and N is the number of observations in the data set.

RESULTS

Each system of equations was simultaneously fit to the developmental data and final coefficients were estimated. Each set of simultaneous fits produced total system squared errors close to those estimated from the individual least squares procedures. A system's performance on the validation data based on bias, precision, and percent variation explained is found in Table 2.

Taper, total volume, and volume ratios to height and diameter limits were adequately estimated by all systems. Whole stem profile increment models in each system had poorer fits and were less precise in predicting diameter or cross-sectional area increment. Equations predicting cross-sectional area increment (form factor, Cao and others, and Max and Burkhart) had better fits than Schumacher's which predicted diameter increment. Examination of diameter increment along the stem indicated a more complex function was needed than for area increment, thus contributing to the poorer fit.

All were close in prediction and fit excluding the Schumacher system. Ranking these systems based on performance in bias, precision, and percent of variation explained found the Max and Burkhart system to have the better overall performance. Final coefficients in each of the component models are found in Table 3.

SUMMARY

Simultaneous estimation of tree taper, total volume, merchantable volume to height and diameter limits, and whole stem profile increment provide mathematical compatibility for estimating individual tree growth and yield. Four systems of equations were compared for their performance on data from red pine plantations in Michigan's Upper Peninsula.

In all systems taper, total volume, and merchantable volume to height and diameter limits were good predictors. The whole stem diameter increment models produced poorer fits. Comparison of each system's performance based on bias, precision, and percent of variation explained showed the Max and Burkhart system to give a better overall performance on these data.

Table 2. Values of the test statistics for all systems.

Validation Data

	Taper	Total Volume	Volume Ratio to Height Limit	Volume Ratio to Diameter Limit	Stem Increment
Form Factor	(cm^2)	(m^3)			(cm^2)
Bias	-3.7257349	0.0010451	0.0014408	0.0010373	0.0000160
Precision	21.0389388	0.0126543	0.0218551	0.0449724	0.0002627
PVE	0.9753388	0.9684727	0.9929489	0.9703258	0.7289434
Schumacher	(cm)	(m^3)			(cm)
Bias	-0.2234725	0.0023624	-0.0029481	-0.0031405	0.0375220
Precision	0.9759380	0.0112379	0.0219435	0.0467866	0.2376698
PVE	0.9713493	0.9708416	0.9930505	0.9680373	0.4868748
Cao and others	(cm^2)	(m^3)			(cm^2)
Bias	-7.7235785	-0.0066383	-0.0001307	-0.0073975	-0.0000198
Precision	21.7080455	0.0193006	0.0227588	0.0474328	0.0003635
PVE	0.9737457	0.9519775	0.9924148	0.9672988	0.7918037
Max & Burkhart	(cm^2)	(m^3)			(cm^2)
Bias	-3.7988928	0.0003766	-0.0018283	-0.0042401	0.0000119
Precision	19.7988928	0.0131428	0.0223420	0.0444600	0.0002255
PVE	0.9790563	0.9680876	0.9927515	0.9711877	0.7995091

Table 3. Coefficients and fit statistic for a compatible system of equations based on Max and Burkhart's taper equation.

Taper Equation:[a]

$$d^2 = D^2 [-3.809326\{(h/H) - 1\} + 1.799961 \{(h/H)^2 - 1\} + 65.640825 (0.057348 - h/H)^2 I_1 - 1.942427 (0.667283 - h/H)^2 I_2]$$

where

$$I_i = \begin{cases} 1 \text{ if } h/H \leq a_i \\ 0 \text{ if } h/H > a_i \end{cases} ; \; i=1, 2$$

Total Volume Equation:

$$TV = \alpha D^2 H$$

Table 3 continued.

where

$$\alpha = .00007854\ [(1.799961/3) - (3.809326/2) - (-3.809326 + 1.799961) + (65.640825/3)(0.057348)^3 - (1.942427/3)(0.667283)^3]$$

<u>Volume Ratio Equation to a Height Limit</u>:

$$Rh = 1/\gamma\ [(1.799961/3)(h/H)^3 - (3.809326/2)(h/H)^2 - (-3.809326 + 1.799961)(h/H) - (65.640825/3)\ \{(0.057348 - h/H)^3\ I_1 - (0.057348)^3\} + (1.942427/3)\ \{(0.667283 - h/H)^3\ I_2 - (0.667283)^3\}]$$

where

$$\gamma = (1.799961/3) - (3.809326/2) - (-3.809326 + 1.799961) + (65.640825/3)\ (0.057348)^3 - (1.942427/3)\ (0.667283)^3$$

<u>Volume Ratio to a Diameter Limit</u>:

$$Rd = 1/\gamma\ [(1.799961/3)\ (w/H)^3 + (-3.809326/2)\ (w/H)^2 - (-3.809326 + 1.799961)(w/H) - (65.640825/3)\ \{(0.057348 - w/H)^3\ J_1 - (0.057348)^3\} - (-1.942427/3)\ \{(0.667283 - w/H)^3\ J_2 - (0.667283)^3\}]$$

where

$$w = (H/2A)\ [-B-(B^2 - 4AC)^{1/2}]$$

and

$$A = 1.799961 + 65.640825\ J_1 - 1.942427\ J_2$$

$$B = -3.809326 -(2)(0.057348)(65.640825)\ J_1-(2)(0.667283)(-1.942427)\ J_2$$

$$C = -(-3.809326 + 1.799961) + (65.640825)(0.057348)^2\ J_1 + (-1.942427)(0.667283)^2\ J_2 - (d/D)^2$$

$$J_i = \begin{cases} 1 \text{ if } d \geq M_i \\ 0 \text{ if } d < M_i \end{cases}$$

Table 3 continued

where

$$M_i = D\,[-3.809326(a_i - 1) + 1.799961\,(a_i^2 - 1)$$
$$- 1.942427\,(0.667283 - a_i)^2]^{1/2}$$

and

$$a_1 = 0.057348$$
$$a_2 = 0.667283$$

<u>Whole Stem Cross-Sectional Area Increment</u>:

$$\begin{aligned}\Delta ca_h = .00007854[&(Di^2[-3.809326\,(h/Hi) + 1.799961\,\{(h/Hi)^2 - 1\}\\ &+ 65.640825\,(0.057348 - h/Hi)^2\,I_1\\ &- 1.942427\,(0.667283 - h/Hi)^2\,I_2])\\ &- (D^2\,[-3.809326\,(h/H) + 1.799961\,\{(h/H)^2 - 1\}\\ &+ 65.640825\,(0.057348 - h/H)^2\,I_1\\ &- 1.942427\,(0.667283 - h/H)^2\,I_2])]\end{aligned}$$

where

$$I = \begin{cases} 1 \text{ if } h/H \leq a_i \text{ or } h/Hi \leq a_i \\ 0 \text{ if } h/H > a_i \text{ or } h/Hi > a_i\ ;\ i=1,\ 2 \end{cases}$$

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[a] Notation

d	=	Upper Stem Diameter (cm)
D	=	Diameter at Breast Height (cm) at Time t
h	=	Partial Height (m)
H	=	Total Height (m) at Time t
TV	=	Total Volume (m^3) at Time t
Rh	=	Volume Ratio to Height Limit (m^3)
Rd	=	Volume Ratio to Diameter Limit (m^3)
Δca_h	=	Cross-sectional Area Increment (m^2) at Height L
Di	=	Diameter Breast Height (cm) at Time t+1
Hi	=	Total Height (m) at Time t+1

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INFLUENCE OF CHANGE IN CROWN POSITION ON DIAMETER INCREMENT

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Abstract--Successive measurements over a 20-year period on individual trees in Pennsylvania Allegheny hardwood stands were used to study the effect of a change in relative crown position on annual diameter increment at breast height. Multiple linear regressions using indicator variables to designate a shift in crown position were significantly better ($p \leq .05$) than regressions based on diameter alone for predicting diameter increment. These results suggest that there may be value in developing individual tree growth models utilizing crown position as an independent variable.

Keywords: Crown position, diameter increment, indicator variables, linear regression.

INTRODUCTION

The increasing importance of computerized models of forest growth was recently discussed by Titus and Morton (1985). Model-based predictions of stand development can be used for inventory updates, yield table construction, selection of alternative silvicultural options, and strategic management planning.

Common approaches to growth modeling include forest-level, stand-level, and individual-tree models. The individual-tree models are commonly described as either distance-dependent or distance-independent, the distinction being that the distance-dependent models require mapped tree locations and/or distances between trees on the plot under study.

Both types of individual-tree model commonly employ measurements of the tree crown as an independent variable to help predict diameter increment. In the distance-independent models, live crown ratio is the most common measure (Brand, 1981; Wykoff et al. 1982). Other measures include crown depth (length) and crown diameter (Hibbs and Bentley, 1984) and leaf biomass (Reed, 1980).

The distance-dependent individual-tree models commonly use crown measurements and the inter-tree distance data to derive a numerical index of competitive stress for each tree; this index is then used to predict diameter growth. The index may be combined with the live crown ratio, as in FOREST (Ek and Monserud, 1974) and in Daniels et al. (1979).

Arney (1974) used a competitive stress index (CSI) to quantify the encroachment of neighboring tree crowns into the space the tree in question would require for maximum growth. He saw the CSI as a measure of available growing space, whereas live crown ratio is only an expression of the impact of past competition.

If a "measure of available growing space" is an important factor in predicting tree growth, but time and cost constraints prohibit the collection of tree locations or inter-tree distances, perhaps another commonly collected tree attribute, namely crown position (or crown class) could be a useful predictor variable. The assignment of crown class for any particular tree during a cruise or inventory is admittedly a subjective process, but is based largely on the amount of sunlight available to the tree, considering its position in the general canopy (Smith, 1962).

STUDY OBJECTIVES

The objective of this study was to investigate the feasibility of using crown position and, more specifically, a change in crown position, for predicting average annual diameter growth at breast height. The purpose was not to develop an individual tree growth model using crown position; instead, it was desired to show that crown position is or is not useful in predicting diameter increment.

Specialists in forest inventory may see a secondary objective in this study. That is, how useful is "qualitative" data? Is it worth collecting subjective observations on tree condition? Although not designed to answer these questions specifically, it is believed that this study may provide a useful starting point for their resolution.

Ferrell (1983) did use crown position to place red fir and white fir in percent basal area increment classes (< 1%, 1% to 3%, and > 3%), but not for predicting diameter growth. Other independent variables were live crown ratio, percentage of crown dead or missing, and diameter at breast height.

DATA

Data for this study were from 30 permanent plots 1/4 acre (.10 ha) in size in the Allegheny hardwood type of northwestern Pennsylvania[1]. Plots were remeasured at intervals of 3 to 9 years over the past 20 to 25 years. Individual tree data at each measurement occasion included species, diameter at breast height (dbh) measured to the nearest 1/10th inch, defects, risk, vigor, and crown position. Both risk and vigor were tallied as either good, fair, or poor. Vigor was based on crown size, fullness, depth, color, etc. Risk was an assessment of the tree's chance of survival for the next 10 years.

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[1]The cooperation of Texasgulf, Inc., of Johnsonburg, Pennsylvania in making these data available is gratefully acknowledged.

Definitions for crown position were the same as those listed in Smith (1962):

Dominant. Trees with crowns extending above the general level of the crown cover and receiving full light from above and partly from the side; larger than the average trees in the stand, and with crowns well developed but possibly somewhat crowded on the sides.

Codominant. Trees with crowns forming the general level of the crown cover and receiving full light from above, but comparatively little from the sides; usually with medium-sized crowns more or less crowded on the sides.

Intermediate. Trees shorter than those in the two preceding classes, but with crowns either below or extending into the crown cover formed by codominant and dominant trees, receiving a little direct light from above, but none from the sides; usually with small crowns considerably crowded on the sides.

Overtopped. Trees with crowns entirely below the general level of the crown cover receiving no direct light either from above or from the sides.

Of particular interest in this study were trees exhibiting a change in crown position from one measurement occasion to the next. Sufficient data were available for analyses on sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), American beech (*Fagus grandifolia*), white ash (*Fraxinus americana*), and black cherry (*Prunus serotina*).

METHODS

BMDP module P1R (Dixon 1983) was used to construct multiple linear regressions for predicting annual dbh growth. Regressions were developed on a species specific basis for each crown position class. Tree diameter at breast height at the start of the measurement interval was a dependent variable. Indicator variables (1,0) were used to represent a shift in crown position between measurement occasions. For example, the general form of any particular regression would be

$$DGROW = a + b_1 D + b_2X_2 + b_3X_3,$$

where DGROW = average annual dbh growth, (change in dbh divided by number of growing seasons in measurement interval),

D = initial dbh

X_2 = 1 if crown position improves (codominant to dominant, intermediate to codominant, etc.),
= 0 if crown position does not improve,

X_3 = 1 if crown position worsens (codominant to intermediate, intermediate to suppressed),
= 0 if crown position does not worsen, and

a, b_i = the usual least squares regression coefficients.

For each species/crown class combination, the reduced model was defined as the regression using only initial dbh (D) as the independent variable. The full model used D, X_2, and X_3. In this way the general linear F test (Neter and Wasserman, 1974) could be used to test if the full model, incorporating shifts in crown position, was statistically significantly better than the reduced model. Table 1 displays the sample sizes (number of trees) for each species/crown class combination.

Table 1. Number of trees used for regression analyses.

Species	Original Crown Position	Crown Position at Remeasurement				Total
		Dominant	Codominant	Intermediate	Suppressed	
Sugar maple	Codom.	11	32	24	-	67
	Inter.	-	16	33	20	69
	Supp.	-	-	22	42	64
Beech	Inter.	-	17	24	7	48
Red maple	Codom.	21	35	13	-	69
	Inter.	-	23	36	16	75
White ash	Codom.	6	26	4	-	36
	Inter.	-	4	5	6	15
Black cherry	Domin.	29	8	-	-	37
	Codom.	13	35	6	-	54
	Inter.	-	8	18	6	32

RESULTS

The full model was significantly better than the reduced model at the .01 level for sugar maple, beech, and red maple (Table 2). Including shifts in crown position for codominant white ash did not improve the ability to predict diameter growth, although intermediate white ash did benefit by their inclusion. It should be noted that the full model for codominant white ash was nearly significantly better than the reduced model at the .05 level.

Black cherry, the most intolerant of the species studied, showed no difference between the full and reduced models until the intermediate crown class was considered. These results correspond with observations made by Hough and Taylor (1946). They reported that partial cutting does little to stimulate the growth of dominant and codominant cherry, since in those positions it is already exhibiting near-maximum growth.

Table 2. Reduced and full models for each species/crown class combination.

Species	Original Crown Class	Model (DGROW =)	R^2	GLF Signif. Level
Sugar maple	Codom.	$.04781 + .00713D$	.112	
		$.11904 + .00277D + .01576X_2 - .07873X_3$	.388	.01
	Inter.	$-.00317 + .01244D$	.080	
		$.05127 + .00506D + .04582X_2 - .03313X_3$	.215	.01
	Supp.	$-.02914 + .01652D$	.100	
		$-.02727 + .01423D + .03808X_2$	.210	.01
Beech	Inter.	$.12477 + .00186D$	.004	
		$.11925 + .00143D + .04497X_2 - .05076X_3$	.316	.01
Red maple	Codom.	$.06995 + .01061D$	.140	
		$.14937 + .00287D + .04668X_2 - .08694X_3$	.433	.01
	Inter.	$.07284 + .00802D$	.034	
		$.10834 + .00376D + .03208X_2 - .06719X_3$	.224	.01
White ash	Codom.	$-.00866 + .01213D$	.369	
		$.03521 + .00809D + .03498X_2 - .03955X_3$	.482	N.S.
	Inter.	$.00604 + .01018D$	.047	
		$.24581 - .02083D + .10845X_2 - .03177X_3$	.649	.01
Black cherry	Domin.	$.04416 + .00916D$	.126	
		$.10320 + .00599D - .03612X_3$	.160	N.S.
	Codom.	$.11574 + .00297D$	.019	
		$.15250 + .00014D + .01885X_2 - .06986X_3$	.114	N.S.
	Inter.	$.05724 + .00799D$	.026	
		$.13427 - .00340D + .08227X_2 - .06838X_3$	.280	.05

CONCLUSION

It appears that including a tree's expected crown position in a model to predict diameter growth does have merit, at least for species in Pennsylvania's Allegheny hardwood stands. "Expected" crown position would be of interest because in a stand undergoing heavy mortality or partial cutting, the model could make use of shifts in crown position, due to the removal or demise of neighboring trees. The results of this study indicate that this approach may have greater value in the tolerant species than in the intolerant species. Further work in this area should consider the addition of current tree vigor as an aid in predicting growth, since the interaction of tree vigor and crown position is an important factor in determining response to release (Hough and Taylor, 1946). Also, the use of live crown ratio as a supplement to crown position should be studied. Finally, if crown position still appears to be a useful attribute for predicting tree growth, a biologically sound individual tree growth model should be developed that incorporates crown class with other tree and stand characteristics.

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GROWTH LAYER ANALYSIS AS A METHOD OF EXAMINING TREE GROWTH AND DEVELOPMENT RESPONSES

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Abstract--A stand-alone, microcomputer tree ring increment measuring (TRIM) system was developed for precise measurement of tree rings and for growth layer analysis. Examples of growth layer analysis focus on tree growth and development patterns; ring widths measured by cardinal directions; tree age response to environmental stress; individual tree versus unit area growth; site-growth relationships; and growth-temperature amplitudes and duration.

Keywords: Annual increment, growth layers, spruce, climate.

INTRODUCTION

The patterns of successive changes in width and length of the annual growth layer of stem wood during the life of a tree integrate much of its history, particularly of crown vigor. We are interested in the biological interpretation of growth and development patterns, but based on a dynamic rather than static understanding -- both for the individual tree and trees aggregated on a unit area plot basis. The need to analyze the patterns of growth and resulting shapes of trees to gain insight into growth of stands and trees was argued by Assman (1970). Berish and Ragsdale (1985) emphasized the importance of knowing what the 'normal' radial growth rates are for mature forest stands, and of considering stand dynamics when interpreting pollution effects, for example. In our approach to stem analysis, the growth layer is the basic unit of study, so we have coined the term growth layer analysis. Critical to this analysis procedure is sectioning of trees at sufficiently close intervals to document the detailed radial and longitudinal patterns of growth. Three case studies are touched upon here.

TRIM

Until the advent of computer technology, growth layer analysis was too time consuming for all but research studies; now it is becoming part of forest management in Ontario. We did this by designing a system that could be put together largely from off-the-shelf parts, was not tied to a mainframe computer, was rugged, easy to use, and precise (see Fayle et al. 1983). We have dubbed it TRIM -- the Tree Ring Increment Measuring system --which consists of hardware (Fig. 1) and software elements.

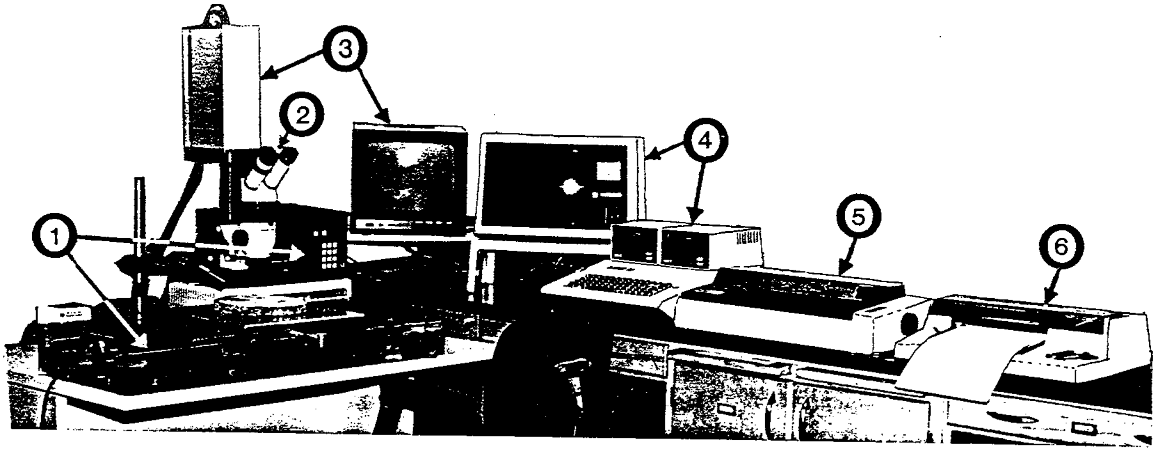

Figure 1. TRIM system showing: (1) measuring table and Sony controller; (2) stereomicroscope; (3) TV camera and monitor; (4) Apple IIe microcomputer, dual disc drives and monitor; (5) 132-column Epson FX-100 printer; and (6) Hewlett-Packard 2-pen (or 6-pen) plotter. The approximate cost is $18,000.00 (Canadian), with all options.

The custom designed measuring table (engineering diagrams available upon request) can be constructed at a local machine shop. All metal components are precision tooled and pressure relieved to maintain continuous accuracy over the 550 mm linear-bearing travel distance of the measuring platform. A screw drive, turned by a geared hand crank, incorporates a split-nut construction, allowing rapid horizontal transfer of the measuring platform. Movement of this 34 x 34 cm platform is detected by a Sony Linear Magnescale mounted in the measuring table and capable of reading at a precision of 0.01 or 0.001 mm. Cumulative distance travelled is displayed on the accompanying Sony controller unit. Transfer of data is via the RS232 port of the controller to the microcomputer.

Individual ring width measurements are initiated by the TRIM operator pressing a button as the microscope cross-hairs intersect the ring boundary on the tree disk. This in turn transmits an interrupt signal to the microcomputer. The software calculates the difference between these cumulative distance signals and displays the ring widths, identified by year, on the monitor for immediate error-checking. Once a complete radius is measured, the ring width sequence is graphically displayed on the monitor along with the previous sequence for verification by the operator. If errors are detected, interactive editing of the data is readily available. Raw data are stored on one disk drive and average data of several radii on the other.

The TRIM software was developed as a set of interactive menu-driven programs specifically aimed at the casual user. This has proven to be operationally attractive in remote field locations where specialized computer operators may not be available. Numerous programs with detailed instruction manuals have been developed. Standard tabular and graphical outputs include growth layer profiles and stem profiles for width and cross-sectional area, annual and cumulative height, cumulative volume, CAIV/MAIV, specific volume increment and radial sequences. Aggregation software allows the user to aggregate all trees in a plot or to selectively stratify and aggregate individual trees by class interval: height, age, dbh, crown width, crown length. Stocking and density stratification is possible from our polar plot or rectangular plot mapping software. In addition, we have also developed field sampling, ring identification and registration manuals.

WHITE SPRUCE AND DENDROCLIMATOLOGY

Growth layer analysis can be used to aid dendroclimatological and dendroecological studies. When increment cores are obtained at breast height only, negligible information can be derived on height increment and crown-to-stem development. Thus interpretation of changes in ring width starts with a disadvantage.

At the northern tree line, environment strongly influences the crown form, photosynthetic activity and growth processes, with subsequent effects on the amount and distribution of wood formed. Selected growth layer profiles (GLPs) for width of 3 white spruce from the forest-tundra (Fig. 2) and open forest zones (Fig. 3) at Churchill, Manitoba, illustrate a few facets. The longitudinal distribution of wood has clearly gone through repeated cycles with strong changes evident in the upper stem. (Interestingly, taken by itself, the shape of the 1881 GLP is not typical of a tree with a crown to its base, yet this pattern frequently occurred.) Decreases in radial increment in the upper stem could be quite sudden or take place over several years. The former occurred in 1783, 1882, 1930 and 1950, particularly in the exposed tree. Recovery could be relatively abrupt or slow.

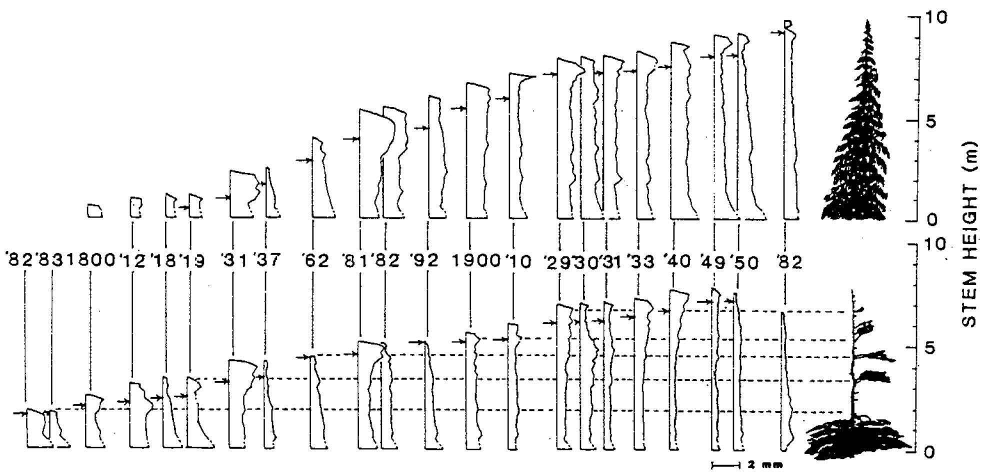

Figure 2. Selected GLPs for width (average of 4 radii, sectioning at 10 cm intervals) for forest-tundra white spruce (lower) on a dry, exposed ridge and (upper) in a poorly drained copse. Arrows mark the 20th internode.

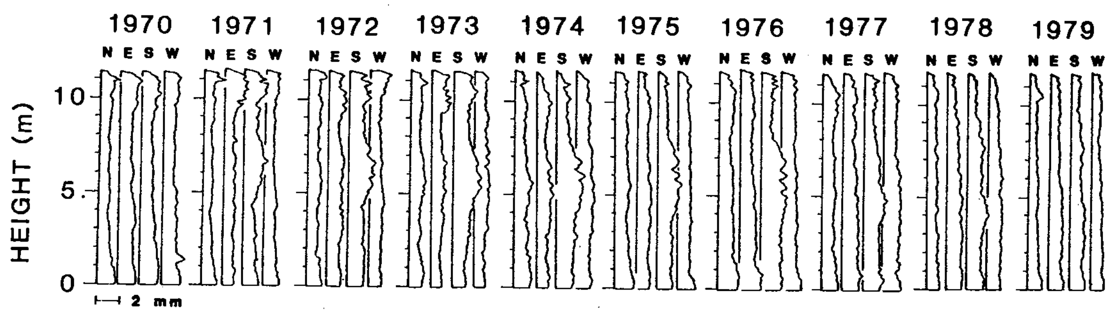

Figure 3. GLPs for width of the north, east, south and west radii in 1970-79 of an open forest white spruce.

Climatic records at Churchill were not kept prior to 1932. An exceptionally cold winter was recorded in 1950 which may have led to the death of the upper stem of the exposed tree (Fig. 2, lower) and temporary loss of terminal growth and foliage in the other (Fig. 2, upper) with regrowth from lateral buds or branches. Although the patterns of ring width changes in the upper stem have been repeated at different tree ages and heights, the triggering factors may not have been the same. This must be borne in mind when using the growth patterns as proxy-climatic information.

Measurement of ring widths along consistent radii up the stem may indicate different events or influences when the configuration of GLPs for the individual radii are compared. In Fig. 3, the GLPs for the 4 radii are similar in 1970. In 1971 a 'bulge' appears in the south GLP centered at 6.5 m. In 1972-74, 'bulges' also occur at 10 m and on the north and east profiles. They gradually move down the stem and disappear, so that by 1979 there is once again little difference amongst the 4 radii. The stem was slightly sinuous and leaning when sampled, indicating that a change in vertical alignment had occurred. No compression wood was evident but the 'bulges' probably date the time that alignment changed. Differences between the 4 radii had developed in several previous periods and may provide clues to environmental factors, such as excessive ice or snow loading during the winter, wind, and (or) deeper melting of the permafrost during the summer, loosening roots frozen therein.

JACK PINE, POLLUTION AND INTERPRETATION OF GROWTH

In 1983 an opportunity arose to examine possible growth effects on jack pine of a nickel smelter at Thompson, Manitoba. Emissions of SO_2 had increased from 0 in 1960, to about 1600 tons per day in 1971 before declining to around 600 tons per day by 1980. Particulate and heavy metal emissions were also substantial. Trees were cut for growth layer analysis at different distances downwind from the smelter, and in a 'control' upwind location. Figure 4 shows the GLPs for width and area of a typical tree 1.3 km from the smelter, in a zone that showed damage symptoms within a few years of startup. Growth has obviously declined in

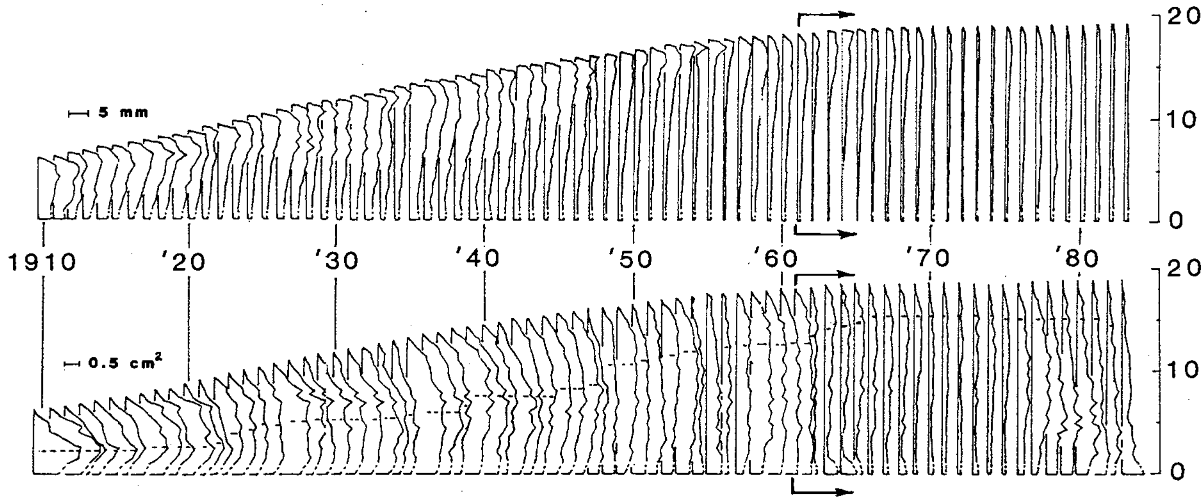

Figure 4. GLPs for width (upper) and cross-sectional area (lower) from age 25 to 98 of a jack pine subjected to emissions from a nearby nickel smelter, commencing in 1961 (arrow). The top of the GLPs marks the cumulative height curve; the dotted line indicates the effective crown base.

the last couple of decades, with some recent improvements. It is tempting to relate these changes directly to the effects of the smelter because we know when emissions started; quantification of the growth response, however, it not straightforward.

First, height growth had levelled off <u>before</u> 1961 and previously noticeable periods of reduced radial growth had occurred, particularly in the upper stem (perhaps from insect defoliations). Secondly, growth layer analysis showed that not only were the 'control' trees younger but their development pattern was different. Thirdly, the longitudinal distribution of increment has changed: in the lower stem, cross-sectional area increments attained levels similar to those prior to start up of the smelter, but they remained low in the upper stem; breast height measurements alone could lead to false interpretations of 'recovery'. Fourthly, the individual tree sampling does not permit any conclusions to be made on a land area basis. For example, the distribution of growth in recent years could have been produced by opening of the canopy and increased stem sway stimulating growth in the lower stem. Fifthly, in this northern part of jack pine's range, overall climatic changes may have a strong influence. The decline in growth from the mid 1940s to the late 1960s and subsequent increase in the 1970s parallel some longterm, overall climatic changes in temperature.

The configuration of the GLP for area together with that for width can provide information on crown development. Our evidence in jack pine (and red pine) suggests that the location of maximum cross-sectional area of the GLP, or where the curve changes slope, usually occurs higher than the live crown base and is perhaps an indication of the effective crown base. Thus progression up the stem of the decline and death of lower branches, release from competition, how rapidly or when crown closure occurs, and an indication of early spacing can be inferred (see Fig. 4). This cannot be derived from the GLP for width alone. Discretion is required in interpretation of the cross-sectional area profiles. For example, a change from an excurrent to a decurrent crown structure (see Fayle and MacDonald 1977) and favorable versus unfavorable growing seasons will affect the longitudinal distribution of increment; no loss of vigor may be entailed.

Ring number sequences for width, i.e. annual rings at a constant number from the pith or internode number from the contemporary apex (Fayle 1973) can be used to interpret response to extrinsic factors as they help to remove the intrinsic effects of the crown. Leblanc (1985) used this sequence to examine growth trends in relation to acid deposition. Changes can still occur, however, with respect to the apex as indicated in Fig. 2 by the arrows marking the location of the contemporary internode number 20. Alternatives are to base the sequence on distance from the contemporary apex (Fayle and MacDonald 1977) or use specific volume increment for, e.g. 1 m intervals from the contemporary apex.

BLACK SPRUCE, GROWTH AND ENVIRONMENTAL INFLUENCES

For yield management, growth responses based solely on selected individual trees can be misleading.

Replicated 20 x 20 m plots with an inner 10 x 10 m destructively sampled area for growth layer analysis were established near Hearst, Ontario. The young stands were pre-stratified by soil and drainage condition and cruised for each major commercial species: black spruce, white spruce and jack pine. Within-tree sampling interval was maintained at 15 cm from base to tip with consistent N-S radii measured on the TRIM system. The plots were field surveyed, mapped and stratified by height class. Initially, individual trees in the mean, ± 1 and ± 2 standard deviations classes were submitted for growth layer analysis, followed by all trees in the plot area. Mature trees, subject to the same site conditions, were sampled to comparatively examine the site-growth relationships between the old and new forest, following the cut. For example, preliminary analysis of height over age in the mature versus 17-year-old naturally regenerated black spruce stand is presented in Figure 5. The slope of the growth curve exceeds site class la (Plonski 1974) which is characteristic of "prime sites" for black spruce management.

Growth over time is subject to a sequence of perturbations where the amplitudes and durations are measures of tree vigor, age, stand and site conditions. As age increases, depletion periods are longer, as noted by the height slowdown in the late 1940s through the 1950s (age 75) with recovery in the 1960s followed by a current decline period beginning in the late 1970s. Many of these perturbations appear to be environmentally induced; evidence provided by the shape of the GLPs in the upper crown suggests that the 1950s decline may be budworm. When today's young black spruce trees, aggregated by plot unit area (curve 4) are superimposed (age zero) over the old forest, the slope of the height curve (4)

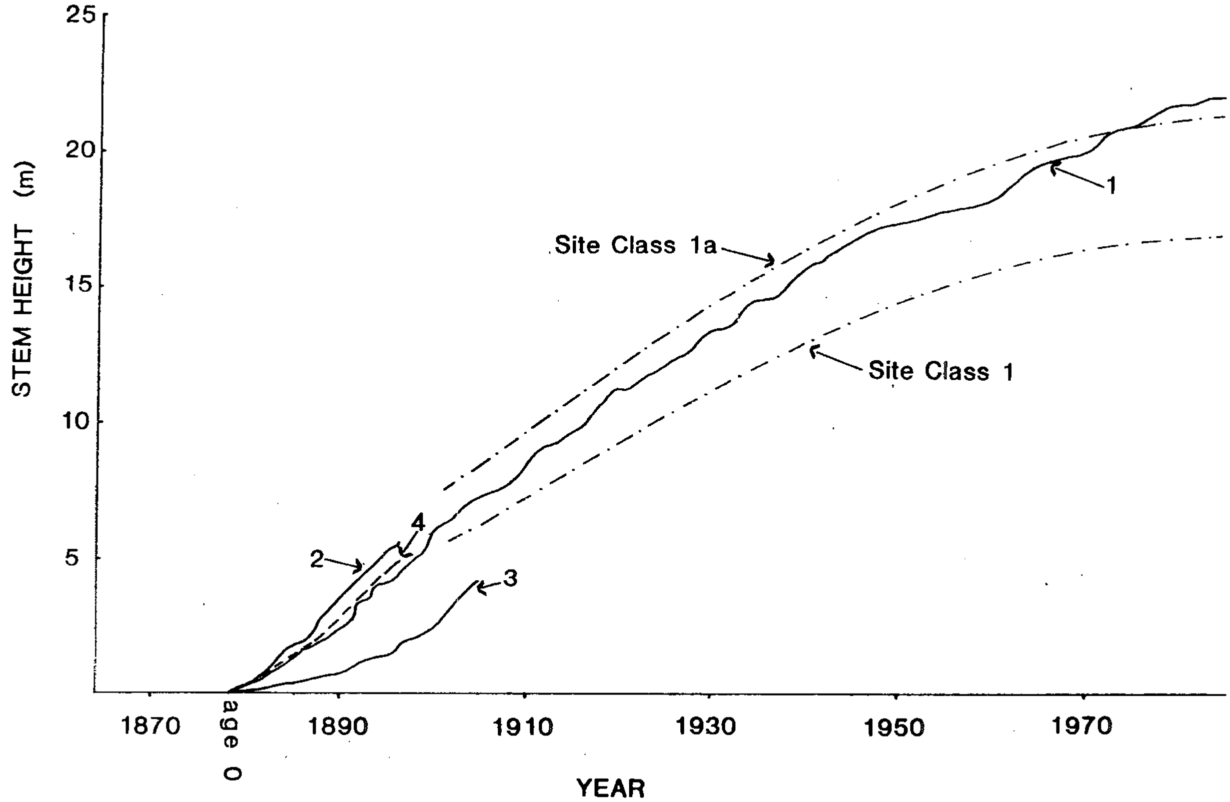

Figure 5. Ontario "normal yield" height over age curves for site class 1a and 1 black spruce compared to a "prime site" mature tree (curve 1), and young naturally-regenerated black spruce selected as the dominant (curve 2) and mean (curve 3) trees, and the average for all trees on a plot (curve 4). Data supplied by the Northern Forest Development Group, Ministry of Natural Resources. (Trees cut in 1984/85; years on X-axis relate to curve 1.)

demonstrated consistency. This is not so with individual tree growth patterns (curves 2 & 3).

Based on the growth layer analysis by plot area, we took a second look at these individual trees and their specific position within the tree community. The initially open-grown trees tend to be tallest (curve 2) exhibiting a competitive growth advantage, attributable not to a change in the slope of the height curve, but directly to the shorter establishment period. The mean height class tree (curve 3), although correctly surveyed and selected in the field, was found to be 7 years older (black spruce layered origin) than all other trees in the plot. The poor height reflects the lengthy establishment period, not a different slope of the growth curve. For example, similar lengthy establishment periods (30-50 or more years) for individual trees are evident in lowland layered-origin black spruce on organic soils, understory red spruce and tolerant hardwood species. Determination of true age (not breast height age) is critical. Likewise we suggest that the identification of the "growth point" (inflection point between the establishment and the site-growth portions of the curve) has important implications as the analytical starting point. This "growth point" should be defined by analyzing the tree community on a unit area basis.

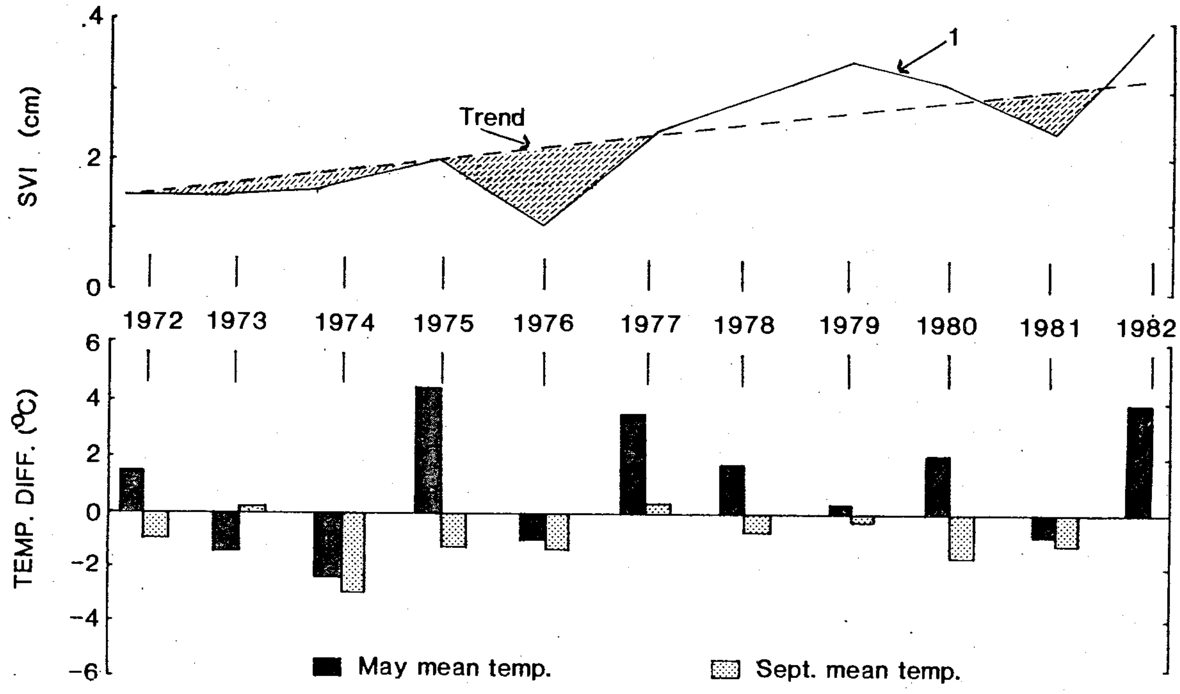

Figure 6. Specific volume increment (SVI) and its linear trend line compared to May and September mean temperature differences from their respective trends.

But what are the principal forcing components within this site-growth relationship? Unfortunately, many foresters use the words site and soil interchangeably, so to avoid confusion, the climatic component will be discussed under the current topic of environmental influences on growth response. Instead of height, specific volume increment (SVI) will be our measure of growth response for these young "prime site" black spruce. SVI is a measure of the cambial activity of the tree. All trees in the plot area, depending upon their density patterns, demonstrated replicated growth responses per year (especially evident in the GLPs). For example, the reduced SVI in 1976, repeated again in 1981, corresponds with the previous September and the current year's May colder conditions demonstrating that cambial activity responds not to a one, but a successive two year climatic event sequence.

Positive first year recovery, principally indicated by warm May temperatures in 1977, will not achieve potential site-growth response in the same year since the tree responds first by building up its photosynthetic capacity. Subsequent climatically positive years continue to reinforce this biological process with the maximum actual SVI occurring in 1979. (For example, height increment was at a minimum in 1979.)

Moisture, as measured by precipitation patterns (monthly, seasonally, annually and frequency of occurrence) plus water deficiency patterns above various water holding capacities (MacIver and Masterton 1984) showed no relationship to SVI. However, water deficiency will become an increasingly important climatic qualifier in the drier boreal regions (MacIver and Powell 1977).

Deviations from these climatically-induced amplitudes and durations will signal other environmental influences, limiting soil and nutrient conditions and stand dynamics. During periods of minimum stress, "potential productivity" growth responses may be possible, although "actual productivity" is a more realistic basis for further environmental partitioning, forest production modelling and operational forecasting of treatment responses.

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ANNUAL INCREMENT OF STRESSED SPRUCE AND FIR TREES

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Abstract--Spruce and fir trees from northern Maine are used to show the annual increment along the bole of trees growing under stress from spruce budworm (Choristoneura fumiferana Clemens) attacks. The reduction in radial increment occurs first in the upper bole and then is reduced in the lower bole after continued defoliation. The growth rates of trees growing under environmental stress are compared with expected long-term growth responses and decline of natural stands. Mensurational changes in radial increment within the bole that must be considered when comparing tree growth response to environmental stress are discussed, and precautions needed when interpreting isolated results are noted.

Keywords: Spruce decline, stress, growth, annual increment.

INTRODUCTION

The spruce-fir forests of the Northeast are growing under many forms of environmental stress that may alter physiological functions and result in growth reduction. Some examples are the lack or excess of moisture, light, aeration, and nutrient availability. Forest managers are often aware of many of these environmental conditions, and manage stands to reduce stress conditions and increase growth.

Insect attacks, diseases, and pollutants also may cause catastrophic stress on the growth of trees or forest stands. The more intense and lengthy the duration of the attack or stressful condition, the greater the reduction in bole growth. Reductions in tree growth due to stress, both natural or man induced, result in growth patterns along the stem that may vary with tree age and time lapse after the stress condition. Unless researchers consider the changes that may occur in these growth patterns erroneous conclusions may be reached as to why these changes have occurred. In this paper I present some of the mensurational changes in radial increment within the bole that must be considered when measuring tree-growth response to environmental stress, and discuss precautions needed when interpreting isolated results.

GRADUAL STRESS

The most common type of stress experienced by trees is that caused by competition from surrounding trees. Some trees grow faster in height and diameter than others and assume different crown positions within the stand. These different crown positions, usually referred to as dominant, codominant, intermediate or suppressed, are the result of a combination of different stresses that do not allow all trees to grow at the same rate. Duff and Nolan (1953) showed that radial increment increases, with distance from the leader, over the first several internodes from the top. Then, radial increment decreases in the older internodes farther down the bole as the age of the cambium increases.

By plotting the average radial increment of trees from different crown positions on the same plot over standardized height rather than cambial age, the annual increment follows an expected general growth pattern over the life of the tree (Fig. 1). The standardized height is the measurement height above ground divided by the total height of the tree. This method provides a basis for comparing the radial increment of trees with different heights. Using balsam fir (Abies balsamea (L.) Mill.) as an example, the radial growth along the bole can be compared for trees of different crown positions (Fig. 1). Trees stressed from competition in a lower crown position have smaller radial increments at comparable locations on the bole, but the growth curves remain similar in shape. Also, as the density or crowding of the stand increases, the crown length and the radial increment in the crown decrease.

CATASTROPHIC STRESS

Catastrophic stress is caused by drastic changes in environmental conditions for short periods of time (a few years). Examples of these changes might be insect or disease attacks or abrupt changes in weather conditions. To follow the changes in annual growth response that occur along the bole of trees under catastrophic stress, all spruce and fir trees on forty-four 0.01 ha plots defoliated by the spruce budworm (Choristoneura fumiferana Clemens) were sectioned and radial growth measured every 1.5 m along the bole (Solomon 1983a). Results of this study indicated that the radial growth response may vary with tree age. Young trees may show larger reductions in growth than older trees when stressed. Piene (1980) showed that the bole-growth response in younger trees is identifiable along the entire bole when they are defoliated. In older dominant trees, the reduction in growth is seen first in the upper bole, and after several years of defoliation can be identified in the lower bole (Belyea 1952; Solomon 1983b).

As the budworm first defoliates the crown of a fir tree, the growth reduction is small. However, after several years of attack the bole growth is reduced within the crown and then, if defoliation continues, is observed in the lower bole (Fig. 2). Younger trees, having a large proportion of their bole length with branches, show a decline in growth at breast height due to defoliation sooner than older trees (Solomon 1985). When trees have catastropic stress removed, such as by protection from insect attack, growth increases in the upper bole first and eventually increases in the lower bole several years later (Fig. 2). These 36-year-old dominant fir trees were defoliated annually from 15 to 90 percent starting in 1973, and were protected in 1975, and 1977 through 1980.

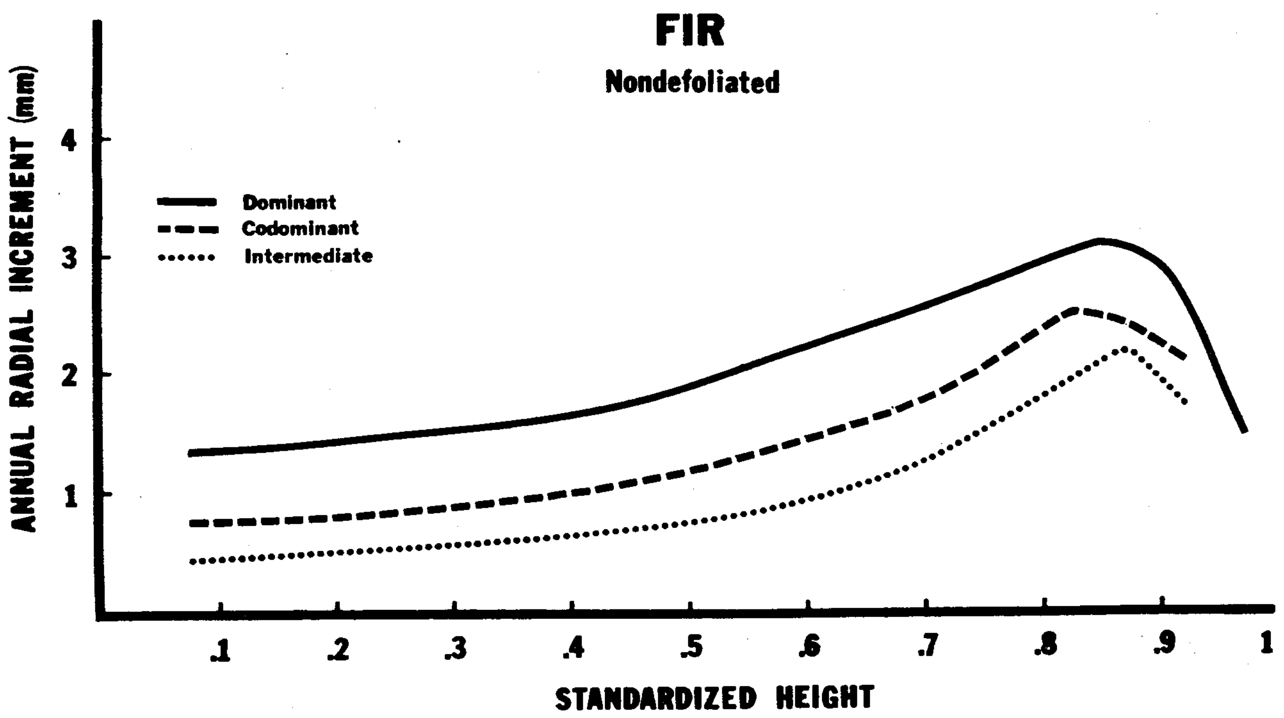

FIGURE 1 -- ANNUAL RADIAL INCREMENT (MM) OF NONDEFOLIATED DOMINANT (▬▬), CODOMINANT (▬ ▬), AND INTERMEDIATE (•••••) BALSAM FIR TREES OVER A STANDARDIZED HEIGHT ABOVE GROUND.

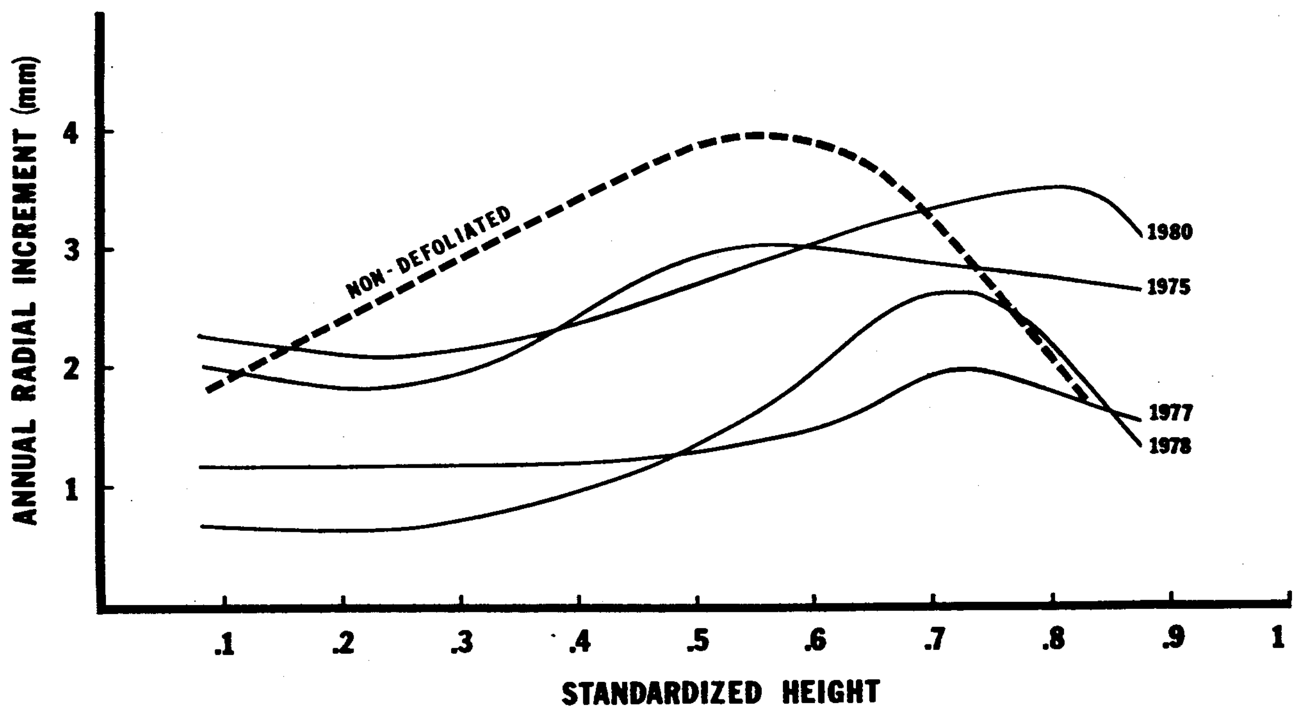

FIGURE 2 -- ANNUAL RADIAL INCREMENT (MM) OF 36-YEAR-OLD NONDEFOLIATED (▬ ▬) AND 15 TO 90 PERCENT ANNUALLY DEFOLIATED (——) BALSAM FIR TREES THAT WERE PROTECTED IN 1975 AND 1977 THROUGH 1980 OVER STANDARDIZED HEIGHT ABOVE GROUND.

MEASURING CHANGES IN INCREMENT

Some forms of stress, although harsh and severe at the time of occurrence, may result in an annual reduction in growth for several years. For example, low spring temperatures or drought may cause considerable changes in one annual radial increment. However, the effects of these types of stress may exist for only a year or two and the tree's physical structure or capacity to recover may not be altered sufficiently to cause a continuing reduction in the radial increment. In some cases, continued reductions in ring width over time have been established (Duff and Nolan 1953). These reductions, although influenced by competition and other stresses, may be the result of the age of the tree and its inability to expand in size, increase in height, or expand crown and roots after it has reached full size potential.

The mean ring width at breast height of seven 79-year-old balsam fir and eleven 98-year-old red spruce dominant and codominant trees from even-aged stands at Northeast Carry, Maine, were plotted on the same time scale (Fig. 3-4). Various stresses can be seen within the plotted data. For example, the regionwide spruce budworm attack from approximately 1910-20 can be distinguished for both spruce and fir. For comparison, Meyer's (1929) breast-high diameter tables were used to determine growth trends of average fir trees and average dominant and codominant spruce trees over time based on a comparable site index. Plots in Meyer's (1929) study that were badly affected by budworm were not included for red spruce tables and the plots that showed some damage for all species were adjusted to compensate for any reduction in diameter growth as well as the loss in numbers of trees. After computing the periodic annual growth for spruce and fir stands at different ages, the mean annual ring widths for site index 50, were plotted over tree age in years (Fig. 3-4). Meyer's 1929 curves for both spruce and fir were aligned on the average annual ring width for the middle of the growth period starting at age 25. This provides a basis for comparing similar species at the same age representing groups of trees or average stands.

The mean annual ring width of both species did not continue to decrease at the same rate after a decline in the level of budworm attack between 1919-1920. However, for several years after attack, the mean ring width increased rapidly for fir but continued at the same width for spruce. This is indicative of a young fir tree's ability to respond with rapid crown expansion and return to the expected growth rate of nonstressed trees of a similar age. As can be seen, the balsam fir trees were able to respond in growth and reach the expected growth of a 20-year-old fir tree after a full complement of foliage was produced (Piene 1980). Spruce did not respond to the expected level possibly due to the loss of foliage on the internodal branchlets that are not as persistent in fir. Also, a second budworm attack around 1940 (Weed 1977) may have had some influence on the trees' recovery so that the mean annual ring width did not continue at the expected growth for fir or even reach that growth for spruce.

Caution should be used when attempting to attribute changes in the mean ring width at breast height to external stresses. Unless the stress continues over long periods of time and is catastrophic enough to affect the entire plant, the resulting ring widths may not be reduced

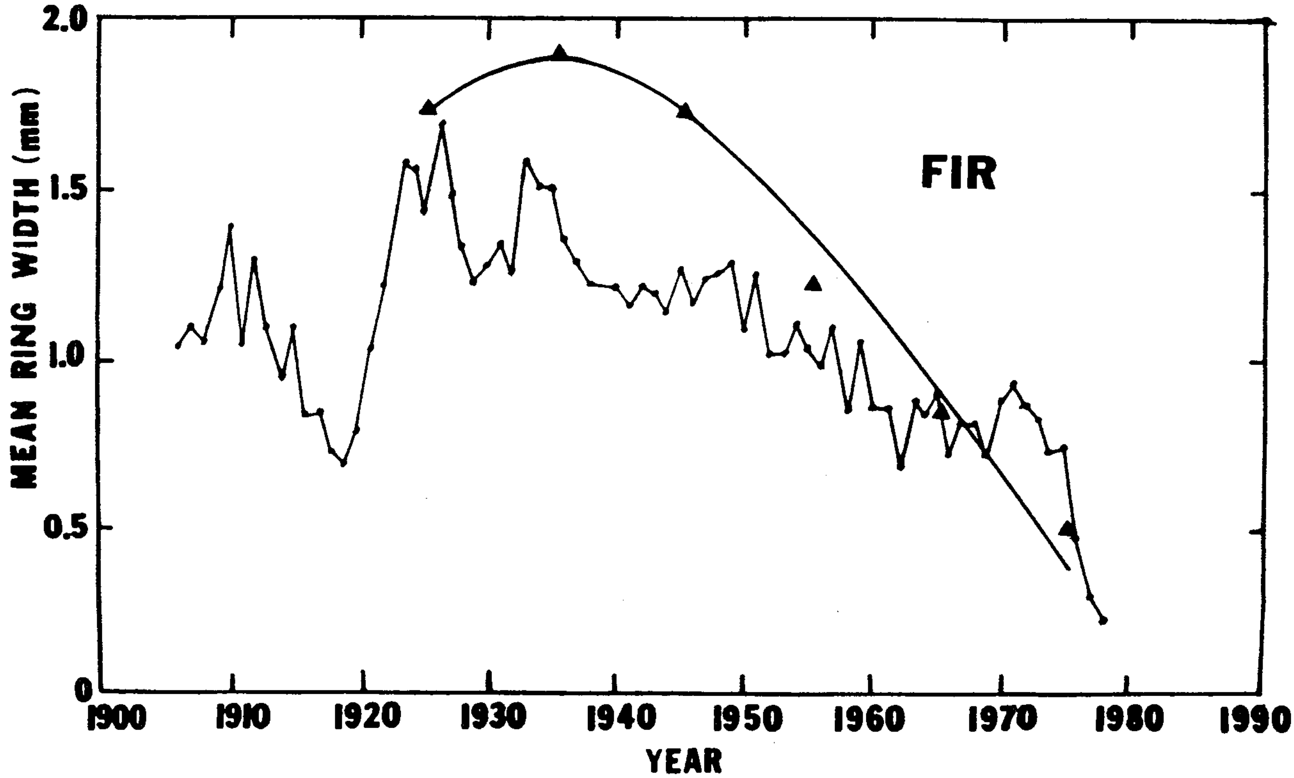

FIGURE 3 -- MEAN RING WIDTH (MM) OF DOMINANT AND CODOMINANT BALSAM FIR TREES FROM NORTHEAST CARRY, ME (• • •) AND MEYER (1929) (▲ ▲ ▲).

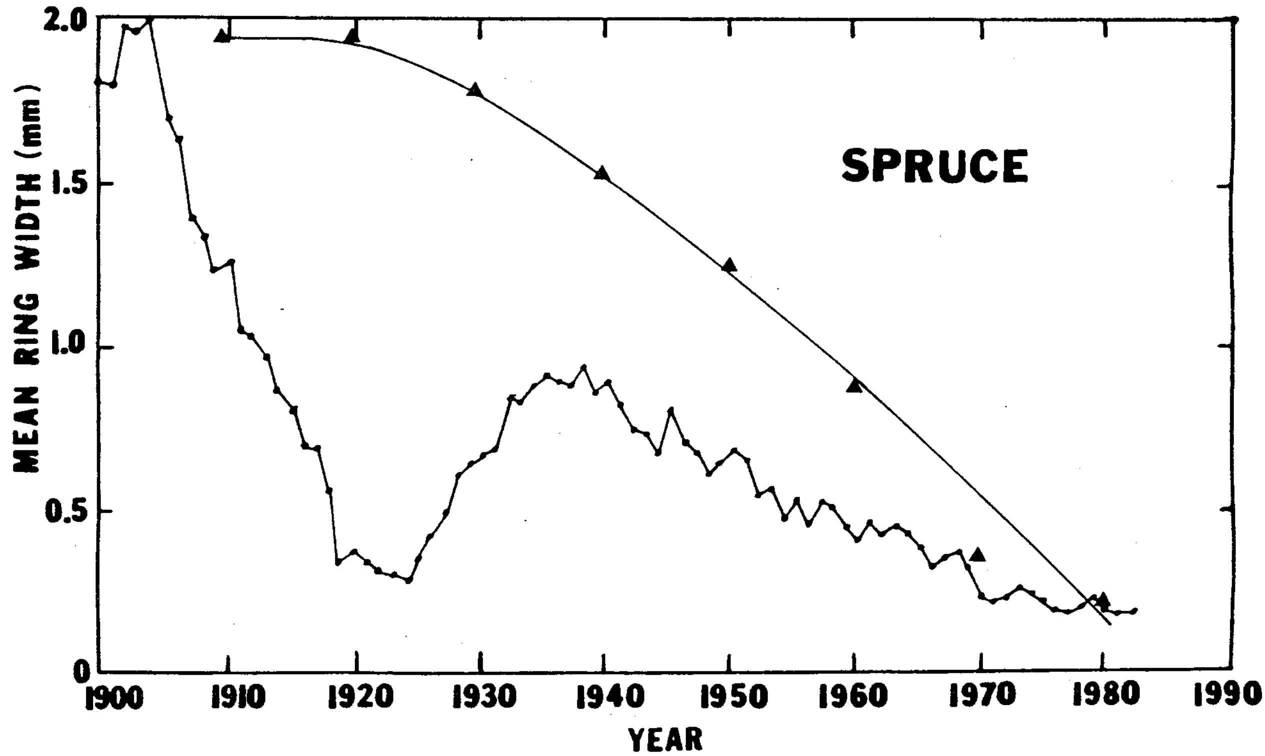

FIGURE 4 -- MEAN RING WIDTH (MM) OF DOMINANT AND CODOMINANT RED SPRUCE FROM NORTHEAST CARRY, ME (• • •) AND MEYER (1929) (▲ ▲ ▲).

significantly. This can be seen in 1965, for example (Fig. 3-4), when the entire plant is stressed by a region-wide drought. When measuring the growth response of stressed trees and making comparisons of that growth to "expected normal" growth, considerations must be given as to tree condition. Frequently we concern ourselves with site and density and their impact on tree growth, but we neglect the longevity of the species and its ability to respond to changes in growth at different ages. Certainly, younger, smaller spruce and fir trees can grow in height and diameter and can develop larger crowns and root systems. However, when older trees are stressed gradually, the reduction in ring width is not as pronounced and the recovery not as noticeable because the capacity to add additional height and crown is limited. Similarly, smaller, older (100+ years) spruce trees in a suppressed crown position produce wide annual rings when released to grow because they can expand their crown and grow in height as a younger dominant tree.

Attempts have been made to identify periods of stress through dendrochronological techniques. However, the base tree used to represent the normal growth pattern usually is affected by some type of stress, either gradual or long-term catastrophic (Fritts 1974). Similar techniques have been used in attempts to identify the influence of atmospheric deposition on red spruce (McLaughlin 1985). Although current growth patterns may be comparable to past growth patterns of trees of the same age, care should be used when explaining what environmental stress might have influenced the radial growth of the trees prior to that point in time.

Recent work has attempted to show the decline in radial increment of ten 84-year-old red spruce trees thought to be stressed by air pollution starting in 1965 (McLaughlin 1985). Using regression, an exponential function was plotted through their points to indicate the general growth pattern and the apparent decline starting in 1962. The difference between the general growth trend for the first 60 to 70 years of the tree's life and the last 10 to 15 years was presumed to indicate substantial growth loss (Fig. 5). However, if the average stand conditions from Meyer's tables for dominant and codominant spruce trees on site index 40 are plotted over time and compared with these trees, the growth loss is minimal. This seems to indicate that average dominant and codominant red spruce trees are growing as expected compared to other trees on similar sites. Similar decline in natural growth has been demonstrated for red spruce and balsam fir (Hornbeck et al. 1986). Although this is not an exact measure of continuous growth of a single stand, it does provide the growth reactions of an average stand at a specific age.

To reduce the amount of variation in ring widths when measured annually, tree growth presented as basal area increment may indicate the same long term decline (Hornbeck and Smith 1985; Phipps 1983). Similarly, the overall periodic growth pattern increases and then decreases for trees with minimal stress especially since ring widths decrease as the size and age of the tree increase beyond a comparable threshold age.

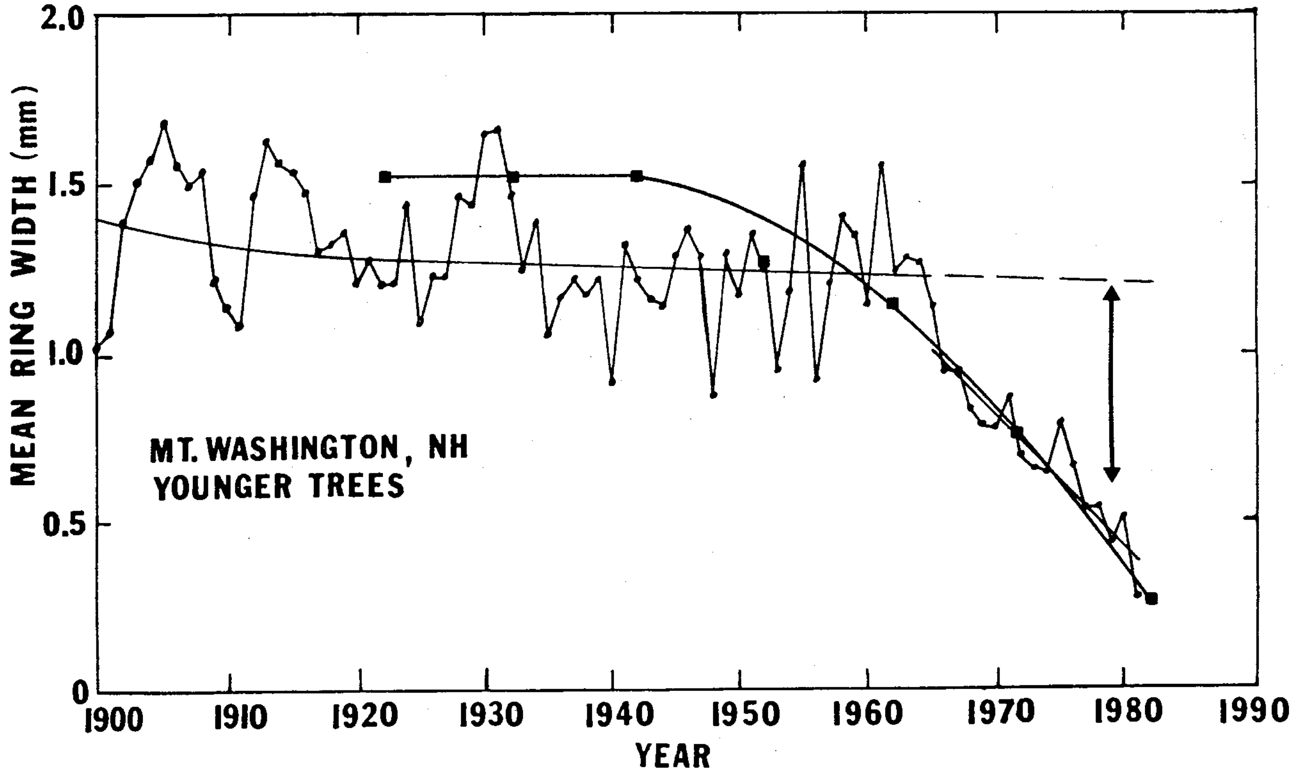

FIGURE 5 -- MEAN RING WIDTH (MM) OF DOMINANT AND CODOMINANT RED SPRUCE TREES FROM MCLAUGHLIN (1985) (●—●—●), MEYER (1929) (■—■—■) AND AN EXPONENTIAL FUNCTION (——).

CONCLUSION

Mean annual ring width is a common measure of tree or stand growth. However, research has shown that (1) radial increment is not the same at different positions along the tree bole, and (2) growth response to stress varies along the bole depending on the type of stress and the age or condition of the tree. It follows that measurements of radial growth at one point on the tree (e.g., dbh) are not fully adequate to either characterize volume growth over a range of ages, sites, stand densities, etc., or to detect early signs of environmental stress since annual rings decrease first in the upper bole.

In addition, past growth cannot be used as a model for projecting future growth unless careful consideration is given to the levels and types of environmental stress, and to when the stress occurs in the life of the tree.

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ENVIRONMENTAL INFLUENCES ON ECCENTRICITY, OUT-OF-ROUNDNESS AND BARK THICKNESS IN *PINUS RADIATA*

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Abstract--Multiple linear regession models using data from 96 plots show eccentricity, bark ratio and wandering pith to be related to a number of environmental factors. In contrast bark thickness is relatively independent of site conditions. Although considerable refinement can be made using additional environmental measurements, the R^2's were too low (30%-44%) to warrant inclusion in simulation models.

Keywords: Eccentricity, mensuration, *Pinus radiata*, bark thickness

INTRODUCTION

Bark thickness and stem eccentricity have received relatively minor attention from forest mensurationists in spite of their role as important parameters in volume estimation and in the assessment of sawtimber quality. Most studies have concentrated on the relationship between bark thickness, eccentricity or out-of-roundness and individual tree measurements such as height, diameter, taper, or age. The emphasis has been on the measurement and estimation of these parameters rather than an examination of how these characteristics vary in relation to the growing site or related environmental factors (Gordon, 1983; Monserud, 1979; Pederick, 1970).

Some reasons for paying a greater interest to bark thickness are: increased use of simulation models for individual tree and stand volume prediction, use of automatic scaling devices at processing plants, use of bark and biomass for energy production, and the need to predict past overbark measurements from stem analysis data. The variation in bark thickness along the stem is an important characteristic for the prediction of injury and mortality following fire (Grassia, 1980). Systematic variation in bark thickness will introduce bias in the prediction of stem volumes if overbark diameter measurements are used in conjunction with regional volume estimation functions (Loetsch, Zöhrer and Haller, 1973; Smith and Kozak, 1981).

Bark thickness varies according to site, age, species and genetic composition (Pederick, 1970). Changes in the bark ratio (overbark/underbark diameter) play an important role in stem form and underbark stem form is often less variable between species than over bark stemform (Assmann 1970). In pine trees the bark remains relatively thin in the upper two thirds of the crown, but increases rapidly in the lower bole where it is associated with, and is a major contributor to, butt swell (Sands, 1975). Bark ratio shows a clear curvilinear relationship with tree height, remains static for a major portion of the central bole, but decreases towards the base and in the upper crown (Gordon, 1983).

Evidence for site specific changes in bark thickness is uncertain. Locality and individual trees within each locality were found to be significant factors associated with the variation in bark ratio, but the proportion of the variation explained was low (<15%) in New Zealand (Gordon 1983). Hill sites were separated from other poorer drained soils because in the former the bark was found to be thicker in the lower parts of the stem in Pinus elliottii (Miller, 1961). A regional study, using breast height measurements from site index plots, found little difference between the relationships for double bark thickness and diameter overbark over a considerable area for Douglas-fir (Monserud, 1979). Changes in bark thickness may be confounded with genetic variation in natural populations and this may tend to obscure site differences (Pederick, 1970; Smith and Kozak, 1981).

The terms eccentricity and out-of-roundness are often confused in the literature. Out-of-roundness or ellipticity clearly refers to the deviation of the cross-sectional shape of a tree section from that of a circle. Eccentricity is the deviation of the pith from the centroid or geometric centre of any section. Out-of-roundness commonly increases with size of the tree, it has been associated with tree lean, crown geometry, prevailing wind direction and slope angle (Kellog and Barber, 1981). Out-of-roundness decreases away from branch whorls and is smaller towards the apex of the tree.

Measurements of eccentricity are often confounded with those of out-of-roundness and there is general agreement that a close relationship exists between these two parameters. Eccentricity is associated with the formation of compression wood in pines and can influence the utilization for veneer, plywood and sawn timber (Nicholls, 1982). An additional characteristic which is of importance in sawn timber is "wandering pith". The orientation of the longest radius may change with position up the stem in some trees. This "cork-screw" effect or rotation of the eccentricity up the stem is responsible for a number of drying defects in sawn timber when associated with compression wood.

The objective of this study is to examine the changes in bark thickness, bark ratio, eccentricity and wandering pith in the Southern Cape region of South Africa. This work forms part of a larger study which examines the influence of site factors on height and diameter growth, stemform and tree volume in Pinus radiata.

METHODS

Sampling and Measurements

Stands for sampling were drawn at random from a list of compartments which were 18 years or older, after stratification into 500 foot (152.4

m) altitude classes. Plots were established on areas of uniform slope shape, aspect, slope angle and soil type. Particular attention was paid to uniformity of stocking, ground cover and to the avoidance of pronounced breaks in the tree canopy. At each plot simultaneous measurements were made of tree and stand parameters, and a number of environmental factors were recorded (Tables 1 and 2).

The environmental measurements included 12 exposure indices obtained by recording the altitude at eight points on circles located at a radius of one, three and five kilometres from the plot and measuring the area higher than the plot within these circles. Soil morphological measurements included binary, ranked and continuous variates used to depict soil depth, dominant pedological processes, colour, structure and other characteristics known to influence tree growth from both the top- and subsoils.

Soil chemical analysis yielded a further 21 possible independent variates. The data set was reduced to 78 observations for subsoil chemical factors due to the absence of well formed B horizons on some plots.

Table 1. Particulars of 96 stratified random plots in *P. radiata* stands. Southern Cape

Particulars	Units	Mean	Standard Deviation	Range Min.	Max.
Plot size	m^2	835.9	337.8	254	1780
Age	yrs	24.9	5.1	18	50
Stocking	Stem/ha	500.8	260.5	185	1516
Mean DBH	cm	30.7	7.9	16	54
Mean height	m	26.6	5.7	13	43
Site index	m	25.7	4.5	13	37

N = 96

Stem Analysis

Four trees were selected for stem analysis. Based on the diameter distribution recorded for each plot, trees closest to the plot centre and with diameters corresponding to (1) the mean of the lower and (2) upper quartile, (3) the quadratic mean and (4) the quadratic mean less one and a half standard deviations were felled. Sections were cut at varying intervals up the stem at the internodes. Compulsory cuts were made at breast height (1.3 M) and at seven metres unless a branch whorl was present.

Table 2. Particulars of trees used for stem analysis.

Particulars	Units	Mean	Standard Deviation	Range Min	Range Max
DBH	cm	28.6	9.6	8.1	69.0
Height	m	26.5	6.4	9.9	48.8
Height prunned	m	5.7	1.9	1.0	9.8
Height line crown	m	11.5	5.3	1.0	27.6
Height to smooth bark	m	9.1	5.3	1.0	30.0
Crown width	m	2.1	0.85	0.3	5.5
Crown percentage	%	51.9	12.2	19.8	81.0
*Competition index 1	m^{-1}	1.4	0.6	0.5	4.3
**Competition index 2	m^{-2}	5.5	1.4	2.6	14.2

N = 96

* After Hegyi, 1974.
** Same as competition 1 but using square of distance.

At each section, the overbark and underbark diameters were taken using a diameter tape, the longest diameter, the diameter at right angles to this through the pith, and the section height were recorded. Bark thickness was measured with a vernier caliper at three places around the section and averaged. The orientation of the longest radius (using magnetic north) was noted from marks placed on the tree before felling.

An assessment was made of the crown class. Measurements were taken of height to the live crown, the point where the bark changed from being fissured to smooth, maximum and minimum crown radius, and the diameters and distance to the nearest five competing trees.

Eccentricity was calculated from the ratio of the longest diameter to the diameter at right angles. This is a confounded measure. Bark ratio was expressed as the quotient of overbark (DOB) to underbark (DUB) measured after having removed the bark. Weighted averages were calculated for eccentricity, bark thickness and bark ratio using the square of the underbark diameter.

Mean and variance were computed for the longest radius using directional statistics (Mardia, 1972).

Data Analysis

Analysis was performed using SAS (SAS Institute Inc., 1982). Two data sets were compiled from the basic measurements. The particulars of individual sections cut at 1.3 m and 1.7 m were compared with the corresponding tree characteristics (Table 2). A second data set contained plot means of the four trees where individual tree values were weighted means (Table 3).

Table 3. Weighted mean parameters per tree.

Parameter	Units	Mean	Standard Deviation	Range Min	Range Max
BWT	mm	11.6	3.9	0.01	25.6
EWT	-	1.07	0.03	1.01	1.25
BRWT	-	1.11	0.03	1.03	1.45
SO	deg^2	0.96	0.01	0.81	0.99

N = 384
BWT = weighted bark thickness per tree
EWT = weighted eccentricity per tree
BRWT = weighted bark ratio per tree
SO = circular variance of the orientation of the longest radius (wandering pith)

The stepwise model used to screen the independent variates had three dependent variates and ten independent variables. It was run twice, i.e. for 1.3 m and 1.7 m sections.

A similar model was used to screen the variables for the prediction of plot weighted means. This model had 85 independent variables when the reduced data set with subsoil chemical factors was run.

To test for the influence of categorical variables such as tree class, presence/absence of mottles, stonelines and rooting restrictions, a final run using the GLM procedure was made with dummy variables and the variates shown by the stepwise model to be contenders (SAS Institute Inc., 1982).

RESULTS

Bark Thickness

The influence of individual tree characteristics on the estimation of bark thickness at two heights was examined first. As expected diameter played a major role in the final model (constructed using the stepwise procedure). At breast height 59% of the variation was explained while at 7 m the model R^2 improved to 0.66. Height to smooth bark, a competition index (Hegyi, 1974) and crown class although highly significant, contributed less than 12% to the regression sum of squares (Table 4).

Diameter at breast height for the plot was the best predictor for weighted average bark thickness. Inclusion of topographic, soil morphology and soil chemistry measurements improved the R^2 from 0.54 (for stand factors only) to 0.65. Ground cover, rooting depth, sodium and magnesium in the A horizon made minor contributions.

Table 4. Results from stepwise regression models using individual sections.

Dependent variable	Regress df	R^2	F
1.3 m			
ECC	3	0.067	9.07
BARK	5	0.594	109.8
BRKR	4	0.096	9.99
1.7 m			
ECC	1	0.008	3.28
BARK	4	0.661	183.4
BRKR	6	0.154	11.38

ECC = eccentricity (DMAX/DMIN)
BARK = bark thickness in mm
BRKR = (DOB/DUB) both measured by diameter tape
N = 384

Bark Ratio

The bark ratio was more difficult to predict using the existing data set and the variation accounted for was 9.6% at 1.3 m and 15.45% at 7 m showing similar trends to bark thickness. Height to smooth bark played a dominant role in both models (Table 4).

Environmental factors played a greater role in the prediction of weighted bark ratio plot means than in bark thickness. Model R^2 increased from 0.28 to 0.44 after ground cover, rooting depth, calcium, sodium in the A horizon and B horizon magnesium were added to stocking and site index (Table 5).

Table 5. Results from stepwise regression models based on plot averages of individual tree means.

Dependent variable	Regression d.f.	R^2	F
EWT	4	0.304	9.61
BWT	4	0.646	39.9
BRWT	6	0.437	11.4
SO	7	0.425	9.01

N = 96

Eccentricity

At breast height the selected model explained only seven percent of the variation and this decreased to less than one percent at seven metres. At the plot level prediction was much improved. Age, ground cover, carbon content, sodium in the A horizon, and terrain unit together explained 30% of the variation in this data set.

Orientation of the Longest Radius

There was no apparent relationship between the direction of the longest radius and any tree characteristic for either of the two stem heights (1.3 m or 1.7 m).

The variance of this measurement, which gives an indication of the degree of wandering pith, was associated with site index, organic carbon, geology, soil moisture, topsoil sodium, and subsoil calcium (model R^2 = 0.42).

DISCUSSION

Although the SAS stepwise procedure tests all variates included in the model prior to adding further steps, this technique can only be regarded as a rough screening method. The model R^2, the partial sum of squares and the t test for the parameter estimates were used to evaluate relative contributions to the model. No attempt has yet been made to improve individual model fit by the examination of residuals, use of jackknife procedures to identify high leverage observations, or to reduce variance inflation by substitution in cases where multicollinearity may have been a problem (Montgomery and Peck, 1982).

Tree class and breast height diameter have a major influence on weighted bark thickness per plot. Environmental factors accounted for ten percent of the partial sum of squares (model R^2 = 0.63). There was a slight indication that trees on better sites (lower slopes, high organic content and deeper rooting soil profiles) have thicker bark. No influence due to age, tree height or exposure could be detected. Bark ratio showed less dependence on stand factors and six factors (soil moisture, ground cover, stocking, age, rooting depth and drainage class) accounted for 75% of the partial sum of squares (PSS) (model R^2 = 0.49).

As has been noted in other studies, eccentricity was more difficult to explain (model R^2 = 0.37). Tree class was not significant although age, stocking and site index contributed 30% to the PSS. Sites with older trees, lower stocking, low in subsoil phosphate but high in organic matter tended to have higher eccentricity. Wand with low clay in the soil profile (sandy parent materials), high organic matter, greater precipitation and lower soil pH values. This tends to suggest that stands planted on dune sands are more prone to wandering pith than are equivalent stands on granites, clays or colluvial soils. Tree class, diameter and height had little apparent influence on this parameter. The influence/ contribution of age was far less than its role in the prediction of eccentricity.

CONCLUSIONS

Bark thickness is a difficult parameter to measure in a nondestructive way, yet it has important implications for fire resistance, processing and transport costs, and plays a role in the estimation of tree and stand volume.

Analysis showed that environmental factors only account for roughly 5% of the variation in bark thickness. Improved estimation of bark thickness *per se* through the incorporation of site factors does not warrant additional attention.

Environmental factors were shown to play a far greater role in the prediction of bark ratio, eccentricity and wandering pith. The proportion of the variation accounted for is, however, still too low (30%-44%) to make a marked impact on simulation modelling or for the incorporation of additional measurements in existing decision aids.

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UTILIZATION OF TREE INCREMENT DATA IN FOREST STAND GROWTH PROJECTIONS

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Mankind has long been fascinated by tree rings. In one of my more philosophical moods, I concluded that this is because the tree bears a definite record of its past, while the passing of most of us is soon obliterated by the sands of time. Foresters, one of the more pragmatic segments of our species, find tree rings a useful means of evaluating past growth and predicting future increment. Our zest to study them is only momentarily diminished when we lose $100 increment borers in $3 trees.

Height increment, except for uninodal conifers, is more difficult to measure. Yet height and not diameter is the more important variable when estimating volume with the popular point sampling techniques. It is a cruel fact that we often measure diameter more closely than necessary and height more crudely than we should simply because we are too short (or trees are too tall). In the same vein, we recognize that for the same reason diameter is not measured at the optimum location.

With great courage, however, foresters make growth projections far into the future using diameter and height variables. Unexpected showers which soak us and the tally sheets recording this data should serve to remind us that projections always entail risks. Our techniques are improving in this exciting endeavor as the papers given will demonstrate.

UNBIASED ESTIMATION OF BOLE INCREMENT

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Abstract--A two-stage sampling procedure that furnishes an unbiased estimate of the volume increment of a tree bole is described. Simulation and a field-test indicate the expected precision of an estimate.

Keywords: Monte Carlo integration, importance sampling, growth.

INTRODUCTION

Currently, in forest samplings, quantities such as volume and volume increment are not estimated directly. Instead, predictor variables such as diameter at breast height and tree height are measured, and regression equations are used to estimate volume indirectly (Husch, et al. 1982). If a regression equation derives from a population different from the population of current interest, then the resultant estimates of volume or increment may contain a serious bias that generally is not estimable and does not decrease with increasing sample size.

In this paper, we describe a two-stage sampling procedure that furnishes an unbiased estimate of the volume increment of the bole of a tree. Importance sampling -- a continuous analogue of sampling with probability proportional to size -- is used in the first stage to randomly select a cross section of a bole with probability proportional to its predicted area increment. In the second stage, radii are selected at random from this cross section for unbiased estimation of the area increment. Multiplication of this unbiased estimate by the first-stage inflation factor gives the unbiased estimate of the volume increment of the bole.

Importance sampling is a variance-reduction technique of Monte Carlo integration (Rubinstein 1981). In addition to estimating volume increment, uses of importance sampling in forestry-related applications include estimation of total tree biomass or volume (Valentine, et al. 1984), log volume (Furnival, et al., 1986), and bole volume (Gregoire, et al., 1986).

FIRST-STAGE SAMPLE

We denote the length of a bole by H, and the cross-sectional area increment at any point h along the bole by A(h), where $0 \leq h \leq H$. Therefore, the volume increment (v) of the bole is:

$$v = \int_0^H A(h)dh \tag{1}$$

We use importance sampling to estimate this integral. To proceed, we need a proxy function, S(h), that approximates A(h) and integrates to give an approximation of the volume increment of the bole:

$$V(H) = \int_0^H S(h)dh \qquad 0 \leq h \leq H;\ S(h) > 0 \tag{2}$$

We use the proxy function to define a frequency function for h:

$$f(h) = S(h)/V(H) \tag{3}$$

so that

$$1 = \int_0^H f(h)dh \qquad f(h) > 0 \tag{4}$$

Thus, we can represent the integral in (1) as the expectation of A(h)/f(h):

$$v = \int_0^H f(h)[A(h)/f(h)]dh \tag{5}$$

Consequently, if h_i is one of m points along the bole selected independently and proportional to f(h), then an unbiased estimate of v is:

$$\begin{aligned} \tilde{v} &= 1/m \sum_{i=1}^{m} A(h_i)/f(h_i) \\ &= V(H)/m \sum_{i=1}^{m} A(h_i)/S(h_i) \end{aligned} \tag{6}$$

The point of measurement, h_i, of the cross-sectional area increment, $A(h_i)$, is determined by calculating the root of

$$V(h_i) = uV(H) \qquad 0 \leq h_i \leq H \tag{7}$$

where u is a uniform [0,1] random number.

For the proxy function, we can use a segmented-linear function that interpolates approximate area increments, $S(L_s)$, obtained from radial measurements at arbitrary points (L_s, s-1,2,...,t) along the bole, including $L_1=0$ and $L_t=H$. The proxy function is integrated piecewise by the trapezoidal rule (Smalian's formula) to give $V(L_s)$ for $s=2,3,\ldots,t$. The point, h_i, for measuring area increment occurs on the z^{th} segment (that is, between L_z and L_{z+1}) if

$$V(L_z) < uV(H) < V(L_{z+1})$$

The exact point of measurement (that is, the root of (7)) is:

$$h_i = L_z+[-b+(b^2-4ac)^{.5}]/2a \qquad (8)$$

where

$$a = [S(L_{z+1})-S(L_z)]/(L_{z+1}-L_z)$$

$$b = 2S(L_z)$$

$$c = 2[V(L_z)-uV(H)]$$

The value of the proxy function at h_i, which is needed for (6), is:

$$S(h_i) = S(L_z)+(h_i-L_z)a \qquad (9)$$

The importance sampling is facilitated by a programmable pocket calculator or a battery-powered personal computer.

SECOND-STAGE SAMPLE

Measurement of area increment, $A(h_i)$, can be difficult and costly. However, the area of a non-circular cross section can be unbiasedly estimated with random radii measured from a fixed interior point (Matern 1956). To estimate area increment at h_i, we draw a straight baseline from the pith to the perimeter of the cross section. Then, at a random angle from the baseline, we measure the radius (r_1) to the beginning of the incremental period of interest and the radius (r_2) to the end of this period, and estimate $A(h_i)$ by

$$\hat{A}(h_i) = \pi({r_2}^2-{r_1}^2) \qquad (10)$$

If radii are measured at two or more random angles, we obtain separate estimates of $A(h_i)$ with (10) and then average these separate estimates to produce one combined estimate for insertion into (6).

ACCURACY OF IMPORTANCE SAMPLING

Data from 283 spruce or fir trees located in Maine were collected by Dr. Dale Solomon in connection with the CANUSA Spruce Budworms Research Program. Discs were cut at 1- to 1.5-m intervals over the length of the bole of each tree from stump height to within 1.5 m of the tip of the crown. Outside-bark diameter (measured with a diameter tape), annual radial increments along a single radius selected by the investigator, and bark thickness were measured on each disc.

We analyzed these data to gauge the precision of our first-stage procedure. For each disc, radial increments and the bark thickness were adjusted to sum to one-half of the outside bark diameter and, then, the adjusted radial increment for the most recent 10-year period was converted to 10-year area increment (assuming a round cross section). For each tree, the 10-year area increments at their known disc heights were fitted with an interpolating cubic spline. The evaluation of the specific spline for a particular tree at height h was defined as the true 10-year increment, A(h), and the integral of the spline was defined as the true 10-year volume increment of the tree.

Table 1. Results of preliminary field test of procedure for estimating 10-year volume increment of individual tree boles. Volumes are given in cm^2m.

Tree	V(H)	$\tilde{v}$	se($\tilde{v}$)	100%se($\tilde{v}$)/$\tilde{v}$
1	455.5	507.4	89.9	17.7
2	1479.3	1270.7	25.2	2.0
3	653.0	502.2	34.4	6.8
4	449.9	368.7	3.3	0.9
5	191.1	206.9	28.3	13.7
6	589.9	741.4	15.9	2.1
7	894.8	856.0	101.3	11.8
8	637.9	596.8	0.5	0.0
9	849.3	761.6	61.4	8.1
10	925.3	938.0	58.8	6.3
Σ	7126.0	6749.7	168.7	2.5

A segmented-linear proxy function, S(h), was developed for each of the numerically defined trees. Evaluation of the spline at the butt, breast height, height to the base of the live crown, and the height of the top disc provided the needed area increments to define the three segments of this function (figure 1).

The variance of $\tilde{v}$ based on measurement of m cross sections selected by importance sampling was calculated as:

$$Var(\tilde{v}) = V(H)/m\int_0^H [A(h)^2/S(h)]dh - v^2 \tag{11}$$

The relative sampling error was calculated as 100%Var($\tilde{v}$)0.5/v for m=1 for each of the 283 trees. For 282 of these trees, this error ranged from 3.7% to 34.4%. The other tree had an error of 67.6%. The average error was 14.1%. A reduction in this average error can be achieved by adding more segments to the proxy function so that it more closely approximates the actual cross-sectional area increment profile, or by selecting more cross sections at random by importance sampling. Construction of a proxy function with an additional measurement of cross-sectional area increment midway between breast height and the base of the live crown reduces the

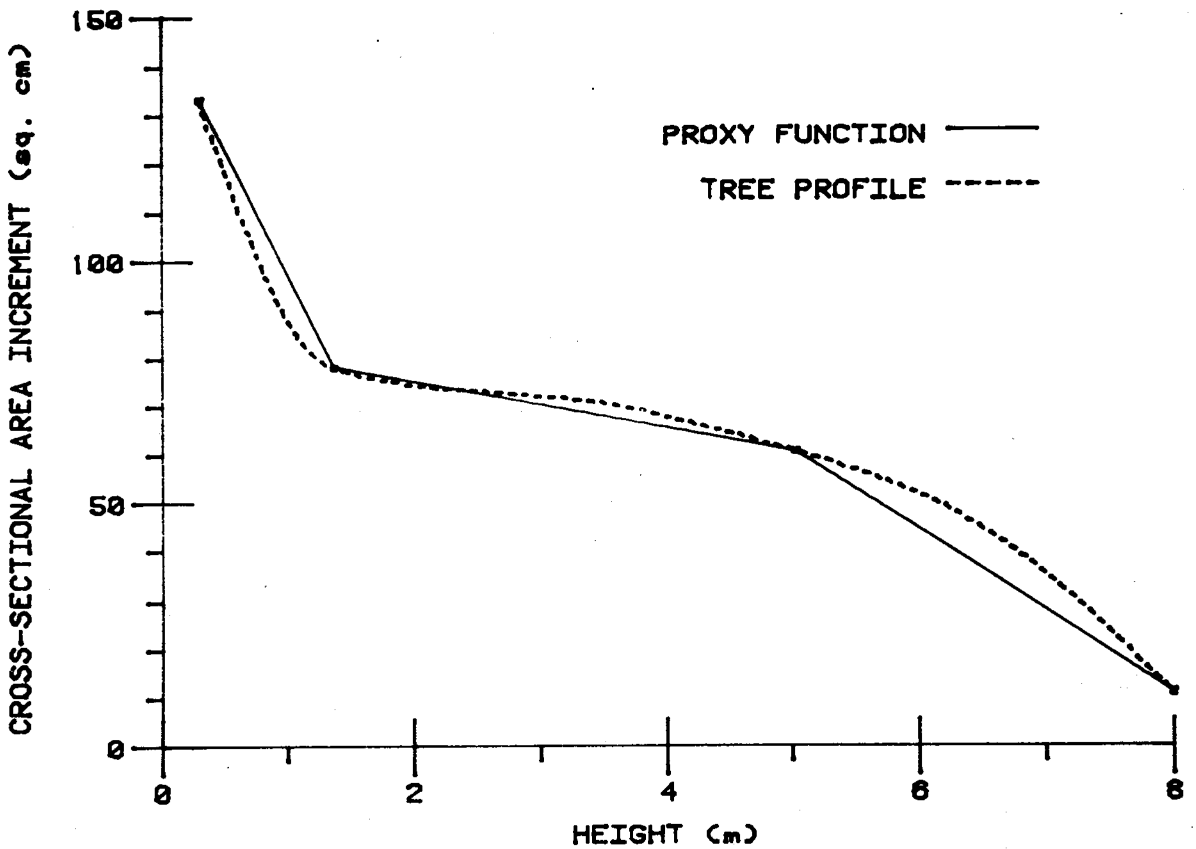

Figure 1. A triply segmented-linear proxy function for a cross-sectional area increment profile of a tree bole.

average error to 12.5%. However, retaining the triply segmented-linear proxy function and selecting m=2 cross sections per bole at random by importance sampling reduces this error to 10.0%.

In a preliminary field test of the procedure, we estimated the volume increment over the last 10 years by our two-stage procedure for 10 trees in a spruce/fir stand at the Hubbard Brook Experimental Forest in W. Thornton, NH. Each tree was felled and a proxy function was developed from four radial measurements at each of four heights: butt, breast height, height of the base of the live crown, and height to a 5-cm-diameter cross section. Two cross sections per tree were selected by importance sampling, and 5 radii selected at random were measured on each of these cross sections. The results of this test are given in Table 1. A battery-powered portable microcomputer greatly facilitated the sampling in the woods.

DISCUSSION

Our sampling procedure was developed primarily for use by investigators of the effects of atmospheric deposition on tree growth. Trees grown under experimentally controlled conditions or in an experimental arrangement along a depositional gradient can be subsampled to determine volume increment with a high degree of precision. It is also reasonable to use the procedure to develop regression equations relating volume increment to more easily measured predictor variables. Use of this or any other subsampling procedure in an inventory survey will result in an over estimation of stand increment unless the volume lost from tree mortality during the period of interest is taken into account. Stand volume increment can be estimated by repeated applications of the procedure described by Gregoire et al. (in press).

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STAND VOLUME INCREMENT ESTIMATION WITHOUT TREE VOLUME TABLES: THE CRITICAL HEIGHT METHOD

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The critical height (h_c) of a tree which is included in a point sample is defined as the height to a point on the tree bole where the stem diameter exactly subtends the point-sample sighting angle. The estimator (v) for stand volume is:

$$v = \text{BAF} \, \Sigma \, h_c$$

where BAF is the point sampling basal area factor.

This estimator is proved to be unbiased under several assumptions about tree taper, including a compatible volume equation - taper function model. For estimating stand volume increment from monumented point-sampling plots, the estimator very likely has a smaller variance than the usual compatible estimator of growth and is also a compatible estimator (i.e. [Volume at time 2) = (Volume at time 1) + growth]). Variances of the ongrowth and nongrowth components of the volume growth estimator based on critical heights are shown to be less than the variances of these components in the usual compatible estimator.

THE EFFECT OF NITROGEN FERTILIZER ON PROPORTIONAL GROWTH RELATIONSHIPS OF DOUGLAS-FIR

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Abstract--The effects of nitrogen fertilizer on contributions of basal area increment and height increment to volume increment are examined for Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco). Results indicate that volume growth rate on fertilized stands of a given site index is not proportionately distributed as one might expect for unfertilized stands of higher site index.

Keywords: proportional increment, nitrogen, response, forest fertilization

INTRODUCTION

Nitrogen fertilization has become an important silvicultural option for land managers to consider in the Pacific Northwest. Operational fertilization has gained widespread acceptance as a method of significantly increasing timber and fiber production of Douglas-fir (Pseudotsuga mensiesii (Mirb.) Franco). There is ample evidence in forestry literature of both absolute and relative increases in growth increment from fertilizer. There is also evidence that volume growth response to fertilizer is greater for stands of lower productivity, and thus may be interpreted as a short-term increase in site index. In fact, many growth and yield forecasting systems compute this response either by projecting a greater growth response on stands of lower site index, or by introducing a short-term increase in actual site index to reflect this increased growth. However, these adjustments may be oversimplifying the effect of fertilizer on tree and stand growth, since there is really not very much information available on how this response is distributed between the major volume components of height and basal area.

One method for examining the contributions of basal area increment and height increment to total volume increment is through the use of proportions or percent growth. The notion of expressing growth as a percentage for forecasting volume is not new to forestry (Gevorkiantz 1927, Hanzlik 1927, 1928, Rudolf 1930). The potential for altering these relationships with fertilizer has been examined by Jenkins (1975), using dominant and codominant Douglas-fir in natural unthinned fertilized stands for an array of age and site index combinations. This paper addresses proportional growth relationships in young spaced plantations, the impacts of fertilizer on altering these growth relationships, and the implications for projecting volume growth under an intensive fertilizer regimen.

EXPERIMENTAL METHOD

Field Design

Each field installation contained six 0.04-ha sized plots:

3 plots -- unfertilized
3 plots -- received 224 kilograms of nitrogen per hectare

A total of 11 installations (33 plots per treatment) was used in the analyses. These installations represent a major portion of installations which were established in 1980 by the Regional Forest Nutrition Research Project[1] in young spaced stands of Douglas-fir. Prior to applying fertilizer, these stands were reduced to a common level of 750 trees per hectare (30 trees per plot). Total tree height and diameter at breast height were measured initially and thereafter at 2-year intervals on all trees. Basal area per tree was computed initially and after each measurement. Total cubic volume per tree was estimated using equations developed by Bruce and DeMars (1974). Average breast height age of all stands was 9 years, ranging from 6 to 15 years. Based on site index (King, 1966) of nearby older stands, these young plantations are generally site class II or III.

Proportional Growth

Consider the volume (V) of a tree as the product of height (H), basal area (B), and cylindrical form factor (F).

$$V = BHF$$

Then the incremental change in volume ($V + \Delta V$) can be expressed as a function of B, H, and F, and their incremental changes (Δ):

$$(V + \Delta V) = (B + \Delta B)(H + \Delta H)(F + \Delta F)$$

and likewise the proportionate or relative change in the parameters:

$$\frac{(V + \Delta V)}{V} = \frac{(B + \Delta B)(H + \Delta H)(F + \Delta F)}{BHF}$$

such that with a little algebra

$$\frac{\Delta V}{V} \cong \frac{\Delta B}{B} + \frac{\Delta H}{H} + \frac{\Delta F}{F} + \ldots \text{ (+ crossproducts)}$$

[1]Details of RFNRP objectives and design have been documented by Hazard and Peterson (1984).

Assuming a nonsignificant change in form factor and very small contributions from the product of 2 or more proportions over a short period, the proportional growth in volume (P_v) may be approximated with proportionate growth in basal area (P_b) and height (P_h):

$$P_v \cong P_b + P_h$$

Analytical Methods

Analysis of variance was employed with arcsine transformation to test proportional increments for significant differences due to fertilizer. In addition, a variety of nonlinear models was examined to graphically express the growth relationships over stand age. After some experimentation a model of the form $Y = 1/(a + b*Age)$ proved to be suitable for expressing compatible relationships between each proportional growth variable and age. Data for the control group and fertilized group were fitted separately to the model using a nonlinear regression procedure.

RESULTS

Proportional growth relationships of P_v, P_b, and $P_b + P_h$ are shown in Figures 1a and 1b for control plots and fertilized plots, respectively. The graphs are quite similar in that

i) P_b is the principal component of P_v, and

ii) ($P_b + P_h$) improves as an approximation of P_v with increasing stand age.

The effect of fertilization on each of the growth components is illustrated in Figure 2. The shape of trends over stand age do not appear to change with fertilizer. The proportions are, however, increased by the addition of fertilizer, and significant for both P_v ($p = .05$) and P_b ($p = .03$), but not for P_h ($p = .19$). ANOVA results also indicated that the ratio of P_b/P_h was significantly increased ($p = 0.005$) with fertilization. This relationship with stand age, as illustrated in Figure 3 (young plantations), demonstrates that P_b/P_h for the unfertilized plantations approaches 2.0 as breast height age nears 15 years. That is to say, for plantations, the contribution of proportional basal area growth is twice that of proportional height growth, and this relative contribution is increased from fertilization. Examples of these trends for both a low and high site index from Jenkins' (1975) fitted equations are also illustrated in Figure 3 (older natural stands) for discussion below.

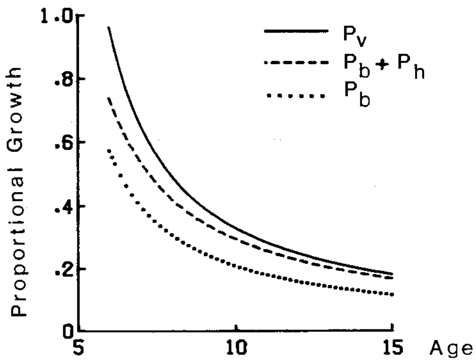

Figure 1a. Proportional growth relationships in young untreated Douglas-fir plantations; P_v, P_b, and P_h represent relative growth of volume, basal area, and height, respectively.

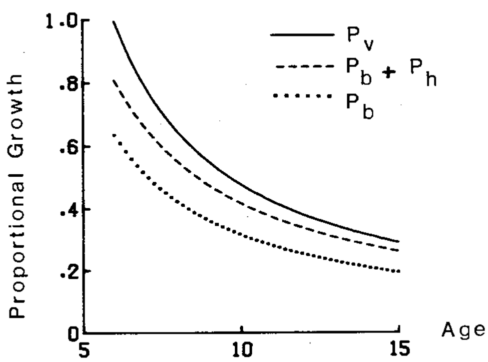

Figure 1b. Proportional growth relationships in young fertilized Douglas-fir plantations; P_v, P_b, and P_h represent relative growth of volume, basal area, and height, respectively.

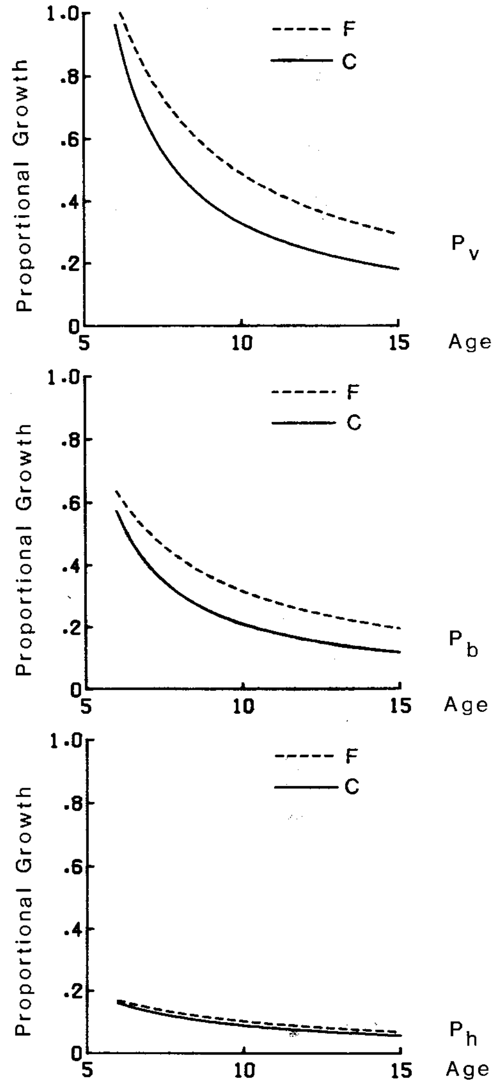

Figure 2. Proportional growth in young Douglas-fir plantations for 0 kg-N/ha (C) and 224 kg-N/ha (F); P_v, P_b, and P_h represent relative growth of volume, basal area, and height, respectively.

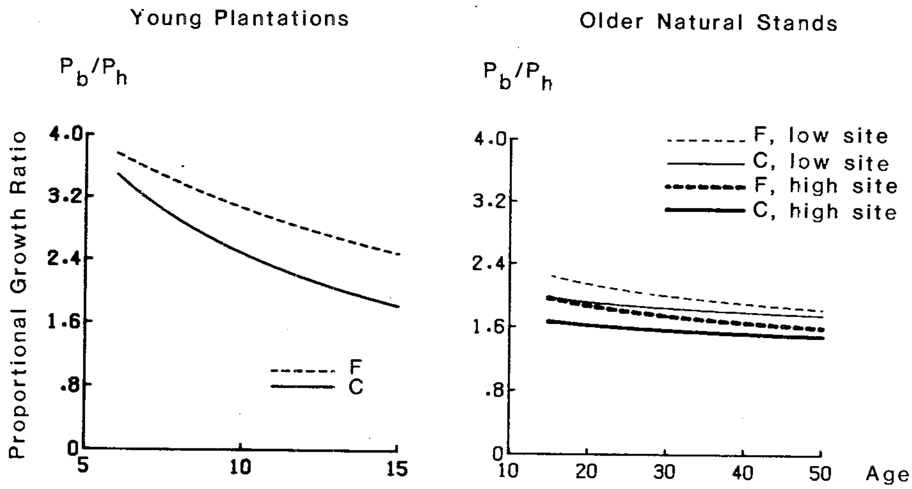

Figure 3. Ratio of proportional basal area growth to proportional height growth (P_b/P_h) for Douglas-fir on young plantations (present author) and on older natural stands of low site and high site (after Jenkins, 1975); 0 kg-N/ha (C) and 224 kg-N/ha (F).

DISCUSSION

Jenkins found that P_b, P_h, and the ratio of P_b/P_h were all inversely related to site index in older (averaged 30 years b.h. age) stands of unthinned and unfertilized Douglas-fir. Furthermore, after fertilization, the P_b/P_h ratio of the same stands was increased across the range of site index.

Although the P_b/P_h is lower for those older stands than in the current study (Figure 3), the impact of fertilization on this lower ratio supports current results from fertilizing young Douglas-fir plantations. Assuming subsequent fertilizations increase or sustain the change in P_b/P_h, a change in form factor could result which if unaccounted for, could seriously bias future growth predictions for fertilized stands. The likelihood of this occurring is greater with an intensive fertilizer regimen since multiple applications imply fertilizing stands of younger age (i.e., earlier in the rotation), and the periodic increment of a young stand represents a larger proportion of the biomass than in older stands. This hypothesis should be examined further, and tested through stem analyses of trees which have grown under a regimen of intensive fertilization.

CONCLUSIONS

The relative increase in volume after fertilization is significant for young plantations of Douglas-fir. Most of this increase is due to the proportional increase in basal area increment. The fact that the ratio of proportional basal area growth to proportional height growth is significantly increased by fertilization could mean a change in whatever form factor is assumed. Regardless of the effect on form factor, it is clear that volume growth response on fertilized stands of a given site index is not proportionately distributed as would be expected for unfertilized stands of higher site index. In other words, these results do not support an assumption that volume gains for a fertilized stand can be predicted by simply raising the site index of that stand. If this redistribution of growth is not accounted for in a regimen of multiple fertilizer applications, the result could be a significant bias in the growth forecasts for fertilized stands.

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VOLUME INCREMENT OF BOTTOMLAND HARDWOOD STANDS

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Abstract--Volume increment was determined for undisturbed and selectively harvested (high-graded) bottomland hardwood forests of southeastern Arkansas. In spite of a substantial difference in current volumes, the annual volume increments were practically identical in both groups of stands: 5.9 cubic meters per hectare in undisturbed stands and 5.6 cubic meters in selectively harvested stands.

Keywords: Hardwoods, volume increment, density, selective harvesting.

INTRODUCTION

Among the factors influencing volume increment, stand density plays a special role. Density reflects environmental conditions, age, and history of a stand, and, unlike many other factors, can be easily controlled by a forester. As a result, a quest for the optimal density, or the optimal level of thinning that maximizes the increment, has been a major aspiration of foresters, empirically pursued since the inception of this profession. The earliest answer was that productivity increases with the number of trees and reaches a maximum in undisturbed stands with the greatest possible tree number and complete crown closure. This answer emerged over 200 years ago in Denmark (Mar:Moller 1954) from a comparison of overcut and high-graded forests with closed and productive ones. During the nineteenth century that answer was superseded by the opposite concept: within reasonable limits, volume increment (of stems) was considered to be approximately proportional to the degree of thinning, that is, to the decrease in tree number. The contradiction between these two answers is not as sharp as it seems since the new concept was developed in a quite different setting from high-graded stands: it came from long-term observations of more or less evenly spaced best (crop) trees, selected at an earlier age and relieved from excessive competition stress during subsequent development by frequent thinning of neighboring trees. The most authoritative support of the concept came from Schwappach (1911) who, based on the results of 30 years of observations on 40 permanent sample plots established in Prussian beech stands, showed that heavy thinning increased the volume increment up to 16%.

The next development happened after 1932 when Wiedemann, Schwappach's successor in charge of the Prussian Forest Experiment Station, using 50-year-old observations of the same beech and other stands demonstrated that, within a wide range of density, productivity is independent from the thinning intensity (and tree number). These results have been confirmed in many countries (Mar:Moller 1954, Tkachenko 1955, Georgievsky 1957, Wiedemann 1960, Carbonnier 1976, Daniel et al. 1979, Drew and Flewelling 1979, Schonau 1983), and at present the majority of foresters believes that thinning can redistribute the increment from smaller to larger stems but not increase its amount. This opinion is not a consensus (Assmann 1970), and considerable efforts, known as thinning studies, are presently directed toward the empirical search for optimal density.

Most of these studies deal with carefully planned factorial experiments. At the same time density often varies as a result of unpredicted disturbances or irregular cuttings. In areas where the so-called high-grading (removal of the best shaped trees with larger diameters) is still practiced, it is important to compare the increment of high-graded and undisturbed stands. This paper reports the results of such a comparison for Arkansas bottomland hardwood stands.

MATERIALS

There is a substantial variability in management of bottomland hardwoods in southeastern Arkansas which made this investigation possible. Although almost all of the stands were high-graded in the past, since World War II this practice is limited to the more accessible stands located near pulpwood plants. Therefore, at present it is easy to find practically undisturbed stands and high-graded stands similar in all respects, except for the effects of selective harvesting.

Undisturbed Stands

These stands were situated far from improved roads in areas where there are plenty of more accessible and yet largely unmanaged hardwoods of similar quality. Historical records, testimony of old-timers, and careful inspection of the stands were used to ascertain the lack of disturbance, at least during the last 40-50 years. The main species found in these stands are oaks (Quercus spp.) and sweetgum (Liquidambar styraciflua L.).

Stands were sampled with clusters of 25 x 25-meter plots. Although time consuming, the square configuration is recommended for research studies as the most useful and accurate (Curtis 1983). The total number of plots in eight clusters (locations) was 49. Each cluster was located in one stream bottom. Each plot was divided into five 5 x 25 meter strips. For each tree larger than 4 cm in diameter at breast height the following variables were recorded: species, crown class, dbh, and spatial coordinates. Total number of measured trees was 2644. Several strips were chosen at random on each plot to check all of the measurements. No significant errors were discovered in this check.

Total height was measured on 354 trees. 307 of these trees were cored to determine age (at breast height) and radial increments for 3, 6, and 10 years. These trees were sampled from all diameter classes in proportion to basal area of each class. 188 of the cored trees were used to measure crown dimensions (height of the first living branch, crown length and width), and upper stem diameters (at crown base and midcrown) using a pentaprism and a Suunto clinometer mounted on a tripod.

To find out the number of years required to reach breast height, 90 samplings of the main species were cut at the base and at breast height level, and the number of annual rings was counted. The average difference between the base and the breast height ages was 3.31 years for the white oak group, 3.22 years for red oak group, and 3.56 years for sweetgum. The average for all species was 3.36 years.

For precise measurement of form factor, 20 trees representing all crown classes were felled. The following variables were determined for each of these trees: 20-30 diameter measurements along the stem; age and bark width at 10-15 different heights; branch diameter, length, and weight; and specific gravity of the stem.

Selectively Harvested Stands

Increment of selectively harvested stands was estimated using continuous forest inventory data provided by a timber company, which included three consecutive remeasurements of plots established in bottomland hardwood stands in southeastern Arkansas. Two groups of stands were selected for subsequent treatments: (1) stands with logs cut 6-10 years ago. They include 309 plot measurements and 6306 tree measurements. (2) Stands with logs cut in the past 5 years. They include 406 plot measurements and 8163 tree measurements. In both cases pulpwood was not cut during the past 10 years. According to our observations, the descriptions of treatments only approximately correspond to the actual situation.

All plots were 0.08 hectare (1/5 acre) in size. Living trees larger than 12.7 cm (5.0 inches) dbh were numbered, tagged and measured. For each tree the species, dbh, and total height were recorded. Stump height for height measurements was 15 cm (6") for all pulpwood trees and 46 cm (18") for hardwood veneer, sawlogs, and tie timber. Repeated measurements allowed increment calculations without obtaining increment cores from the trees.

DATA TREATMENT

For proper calculation and comparison of increments both undisturbed and selectively harvested stands should be classified according to stand dynamics and site quality. Truly uneven-aged stands are balanced, that is, their measurable variables do not change with time. The lack of disturbances during the extended period of time for which their histories are known makes plausible the hypothesis that the studied stands are balanced. To test this hypothesis, major stand variables were regressed on age. It was found that neither basal area, nor diameter and tree number have statistically significant trend (slope was not sufficiently different from zero). Height, however, does show a marginally significant trend. Because the majority of the variables did not exhibit a significant age trend, the stands were assumed to be balanced and subsequent analysis was done without regard to age.

To analyze homogenity of the measured stands with respect to site quality, the mean height increment was selected as the indicator of stand productivity because, unlike height, the mean increment did not exhibit an age trend. An F-test rejected the null hypothesis that there is no significant difference among the locations.

Application of Tukey's studentized range test revealed two statistically different site groups (Table 1). Group A includes all locations except location 1 while group B comprises five locations with lower increments. Considerable overlap of the groups makes the clear-cut separation needed for practical management impossible. These statistical results must be considered together with managerial considerations. Given the present relatively low intensity of bottomland hardwood management, it would be inappropriate to distinguish more than one site class in this situation. Therefore, it was decided to treat all of the data as one whole.

Table 1. Grouping of locations by Tukey's standardized range (HSD) test. Alpha = 0.05, SEE = 0.23 m. Means with the same letter are not significantly different.

Mean annual height increment of cored trees, meters	Sample size	Location	Grouping	
0.62	15	8	A	
0.62	58	6	A	
0.59	46	2	A	
0.51	17	4	A	B
0.48	16	7	A	B
0.48	35	5	A	B
0.43	46	3	A	B
0.38	74	1		B

The annual volume increment of one tree was determined for each diameter class as the difference between the present stem volume inside bark and the corresponding stem volume for the previous year. The previous year's diameter inside bark was found at the difference between the present diameter and the annual diameter increment calculated from the coring of trees in undisturbed stands and from repeated diameter measurements in selectively harvested stands. The volumes of trees were determined from corresponding diameters, heights, and form factors.

Stand volume increment was found using information on the number of trees by diameter class.

RESULTS

In spite of substantial differences in management regime and volume of undisturbed and selectively harvested stands (294 and 154 cubic meters per hectare, respectively), their annual increments were practically identical: 5.9 cubic meters per hectare in undisturbed stands and 5.6 cubic meters in selectively harvested stands. Thus, it appears that in Arkansas bottomland hardwood stands the increment loss caused by the removal of larger trees and the concomitant destruction of a significant number of smaller trees is compensated for by the growth of the remaining stand.

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Beziehung zwischen unterschiedlichen Schadklassen und dem Holzzuwachs bei Fichte *)

J. Nagel, J. Saborowski und H. Kramer

Abstract:

The paper deals with the relation between the damage class (according to the German inventory for forest die back) and the basal area growth with special consideration of the crown surface area. The crown surface area of the sample trees was derived from aerial photo measurements.

With an analysis of covariance differences in the mean basal area growth of spruce could be shown for the four damage classes.

Einleitung

In zahlreichen Arbeiten wurde über die Problematik der Waldschadensinventur gemäß der bundesweiten Erhebung (BRELOH und KIRCH 1984) berichtet. Bisher konnte nur bei subjektiv ausgewählten Baumgruppen und -paaren Zuwachsunterschiede für die Schadklassen beobachtet werden (ATHARI 1983, FRANZ 1983). Genauere Erkenntnisse über die Beziehung zwischen Holzzuwachs und Schadklasse sind bisher noch unbekannt oder konnten nicht festgestellt werden (SCHWEINSGRUBER et al 1983, FRÜHWALD et al 1984).

Bedeutung der Kronenmantelfläche

Das Wachstum von Einzelbäumen ist bekanntlich nicht nur von Klima, Standort und Genotyp sondern auch von vielen anderen Kriterien abhängig. Hierbei bilden insbesondere die Ausbildung des Assimilationsapparates (Krone) und die Stellung des Baumes zu seinen Nachbarn (Konkurrenz) wichtige Parameter für seinen Zuwachs. So zeigten u.a. BURGER (1939) und KRAMER (1966), daß die Kronenmantelfläche eines Baumes sehr gut mit seinem Zuwachs korreliert ist.

Die Kronenerfassung wurde bei den Waldschadensansprachen in der Vergangenheit weitgehend vernachlässigt, obwohl bei gleicher Höhe ein stark geschädigter Baum mit großer Krone den gleichen Zuwachs leisten kann, wie ein gesunder Baum mit kleiner Krone. Erst nachdem KRAMER und DONG (1985) eine verbesserte Methode der Kronenerfassung vorgestellt haben, wird den Kronenparametern bei Waldschadensinventuren eine größere Bedeutung zu gemessen. Als relatives Maß für die Interpretation des Einflußes der Schadklasse auf den Holzzuwachs empfiehlt KRAMER (1985) den Zuwachs je qm Kronenmantelfläche.

*) Die Arbeit wurde mit Mitteln des BMFT gefördert

Da die terrestrische Kronenerfassung relativ aufwendig ist, wird sie bei Waldschadensinventuren nur in begrenztem Umfang durchgeführt werden können. Aus diesem Grund wird am Institut für Forsteinrichtung und Ertragskunde der Universität Göttingen im Rahmen des Forschungsprojektes "Großräumige Erfassung von Veränderungen des Holzzuwachses und der Bestandesstrukturen in immissionsexponierten Waldgebieten" auch die Aussagefähigkeit einer rationeller Baumkronenerfassung im Luftbild untersucht.

Akca (1984) konnte in einem jungen Fichtenbestand eine straffe Korrelation (r=0.78) zwischen dem Volumenzuwachs und der im Luftbild gemessenen Kronenmantelfläche nachweisen. Die Kronenmantelfläche wurde hierbei in den großmaßstäbigen Luftbildern (1:2000) aus der Messung von fünf Lagekoordinaten mit einem Stereokartiergerät abgeleitet. Dabei dienten als Meßpunkte die Kronenspitze und die unteren Kroneneckpunkte der vier Himmelsrichtungen.

Die im Luftbild gemessene Baumkrone entspricht allerdings nicht den Dimensionen einer terrestrisch vermessenen Baumkrone. In Abbildung 1 wird deutlich, daß nur ein Teil der Baumkrone im Luftbild gemessen werden kann.

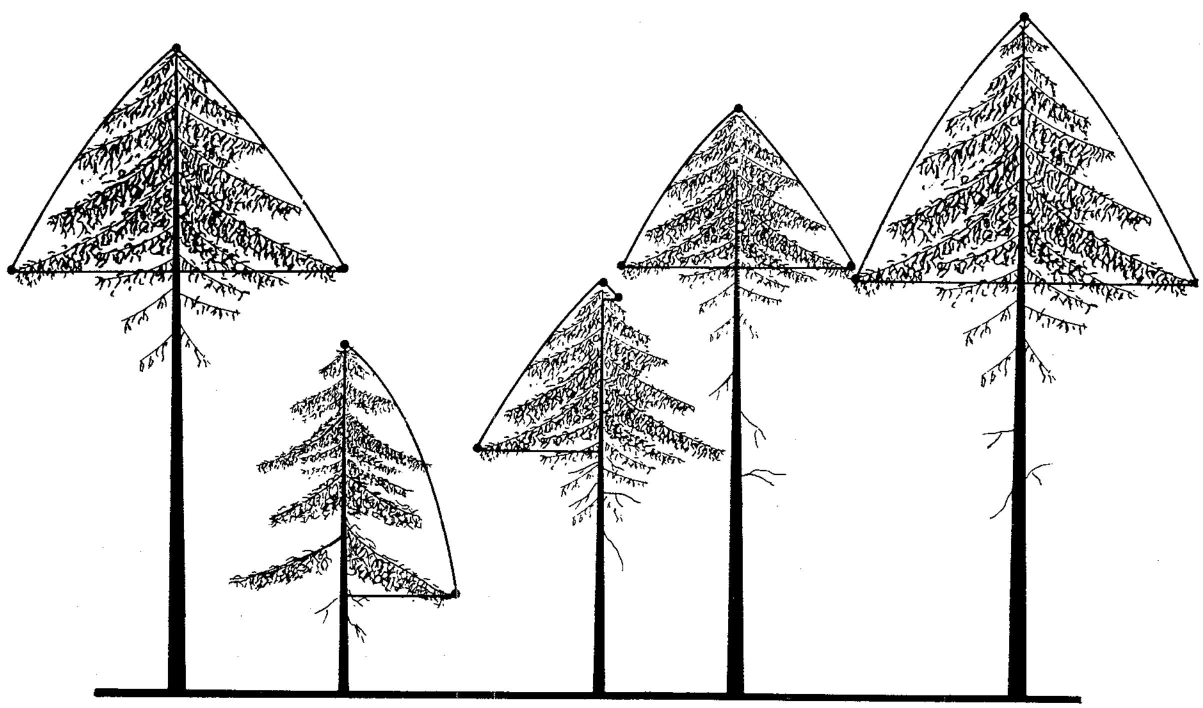

Abb.1: Die im Luftbild meßbare Baumkrone

Dies führt dazu, daß kleine unterständige Bäume z.T. gar nicht oder nur teilweise erfaßt werden. Bei eng stehenden herrschenden und vorherrschenden Bäumen kann jeweils nur die beleuchtete Krone erkannt werden. Die Kronenteile, die z.B. unterhalb von zwei zusammenstoßenden Ästen zweier Bäume liegen, sind im Luftbild nicht auszumachen. Da die

Stellung der Nachbarbäume einen Einfluß darauf hat, welcher Kronenteil sich erfassen läßt, wird bei der Kronenmessung im Luftbild indirekt die Konkurrenzsituation mit erfaßt. Der im Luftbild erfaßte Kronenteil entspricht in etwa der Lichtkrone, und ist insoweit für die Beurteilung der Zuwachsleistung von besonderer Bedeutung.

Ziel der Untersuchung und das Datenmaterial

Im Rahmen des zuvor erwähnten Forschungsprojektes sollten in einem Teilaspekt an zufällig ausgewählten Bäumen aus dem Hils (Niedersachsen) Beziehungen zwischen dem Grundflächenzuwachs einer fünfjährigen Periode (1979 bis 1983) und der Schadklasse untersucht werden. Dafür wurden auf 40 zufällig ausgewählten permanenten Probekreisen an sämtlichen Fichten je zwei Bohrspäne entnommen und anschließend mit einem Johann-Positiometer gemessen. Für die Untersuchung wurden nur die Daten jener Bäume berücksichtigt, bei denen sich die beiden entnommenen Bohrspäne in Nord u. Ost-Richtung synchronisieren ließen. Außerdem mußten diese Probebäume im Luftbild eindeutig zu identifizieren sein. Die Kronenmantelfläche wurde nach der Formel des quadratischen Paraboloids aus der Messung von fünf Lagepunkten in Infrarot-Luftbildern (1:5000) aus dem Jahre 1982 (nach AKCA 1984) abgeleitet. Von allen Bäumen lagen die Daten einer terrestrischen Aufnahme aus dem Jahr 1983 sowie zwei zusätzlicher Schadansprachen aus den Jahren 1984 und 1985 vor.

Nach Untersuchungen von KRAMER (1971) ist der Zuwachs je Quadratmeter Kronenmantelfläche bei Bäumen unterschiedlicher Dominanz verschieden. Er ist bei vorherrschenden und herrschenden Fichten etwa gleich hoch. Für die Ermittlung des Grundflächenzuwachses wurden daher nur vorherrschende und herrschende Bäume der älteren Bestände ausgewählt. Ihre Höhe lag zwischen 18 und 27 m. Durch diese Einschränkung stand eine Stichprobe von 162 Bäumen, die sich aus Bäumen unterschiedlicher Alter, Leistungsklassen und Baumdimensionen zusammensetzte zur Verfügung. Der durchschnittliche Brusthöhendurchmesser und die durchschnittliche Höhe sind innerhalb der 4 Schadklassen fast gleich (Tab.1).

Tabelle 1

Schadklasse	n	BHD cm	Höhe m	Kronenmantelfläche qm
SK 0	91	30,3	22,9	38,9
SK 1	36	29,8	22,8	37,3
SK 2	25	30,7	23,4	60,0
SK 3	10	30,0	21,6	39,3

Aus arbeitstechnischen Gründen war es nicht möglich, die Bäume zufällig über das ganze Gebiet verteilt auszuwählen. Der Zeitaufwand für das Aufsuchen wäre nicht vertretbar gewesen. Die Auswahl der Bäume von den permanenten Probekreisen kann aber als weitgehend zufällig angesehen werden. Daher wurde die Stichprobe im folgenden, wie eine zufällige Stichprobe untersucht.

Ergebnisse

Es sollte der Zusammenhang zwischen der bei der Inventur 1983 angesprochenen Schadklasse und dem 5-jährigen Grundflächenzuwachs untersucht werden. Betrachtet man den mittleren 5-jährigen Grundflächenzuwachs getrennt nach Schadklassen (Tab. 2), so ergibt sich eine unerwartete Abstufung, da die Bäume der Schadklasse 2 (krank) mehr Grundflächenzuwachs leisten, als die leicht geschädigten Bäume der Schadklasse 1.

Tabelle 2

Schadklasse	GZ	%	GZ/KM	%	GZ/KM *)	%	GZ *)	%
SK 0	396	100	11,6	100	11,4	100	401	100
SK 1	334	84	10,6	91	10,3	90	351	87
SK 2	335	90	7,8	67	9,1	80	312	78
SK 3	216	55	6,5	56	6,4	56	223	56

GZ = 5-jähriger Grundflächenzuwachs (1979-1983) in cm^2
GZKM = 5-jähriger Grundflächenzuwachs je qm Kronenmantelfläche in cm^2

*) Korrigierte Werte der Kovarianzanalyse (Höhe u. BHD als Kovariante)

Dieser Befund läßt sich durch die auffallend große mittlere Kronenmantelfläche der Bäume der Schadklasse 2 (60 qm) begründen (Tab.1). Die ist wesentlich größer als die durchschnittliche Kronenmantelfläche der übrigen Schadklassen (38 qm).

Es liegt daher nahe, für die vier Schadklassen den durchschnittlichen Grundflächenzuwachs je qm Kronenmantelfläche zu berechnen. Die Mittelwerte dieser relativen Zuwachswerte nehmen (Tab. 2) mit steigender Schadklasse ab. Die Interpretation dieses Ergebnisses setzt jedoch voraus, daß die Bäume aller Schadklassen homogen sind. In einer graphischen Analyse wurde daher der Frage nachgegangen, ob eine Beziehung zwischen dem Brusthöhendurchmesser, der Höhe und der Kronenmantelfläche mit dem Grundflächenzuwachs je qm Kronenmantelfläche besteht. Aus Abb.2 und 3 wird deutlich, daß sich kein Zusammenhang für die Höhe und den Brusthöhendurchmesser zeigen läßt.

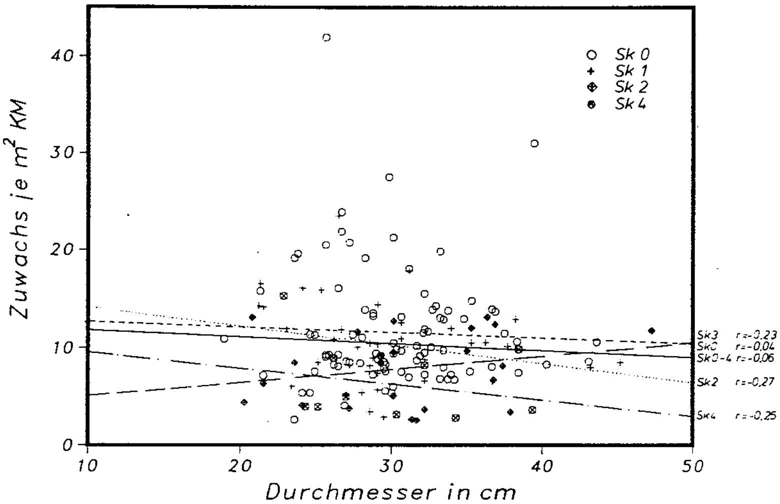

Abb. 2: Grundflächenzuwachs je qm Kronenmantelfläche über dem BHD

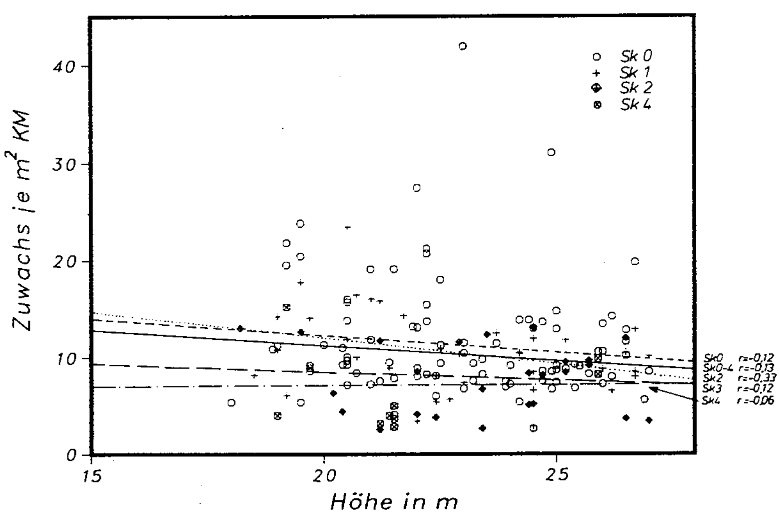

Abb. 3: Grundflächenzuwachs je qm Kronenmantelfläche über der Höhe

In Abbildung 4 ist aber zu erkennen, daß der Grundflächenzuwachs je qm Kronenmantelfläche mit der Kronenmantelfläche schwach negativ korreliert ist.

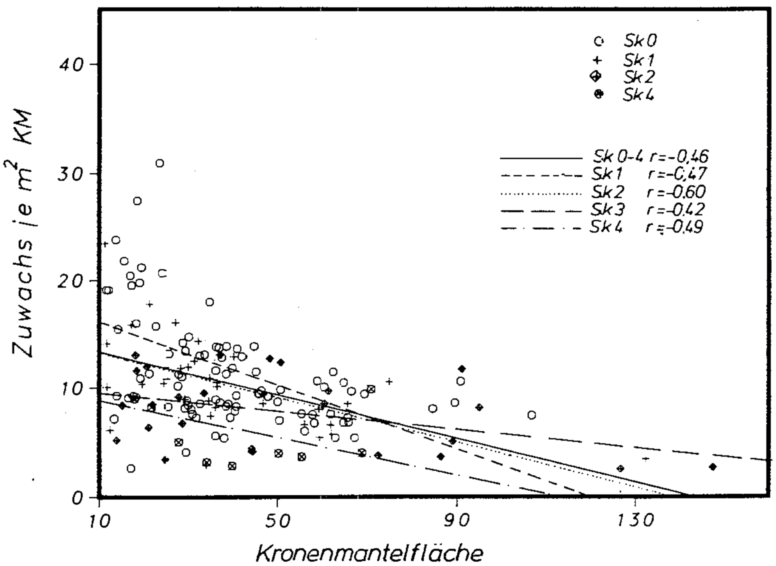

Abb. 4: Grundflächenzuwachs je qm Kronenmantelfläche über der Kronenmantelfläche

Diese eigentlich unerklärliche Beziehung mag ihren Grund in dem uneinheitlichem Datenmaterial haben. Sie könnte aber auch daran liegen, daß kleinere Baumkronen bei der Messung im Luftbild systematisch zu gering eingeschätzt werden und daher bei ihnen der Zuwachs je qm gemessener Kronenmantelfläche besonders groß ist.

Angesichts dieser Beziehung und der durchschnittlich größeren Kronenmantelfläche der Bäume der Schadklasse 2 wurde eine Kovarianzanalyse durchgeführt, wobei der Brusthöhendurchmesser und die Kronenmantelfläche als Kovariate dienten. Im Vergleich zu den ungeschädigten Bäumen (Schadklasse 1), leisten die Bäume nach den mit der Kovarianzanalyse korrigierten Werten in der Schadklasse 1 90%, Schadklasse 2 80% und der Schadklasse 3 56% vom Grundflächenzuwachs je qm Kronenmantelfläche. Die Mittelwerte der vier Schadklassen sind von einander signifikant verschieden (F=4.6, P=0.0039). Einschränkend muß jedoch erwähnt werden, daß die für die Kovarianzanalyse notwendige Gleichheit der Steigungen nicht gegeben ist. Mit den vier Schadklassen ließ sich 9,4% der Varianz erklären. Eine schrittweise multiple Regressionsanalyse, in der die Schadklassen in Form von Scheinvariablen berücksichtigt wurden, zeigte, daß sich die zuvor erwähnten 9.4% der Varianz nicht durch andere Variablen erklären ließen.

In der letzten Spalte der Tabelle 2 wurde eine Kovarianzanalyse für den absoluten Grundflächenzuwachs durchgeführt. Vergleicht man die prozentualen Angaben mit denen der Kovarianzanalyse für den relativen Grundflächenzuwachs (je qm Kronenmantelfläche), so erkennt man, daß die Werte sehr ähnlich sind. Auch die Mittelwerte der Kovarianzanalyse für den absoluten Grundflächenzuwachs sind signifikant von einander verschieden (F=9.3, P=0.000), jedoch war auch hier die notwendige Gleichheit der Steigungen nicht gegeben.

Folgerungen für die Praxis

Anhand des vorliegenden Datenmaterials konnte gezeigt werden, daß sich bei Berücksichtigung der Kronenmantelfläche ein Zusammenhang zwischen Schadklasse und Grundflächenzuwachs besteht. Der durchschnittliche Grundflächenzuwachs betrug in der Schadklasse 1 90%, der Schadklasse 2 80% und der Schadklasse 3 56% vom Grundflächenzuwachs der ungeschädigten Bäume.

Die Untersuchung zeigt, daß auch mit der bisher praktizierten Schadklassifikation grobe Informationen über den zu erwartenden Minderzuwachs gegeben werden können. Vorraussetzung dafür ist jeoch, daß Informationen über die Kronenmantelfläche der angesprochenen Bäume vorliegen. Kosten günstig und rationell läßt sich die Kronenmantelfläche aus großmaßstäbigen Luftbildern (1:5000) ermitteln.

Für künftige Waldschadensinventuren ist daher ein kombiniertes Inventurverfahren zu empfehlen, daß sich sowohl auf terrestrische Erhebungen wie auch auf Daten aus dem Luftbild stützt.

In einer weitgehenderen Untersuchung soll in Kürze an 120 Einzelbäumen, von denen eine Stammanalyse vorliegt, intensiver der Beziehung zwischen dem Volumenzuwachs und dem äußerem Schadbild nachgegangen werden. Ferner soll der Zusammenhang zwischen dem Holzzuwachs und dem Luftbild angesprochenen Schadklasse untersucht werden.

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GROWTH AND YIELD OF SLASH AND LOBLOLLY PINE PLANTATIONS AS INFLUENCED BY PLANTING DENSITY, SITE QUALITY AND AGE

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Abstract--Results from an intensive study of a regionwide database containing over 2000 repeatedly remeasured permanent research plots ranging in age from 2 to 25 years, initial planting densities from 100 to 1800 trees per acre and site qualities from very poor to very high are presented and discussed. It is concluded that initial density should be prescribed by site quality, that whole stand growth and yield models should be flexible enough to allow for all possible interactions between site quality, age and initial planting density, and that in studying relationships between changing environmental factors and forest growth the influences of stand density, site quality and age must be accounted for.

Keywords: Growth models, stand density, site quality, age.

INTRODUCTION

Today, we are faced with many and varied environmental influences on our forest resources. It remains to be seen how factors such as whole tree utilization, repeated harvesting and increased atmospheric pollution will affect forest productivity. It is our opinion that before we can understand the complexities of stand dynamics in the presence of such factors, we must first understand them in the absence of these factors.

Loblolly (*Pinus taeda* L.) and slash pine (*Pinus elliottii*) are two of the most important commercial timber species in the southeastern United States. A great deal of information regarding the stand dynamics of planted stands of these species has been compiled through the years. However, many questions concerning the management of these species remain unanswered. One early and critical decision regarding the management of these species is the choice of planting density (i.e. the number of seedlings planted per acre). It is common practice for large forest landholding firms to choose a single initial planting density for their vast acreages. Clearly, as regards volume production and economic returns, this approach is far from optimal. It is not surprising that these less than optimal decisions are made because of the lack of empirical data on which to base this critical decision. Many small, isolated spacing studies have been reported on by numerous groups and individuals. More often than not these reports are concluded by recommending "optimal" initial densities for desired end-products. The fallacy therein is the complete disregard of initial spacing - site quality interactions. To help fill this void of information, a study was undertaken to compile and analyze a databank covering a large array of ages, sites and initial planting densities for both loblolly and slash pine.

DATA

The data have been compiled through the cooperative efforts of several members of the University of Georgia's Plantation Management Research Cooperative[1] (PMRC). The data are comprised of over 2000 permanent research plots which have been remeasured up to six times. Ages range from 2 to 25 years and initial planting densities from 100 to 1800 trees per acre (tpa). Study installations cover a broad geographic area from the lower coastal plain of southern Virginia down to northern Florida and across the Gulf Coast to western Alabama. A detailed description of the data is given by Borders and Bailey (1985).

ANALYSIS

The following whole stand attributes, as related to age, site quality and initial planting density, were analyzed individually for each contributed databank:

1. survival
2. basal area per acre
3. quadratic mean diameter
4. total volume per acre
5. merchantable volume per acre
6. sawtimber volume per acre
7. average height
8. dominant height
9. percent fusiform rust infection, a disease caused by the fungus *Cronartium fusiforme* (Hedge and Hunt ex Cumm).

The ITT Rayonier, Brunswick Pulp Land Company and Container Corporation of America studies were well designed, from a statistical point of view, and were therefore relatively easy to analyze for growth differences due to site quality, initial planting density and their interactions using appropriate analysis of variance techniques. Data contributed by Union Camp Corporation and St. Regis Paper Company come from very large regionwide studies patterned after the correlated curve trend study of O'Connor (1935). A major shortcoming of these two studies was the lack of replication within an installation.

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[1]Companies cooperating by providing data are ITT Rayonier Inc., Container Corporation of America, St. Regis Paper Company (recently merged with Champion International), Union Camp Corporation and Brunswick Pulp Land Company. Additional members in the cooperative are Owens-Illinois, Continental Forest Industries, St. Joe Paper Company, Gilman Paper Company

To investigate site quality - initial density relationships each installation was assigned to one of the following three site-classes based on average base 25 site index for the installation:

1. good - average site index $\geq$ 65
2. average - 55 $\leq$ average site index $<$ 65
3. poor - average site index $<$ 55.

Based on this classification, the data were analyzed with analysis of variance using site class and density as treatments assigned in a completely randomized design. This is not unreasonable since installations were not located in a systematic fashion and planting densities within locations were randomly assigned.

RESULTS

Analysis of the empirical data resulted in the following general relationships between whole stand measures and site quality and initial planting density for both loblolly and slash pine.

Survival

For a given density, survival rate is negatively correlated with site quality. As a direct consequence of this negative correlation, differentiation of survival rates by density occurs earlier on higher quality sites. On a given site, high initial densities result in lower survival rates than lower initial densities.

Basal Area (BA)

Through age 25, BA is directly related to initial planting densities ranging from 100 to 900 tpa. BA growth rate is positively correlated with site quality with higher sites supporting more BA for a given density. Due to faster growth rates on higher sites, for a given density culmination of mean annual increment (MAI) in BA occurs earlier on better sites while for a given site age of maximum MAI in BA occurs earlier for higher initial planting densities.

Quadratic Mean Diameter (DQ)

DQ, which defines the tree of average basal area, is used in lieu of the arithmetic mean diameter because it is a better approximation of the tree of average volume. DQ exhibits a strong negative correlation with initial planting density. The differentiation of DQ by density occurs earlier on better sites with differences between high and low densities being positively correlated with site quality.

Total Volume Outside Bark (TVOB)

TVOB is defined as cubic foot volume from a 6-inch stump height to the top of the mainstem of all trees on an acre. It is positively correlated with initial stand density from ages 5 to 25. For a given density, more TVOB is supported on higher sites. For a given site quality, TVOB growth slows earlier for higher densities. For a given density, TVOB growth slows earlier on better sites.

Merchantable Volume Inside Bark (MVIB)

MVIB is defined as inside bark cubic foot volume to a 4-inch top (outside bark) diameter of all trees greater than 4.5 inches dbh on an acre. Following an early period of high variability, attributed to the influence of the diameter limit, MVIB is positively correlated with initial stand density. Across the continuum of site from poor to good, there is evidence that initial densities from 450 to 900 tpa converge to a common level of MVIB as early as age 20, with the level positively correlated with site quality.

Sawtimber Volume (SVOL)

SVOL is defined as inside bark cubic foot volume to a 6-inch top (outside bark) diameter of all trees greater than 9.5 inches dbh on an area. Only on high sites is there any significant amount of SVOL being produced by age 20. On these sites, SVOL is negatively correlated with initial stand density through age 14; however, by age 20 this negative correlation is not present for densities from 100 to 450 tpa. If current trends continue a positive correlation is very likely to develop at older ages between SVOL and initial densities ranging from 100 to 450 tpa.

Average and Dominant Height

There is a negative correlation between initial planting density and average stand height. However, dominant height was unaffected by initial stand densities ranging from 100 to 900 tpa. For the 1200 tpa density, there was a drop in dominant height of approximately 3-5 feet at age 20. For dominant height, there is no indication of a site quality - initial density interaction.

Percent Fusiform Rust Infection

Percent rust is defined as the percentage of trees with one or more stem galls. These data show a positive correlation between site quality and percent rust infection. There is no evidence of a relationship between initial stand density and percent rust infection. For a given density-site pair, percent rust infection increases relatively quickly from ages 5 to 11, and then levels out beyond age 11.

Crop Trees

In three of the five studies it was possible to investigate density effects on the 100 largest diameter trees per acre for slash pine on average sites. For initial densities ranging from 100 to 450 tpa there were no differences in BA, DQ, TVOB, MVIB and SVOL. However, at initial densities greater than 450 tpa, there was a negative correlation between initial density and these whole stand parameters for the 100 largest trees.

CONCLUDING REMARKS

Most spacing study reports conclude by recommending "optimum" planting densities to achieve certain end products. Professional foresters are aware of most of the biological tradeoffs involved in choices of initial density, many of which have been substantiated by our study. However, the choice of initial density should be based not only on stand dynamics, but on economic factors as well. Thus, no optimum which is purported to be generally applicable will be recommended here. Each management situation will require its own analysis and decision, hopefully with the above biological results as an aid. The approaches by Pienaar (1977) and Bailey (1981) based on economic criteria and sound biological response modeling are recommended.

Although we tend to shy away from generalities, there are two that must be made based on the results of this study. First, initial stand density interacts with site quality for all whole stand parameters considered in this study for both loblolly and slash pine. Consequently, it is overly simplistic for an integrated forest management firm with large landholdings to use a single planting density. It is necessary to prescribe initial planting density by site quality classes. Second, results reported here can be used to guide the development of growth and yield models. The following interactions were found to exist for all whole stand parameters considered (with the exception of average height, dominant height and percent fusiform rust infection):

1. site * age
2. density * age
3. site * density
4. site * age * density

It is imperative that growth and yield models exhibit adequate flexibility to allow for these interactions. Furthermore, we must point out that the influences of stand density, site quality and age must be accounted for in any study having the objective of relating changes in forest growth to changing environmental conditions.

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IDENTIFYING CLIMATIC VARIATION IN GROWTH MODEL ERRORS

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Abstract--This study identified monthly precipitation and temperature variables and groupings of these variables that influence diameter growth at Cloquet, Minnesota. Simple statistical methods were used to determine composite groupings of the most significant variables. After a regional growth model, STEMS, was used to remove many non-climatic sources of variation, species at the Cloquet site showed the greatest response to fall, winter, and spring climate.

Keywords: Climate, correlation analysis, growth model.

INTRODUCTION

Forest trees integrate many climatic, soil, and biological factors in their growth. Although it varies by species and region, precipitation is generally considered to be the single most important climatic factor affecting tree growth. However, in local areas where precipitation is normally adequate, temperature may become influential. Seasonal or even monthly precipitation and temperature are often more important than annual values.

Analysis of tree growth for relationships with climatic factors is difficult because of the large variability in growth due to stand, tree, and site effects. This variability can be reduced by using a regional tree growth model, such as Lake States STEMS (Belcher _et_ _al_. 1982), to account for non-climatic effects. Changes in tree growth and mortality caused by factors such as tree size, site productivity, species composition, and tree competition can be largely accounted for by the projection model.

The objective of this study was to identify monthly precipitation and temperature variables or groupings of variables that significantly influence diameter growth of trees near Cloquet, Minnesota. This was accomplished by 1) using the Lake States regional growth model, STEMS, to eliminate the effects of stand, tree, and site factors on diameter growth; and 2) analyzing the average diameter prediction errors by species against precipitation and temperature variables for each calendar month averaged over four growth intervals, ranging in length from 5 to 7 years.

STUDY AREA

The Cloquet Forestry Center, administered by the University of Minnesota College of Forestry, is located in northeastern Minnesota (46^{o} 42' latitude, 92^{o} longitude), 24 miles west of Duluth. The forest lies on a glacial outwash plain containing scattered low ridges, knolls, and bogs, with an elevation ranging from 1230 to 1290 feet above sea level. Allison and Brown (1946) list the major soils as loamy sand (56%), peat (33%), and sandy loam (11%).

Rauscher's (1984) study of macroclimatic zones in the Lake States classifies this area as experiencing high annual precipitation, most of which comes in the summer. Thirteen percent of the annual total precipitation comes in July--markedly higher than other zones in the Lake States. The area borders a zone classified as having cold climatic conditions.

Although the forest is close to Lake Superior, only in spring is the local weather consistently modified by the Lake (Allison and Brown 1946). During spring the prevailing northeasterly winds provide a cooling effect. Otherwise, the climate is typically continental, with warm summers, cold winters, and large temperature variability. The mean annual temperature during the study (1959 to 1982) ranged from 36.6 to 41.5^{o}F (U.S. Environmental Data and Information Service 1959-1982). January is the coldest and July is the warmest month, with average mean temperatures of 6.0^{o}F and 67.0^{o}F, respectively. The frost-free season normally extends from June 7 to September 7, but a killing frost can occur in any month. Annual precipitation (1959 to 1982) ranged from 20.01 to 37.47 inches (U.S. Environmental Data and Information Service 1959-1982). Although monthly precipitation during May through September is quite variable (0.40 inches in May, 1976, to 9.13 inches in August, 1972), moisture conditions during the growing season are usually adequate (Hsiung 1951). The average precipitation from May through September is 18.30 inches.

Very little change has occurred in the areal distribution of the various upland and lowland vegetation types since 1959 (Moer et al. 1980). Upland types occur on 66 percent of the forest, with aspen, red pine, and jack pine predominating. Minor upland types include paper birch, balsam fir, and white pine. The productive lowland types are black spruce, mixed swamp conifers, tamarack, spruce-fir, lowland hardwoods, and northern white-cedar (Moer et al 1980).

METHODS

Data

Permanent 1/7-acre fixed radius plots were established in the fall of 1959 (Reber and Ek 1982). These plots were remeasured in 1964, 1969, 1976, and 1982. Therefore, our data base consisted of five sets of tree measurements from 199 permanent plots totaling more than 6,000 trees. The following data were recorded: plot site index, dbh for all trees greater than 4.95 inches in diameter, species, status (live, cut, dead), and live crown ratio (only in 1976 and 1982). These plots were selected to exclude steep plots (slope greater than 30%) and open plots (plot basal area less than 25 sq.ft./ac.).

We used Lake States STEMS (Belcher et al. 1982), an individual-tree, distance-independent growth model, to remove the component of growth attributed to stand dynamics. STEMS, which has been extensively tested (Holdaway and Brand 1983), accounts for differences in growth due to species, diameter, crown ratio, site index, relative tree size, stand density, and average diameter. Data from the first year of each interval (1959-1964, 1964-1969, 1969-1976, 1976-1982) provided the starting point for four growth projections of 5 to 7 years each. The measurement at the end of each interval provided observed values to compare with growth predictions. The difference between predicted and observed diameter growth is due to growth model error, a part of which may be attributed to climatic variation from one interval to the next, and other unaccounted variables. We reduced the non-climatic variability by avoiding steep and open plots. We analyzed only trees less than 11.0 inches in diameter, further reducing non-climatic variability because growth model errors can vary by tree diameter, especially for larger trees (Holdaway and Brand 1983). The final data base still contained more than 5,400 trees, many with 5 measurements.

The Cloquet Meterological Station, located in the forest, collects daily climatic data. Daily data have been summarized to produce total precipitation and mean temperature for each month from October 1959 to August 1982 (U.S. Environmental Data and Information Service 1959-1982). From these values we calculated monthly averages for each of the four measurement intervals. For example, average January precipitation and average mean temperature for the first interval was determined using January 1960-1964 values.

Statistical Analysis

Stepwise regression analysis has the goal of selecting the most important prediction variables. However, the stepwise selection procedure can be greatly influenced by intercorrelations among the prediction variables which influence the order of selection, the variables included, and their apparent relative importance. One solution is to reduce the many predictor variables to a few by combining the more important ones and by rejecting the least important ones.

Many studies have summed climatic data over several months. Since there may be a seasonal change in how environmental factors regulate growth, high values of a factor may be limiting in certain months, while low values are limiting in others. Thus, care should be taken not to summarize climatic data over intervals in which the direction of the influence on growth changes, or the summarization will cancel out the effects.

Each species with more than 100 trees was analyzed separately. The dependent variable was the average annual diameter growth projection error per interval for trees with diameters between 5 and 11 inches. The initial independent variables were the 24 climatic variables mentioned earlier: precipitation and mean temperature for each calendar month averaged over each measurement interval.

On the basis of a correlation analysis, we selected the most important monthly climatic variables and then grouped together consecutive monthly variables with strong similar effects. The selection criteria involved fixing arbitrary levels of the simple correlation coefficients for inclusion into composite variables. "Primary" months had correlation coefficients greater than or equal to .75 in absolute value. All "secondary" months around a primary month were also included if the correlation coefficient had the same sign as the primary month's and was greater than or equal to .5 in absolute value (figure 1). Because of the size of the data base and using average growth errors, all correlation coefficients used were significant at P = .001. This method reduced the number of potential variables from 24 per species to 4 to 6 composite or individual variables per species.

	PRECIPITATION Month												TEMPERATURE Month											
	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J
Jack pine			-	=				=	+	‡	+			=	-				‡					
Red pine	=				‡						‡	+	=			=	=	=		=				
White pine	=									+	‡			=	=	=			‡	=			‡	+
Balsam fir	‡	+				‡								‡	‡	+			=		=	-	=	=
Black spruce	=	-	‡												-	-	-	=					‡	‡
Tamarack							=	‡	=	=				‡										
N.white-cedar	=	-				=								-	=	=			‡		‡	+	‡	‡
Quaking aspen	=	-				=									=	=					‡	+	‡	‡
Paper birch	=	=				=									=	-			‡		‡	+	‡	‡
All[1]	=	-				=									=	=					‡		‡	‡

[1] Includes all of the above species and those with fewer than 100 trees.

Figure 1. Diagrammatic representation of monthly simple correlation coefficients for the initial 24 climatic variables at Cloquet, Minnesota. Double symbols represent all months with correlation coefficients ≥ |.75| (called primary months) and single symbols represent all months around a primary month of the same sign as the primary month and with correlation coefficient ≥ |.50| (called secondary months). Pluses represent a positive influence and minuses a negative influence.

The groupings chosen in the preliminary stage were used as independent variables in the multiple stepwise regression analysis (figure 2). Regression analysis selected the three most influential climatic variables for each species. The order in which these composite variables were selected is an estimate of their relative importance. The first group entered accounts for the greatest amount of variability. When using stepwise regression analysis, the later groups added may have a different sign than when their effect is evaluated separately. The interpretation of the final multiple regression results depends on the choice of composite variables and on their order of entry into the equation.

	PRECIPITATION Month												TEMPERATURE Month											
	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J
Jack pine								-1	-3	-3	-3								+2					
Red pine	-3															-1	-1	-1		-2				
White pine														-1	-1	-1			-3	+2				
Balsam fir						-3													-1		-2	-2	-2	-2
Black spruce			+1												-2	-2	-2	-2					+3	+3
Tamarack							-2	+1	-3	-3														
N.white-cedar														-2	-2	-2			+3		+1	+1	+1	+1
Quaking aspen						-3									-2	-2							+1	+1
Paper birch						+3									-2	-2					+1	+1	+1	+1
All[1]	+2	+2													-3	-3							+1	+1

[1] Includes all of the above species and those with fewer than 100 trees.

Figure 2. Diagrammatic representation of multiple regression analysis results depicting the influence of the most significant groupings on tree species at Cloquet in northestern Minnesota. Pluses represent a positive influence and minus a negative influence. Order of inclusion into equation: 1 = entered first, 2 = entered second, and 3 = entered third.

RESULTS

The particular groupings selected in the preliminary screening (figure 1) vary from species to species. Nevertheless, the more common groupings are relatively consistent, and most appear reasonable. Optimal climatic requirements may vary considerably from species to species. Yet, as demonstrated here, closely related species usually are strongly affected by the same climatic variables. Quaking aspen and paper birch are similar. (Northern white-cedar is also nearly identical to them.) To a lesser extent, certain similarities are found among the three pines. Balsam fir and tamarack show the greatest differences.

The strongest composite variables, with possible causes, include:

1) Less snow in February and probably early March enhances tree growth. An unusually deep snow during the colder snow months will increase the length of time the site is covered by snow, which will extend the inactive period and delay the beginning of growth. Late snowfall in April is more likely to melt quickly, having little negative influence.

2) A cool spring (roughly from March through May) enhances tree growth. High air temperature during times when the roots are cold or frozen can lead to internal water stress and injury to exposed tissues.

3) A warm August enhances tree growth. Cloquet is far enough north that on the average, August is about 2.4° cooler than July. A warmer August would help extend the length of the growing season.

4) A warm fall (especially October, and to a lesser extent November) enhances tree growth. Severe cold early in the fall without adequate snow cover can cause shock to tree tissues not adequately hardened by gradually decreasing fall temperatures, thus adversely influencing growth the next spring.

5) A warm early winter (December and January) enhances tree growth. Greater warmth in the early winter months can cause gradual winter hardening, while snow builds up to shield the surface soil and roots from excessive cold.

Other, less pronounced, trends include:

1) Precipitation in July is detrimental to tree growth. This is hard to understand unless precipitation (which, on the average, peaks in July) has become excessive. The last measurement period contained consecutive years early in the interval with 6.2 and 7.0 inches of rain in July. The 6.2 value was preceded by 6.0 inches in May. Since Cloquet is an area of high July precipitation and adequate summer precipitation, the data indicates that precipitation can become excessive.

2) Precipitation in early winter (November and December) enhances growth in the three pine species. Snow early in the season can insulate the soil and contribute to warmer soil temperatures during the winter period, while the absence of early snow can lead to low soil temperature and the freezing of roots. Pine

species may require greater amounts of snow because their foliage intercepts snowfall.

The final multiple regression results (figure 2) help us further highlight the most significant groupings. In order of importance, we judge 1) warm weather in the fall and early winter, and 2) a cool spring to be most beneficial to growth. These are general trends for the Cloquet study area, and obviously vary by species.

This simple approach was necessary because we only had four measurement intervals at 5 to 7 years in length. Had additional short-term remeasurements been available, the data would have been sufficient to look for curvilinear trends and interactions between climatic factors.

SUMMARY

This study has successfully 1) demonstrated that a regional tree growth model can be used to remove sources of variation in a climatic study, 2) evaluated statistical methods to determine the most significant groupings of climatic variables, and 3) identified temperature and precipitation patterns that are correlated with tree growth.

The statistical approach related average annual diameter growth prediction errors to monthly mean temperature and total precipitation in an area of northeastern Minnesota. This was done by 1) using a regional tree growth model, STEMS, to remove stand and tree variation, 2) using correlation analysis to measure the influence of monthly temperature and precipitation on diameter growth projection errors, 3) limiting the number of variables in the analysis by developing composite groupings of monthly temperature and precipitation measurements, and 4) running a stepwise multiple regression analysis to highlight the most important groupings and patterns.

The results demonstrate that species at Cloquet, Minnesota showed the greatest response to fall, winter, and spring weather. It appears that weather during the growing season, unless producing excessive precipitation, is less important to tree diameter growth than the weather prior to it. There are many possible mechanisms for these effects: colder temperatures in the fall may injure tree tissues before they have been adequately hardened or early spring warm temperatures may also decrease frost hardiness, both making trees more susceptible to freezing injury. Growth is more strongly related to monthly mean temperature than to monthly precipitation in an area with generally adequate precipitation but fairly severe winters. The effect of greater precipitation and warmer weather is generally negative in the spring but positive in the fall and early winter.

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DEVELOPMENT OF RELATIONSHIPS BETWEEN SPRUCE BUDWORM DEFOLIATION AND FOREST STAND INCREMENT IN NEW BRUNSWICK

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Abstract--Spruce budworm (Choristoneura fumiferana (Clem.)) defoliation of balsam fir (Abies balsamea (L.) Mill.) and spruce (Picea sp.) stands in eastern Canada causes substantial reduction of timber volume yield, which must be taken into account in forest management planning. This requires data to quantify the relationships between defoliation, forest stand increment, and timber yield. In this paper, we describe the establishment and measurement methodology of a network of permanent sample plots in New Brunswick, designed to provide information on effects of budworm defoliation on yield for a variety of stand types.

Keywords: Spruce budworm, defoliation, balsam fir, mortality, volume increment.

INTRODUCTION

Forest management activities aimed at procuring a sustainable wood supply must be based on projections of the future development of all stands which comprise the forest being managed. The validity of the planned sustainable harvest level depends upon the degree to which forecast stand development matches reality as it unfolds. Consequently, any external stress factors which influence stand development must be realistically reflected in the stand projections. Failure to do so increases the probability of error in stand forecasts, and increases the risk of over-harvesting the forest.

In much of eastern Canada and the United States, defoliation by the spruce budworm is a pervasive external stress which has dramatically influenced the growth of host trees and stands for much of the last 30 years. Defoliation reduces the growth of individual trees by 50 to 90%, and overall volume yield of spruce-fir stands has been shown to be reduced by 67% and 39-81% in studies of budworm outbreaks in Minnesota and New Brunswick, respectively (Batzer 1973, Baskerville and MacLean

1979). Such effects must be incorporated in forest management planning. Addressing budworm effects becomes even more critical if the region is operating under a tight balance between the long-term timber supply and demand. Recent analyses of timber supply have demonstrated this tight balance in several regions, including New Brunswick and Maine, resulting from both the current age structure of the forest and damage inflicted by budworm (Baskerville 1982, Sewall Co. 1983).

In this paper, we describe a recently initiated project designed to develop relationships between defoliation and stand increment in New Brunswick, for use in forest management planning. Our objective here is to explain the rationale behind our selection of a network of plots, study design, measurement methodology, expected results, and usage of the results in operational forestry activities.

EXPERIMENTAL DESIGN CONSIDERATIONS

Defoliation by spruce budworm affects the wood availability from a forest in that: (1) defoliation influences tree growth and mortality, (2) tree growth and mortality define timber yield at the stand level, and (3) the collective yields of all stands, in conjunction with the forest structure and harvest progression, determine the availability of wood over time.

Forest management entails controlling that availability by designing when and where harvesting occurs and choosing when and where protection against defoliation will be carried out. Planning this kind of management requires a supporting analytical system in which defoliation is detected at the stand level, the cumulative effects on future stand yield are inferred, and these stand yields are supplied as input for forecasting the development and resultant wood availability for the forest as a whole. The three components (defoliation, stand yield, and forest development) are linked so that stand level actions of harvesting and protection can be implemented to generate a desired forest-level outcome.

The study described here is aimed at developing the relationships necessary to forecast stand development under varying levels of defoliation. These relationships will be used in conjunction with a computer-based forest resource mapping and analysis system (Geographic Information System) in place at the New Brunswick Department of Forests, Mines and Energy (Erdle and Jordan 1984).

Both harvesting and protection are implemented at the stand level, but the decisions of when and where to exercise them are ideally made from a forest level perspective; that is, in light of the relative behavior of all constituent stands in the forest being managed. A typical management unit forest in New Brunswick covers 400,000 ha and may consist of some 25,000 stands, representing all stages of development and a large array of species combinations. This poses four important characteristics which defoliation/stand yield relationships must possess to be useful in operational management activities. First, the differential impact of defoliation in stands of varying maturity and species mix must be accommodated, and expressed as a volume measure at the stand level. Several studies (MacLean _et al_. 1984, MacLean 1980, Clowater and Andrews 1981) and observation in the field have revealed such differences to be substantial. Second, the stand descriptions to which the defoliation/yield relationships will be applied must be consistent with the descriptions which exist in the New Brunswick forest inventory. This inventory is the only source of geographically referenced information in which all forest stands are represented. The trade-off between detailed stand descriptions and complete forest coverage is necessary in light of the operational use for which the stand forecasting procedures are intended.

Third, defoliation across a forest will vary in time and space between removal of a little to all of the current foliage, and may include "backfeeding" on older foliage age classes when budworm populations are particularly high. Defoliation/yield relationships must accommodate such a wide spectrum of damage conditions. This requires inclusion of a variety of damage levels in a detailed study, and requires a system to extend the relationships to conditions present in the forest but not observed as a part of such studies.

Finally, the defoliation/yield relationships must tie in with the annual aerial defoliation survey, since this is the only means presently feasible for detecting defoliation in all stands across a large forest tract. It is worth emphasizing here that complete coverage and accounting for all stands in a forest is a prerequisite for successful use of defoliation/yield relationships in operational forest management activities.

PLOT SELECTION

When considering the establishment of plots to develop budworm/stand yield relationships, we initially examined existing permanent sample plots and data. As part of the New Brunswick Department of Forests, Mines and Energy (NBFME) Forest Inventory, a network of approximately 1500 permanent plots was established between 1976-79, and remeasured in 1980 and 1983. Even though spruce budworm defoliation was not measured in these plots each year, it seemed worthwhile to utilize a subset of the plots for this study, because of the historical information on stand development and yield.

The NBFME plots were randomly distributed throughout the forest, and consisted of clusters of 9 temporary and 3 permanent prism points (metric basal area factor = 2.0) located 40 m apart (N.B. Dept. Natural Resources 1981). Only the three permanent prism points have been used in this study. Trees sampled at the points were numbered and marked at breast height for diameter measurements, and the age of two dominant or co-dominant trees was measured.

Selection of plots for our study was based on stratification by species (fir versus spruce), maturity (mature versus immature), and protection (protection zone versus non-protected, "setback" zone). Figures 1 and 2 show the entire set of plots divided into the resulting eight strata, in terms of live merchantable spruce-fir volume in 1980 and 1983.

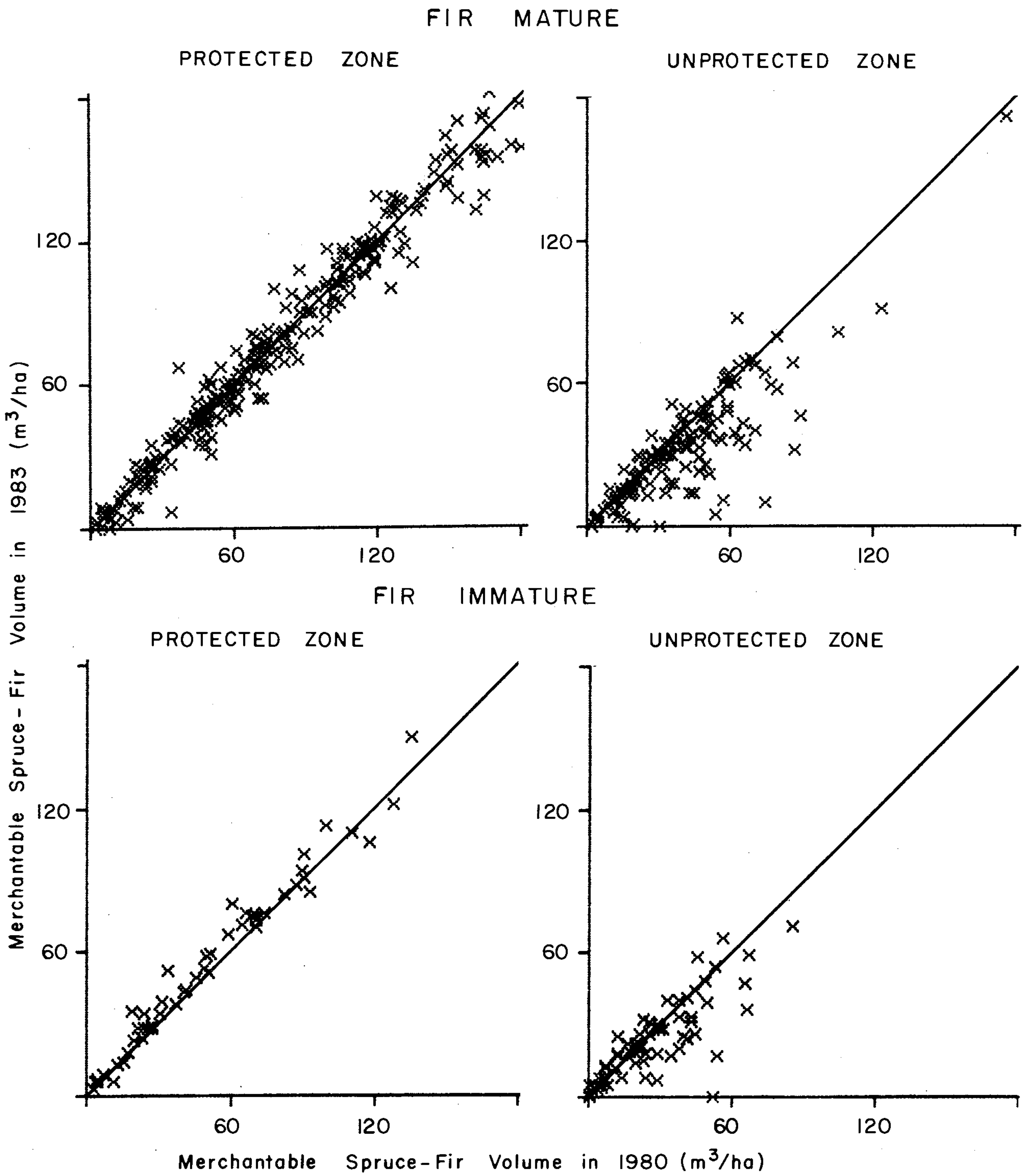

Figure 1. 1983 vs 1980 live merchantable volume (spruce plus fir) for 499 fir plots stratified by maturity and protection zone. Fir plots are those in which fir ≥ 50 percent of the total spruce/fir volume.

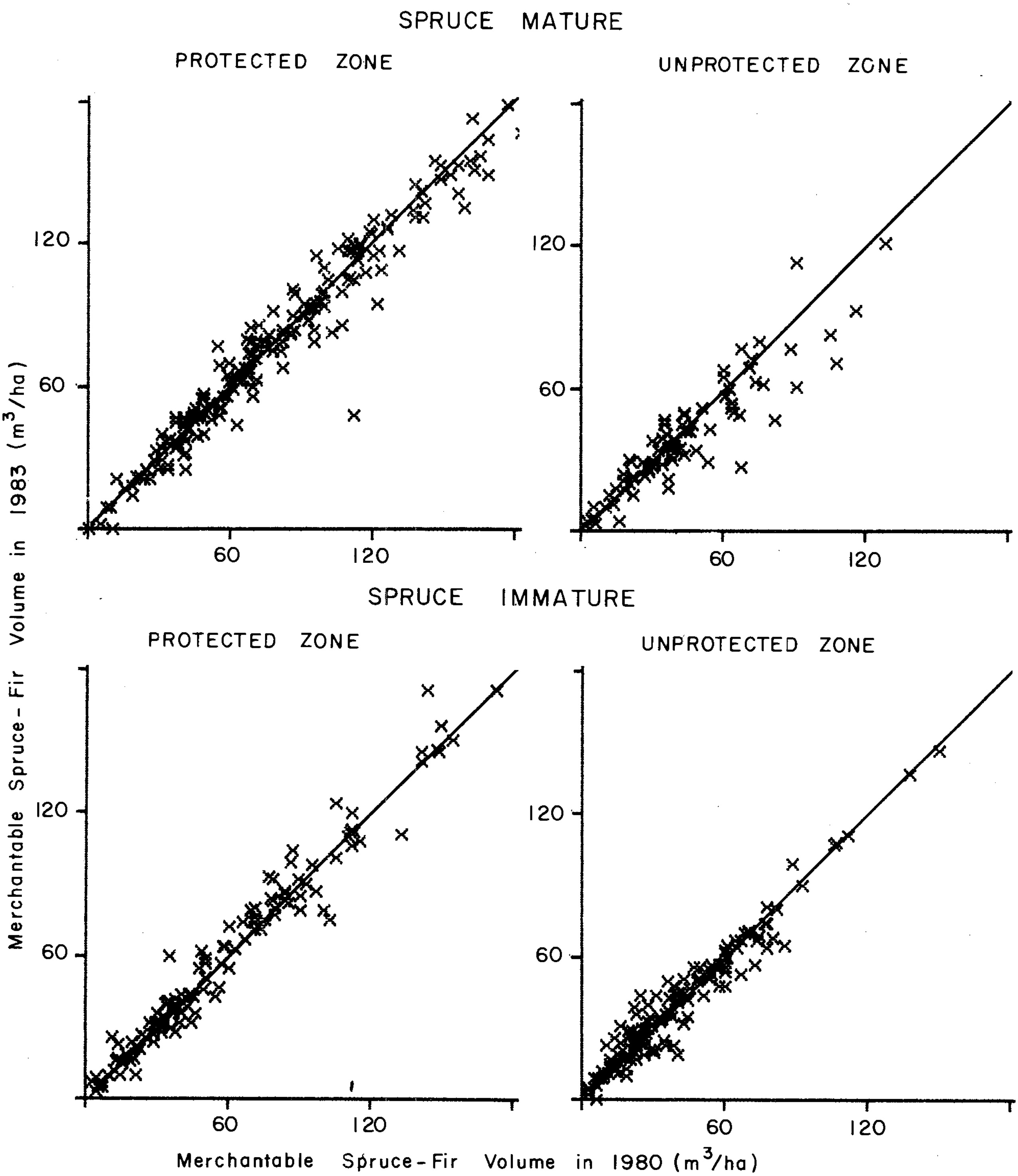

Figure 2 1983 vs 1980 live merchantable volume (spruce plus fir) for 523 spruce plots stratified by maturity and protection zone. Spruce plots are those in which spruce > 50 percent of the total spruce/fir volume.

Wood availability is very sensitive to when net stand increment becomes negative, and at what rate volume loss occurs (Clifford 1981). Because of this, we felt it necessary to explore what combinations of factors trigger net volume decline, and therefore decided to select, where possible, 10 plots with positive net increment (above the 45 degree line in each figure) and 10 with negative net increment (below the 45 degree line) from each of the eight classes in Figures 1 and 2. Plots were chosen to represent the range of volumes present in the class, to give a good geographic dispersion of plots in different categories throughout New Brunswick, and to be reasonably accessible. A total of 136 plots was selected and sampled during the summer of 1985; sample plot locations are shown in Figure 3.

MEASUREMENT METHODOLOGY

Both current defoliation (feeding on the current year's foliage) and total defoliation (or cumulative defoliation, including all age-classes of foliage) were estimated for each host tree at the sample points each year. Ocular methods (scanning the crown with binoculars) with percentage defoliation classes were used; these have been demonstrated to have a relative accuracy of about ±10% defoliation (MacLean and Lidstone 1982). Observers rating defoliation were initially trained and checked for consistency using several test stands. Total (cumulative) defoliation was used as an estimator of impending tree mortality, since studies have shown that fir trees that have lost more than 90% of their foliage usually die the following year, and >75% total defoliation usually results in mortality within 2-3 years (e.g., Blais 1981). In addition, pole pruners were used to sample two midcrown branches of each host tree species present in each plot and defoliation was rated for 10 individual shoots using percentage classes (the "shoot-count" or Fettes method). During the initial branch sampling at each plot, defoliation of foliage age-classes from 1980 to 1984 was estimated. The past budworm defoliation history of each plot was also determined based on data from the aerial defoliation survey conducted annually in New Brunswick; individual-tree and aerial defoliation estimates will be compared.

Growth and yield of the permanent sample plots will be determined by annual assessments of tree mortality and biennial measurements of diameter at breast height for each tree. Trees are checked for mortality by removing sections of the bark and examining the cambium for signs of death (e.g., discoloration and dryness). Species identification and crown class are also recorded for each tree. More detailed assessment of the past growth of individual trees is possible via increment cores, and this will be used for several trees in each plot. The most detailed growth assessment would be via stem analysis and determination of current annual volume increment and specific volume increment, but this requires destructive (and very time-consuming) sampling.

This study has also been coordinated with other spruce budworm surveys conducted in New Brunswick by the Department of Forests, Mines and Energy for use in the forest protection program, so that population level and budworm hazard will also be estimated each year in the same stands.

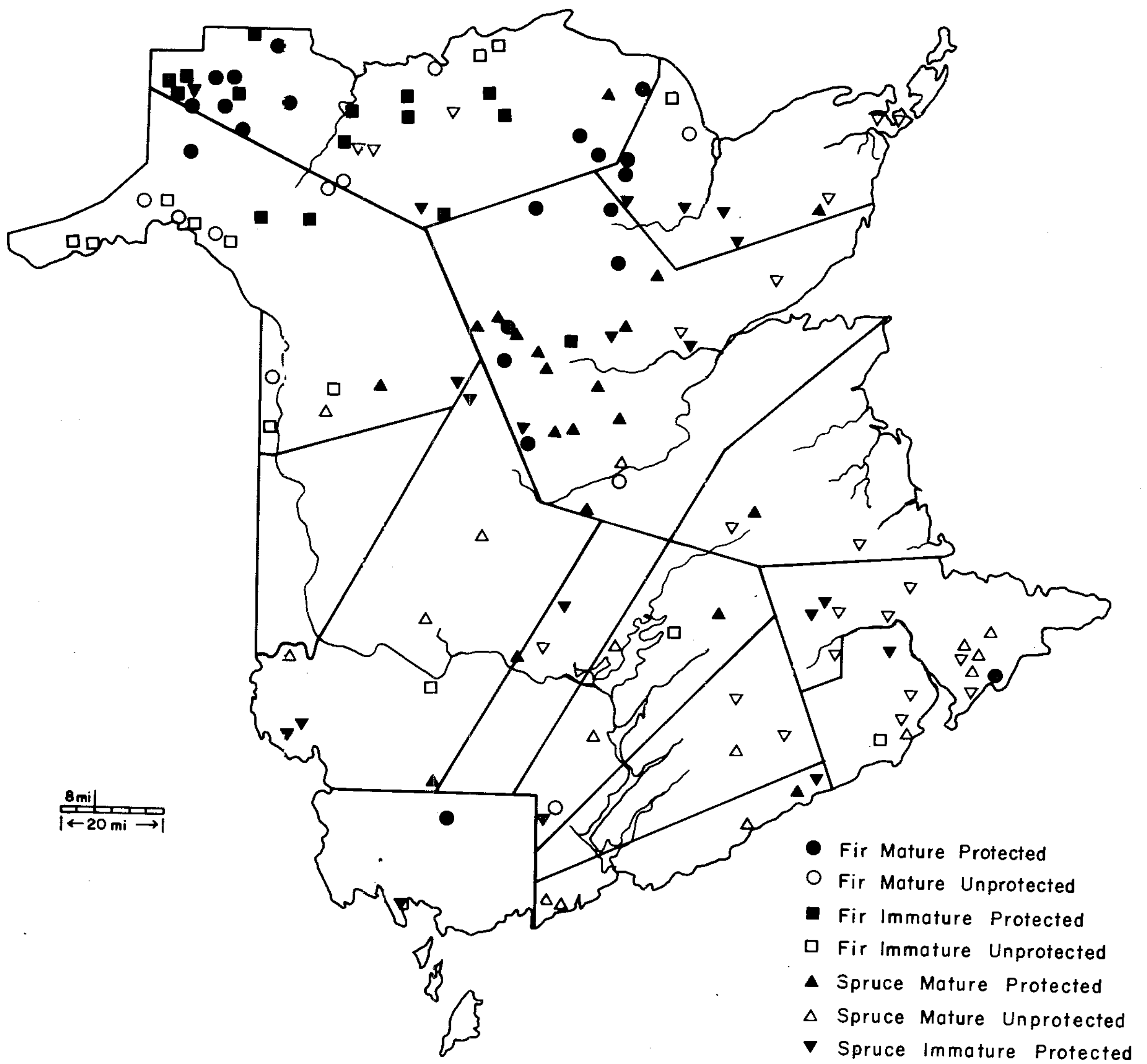

Figure 3. Locations of forest stand sample plots in New Brunswick.

Data analysis will primarily consist of development of relationships between cumulative annual defoliation and periodic growth and mortality, for specific stand types.

DISCUSSION

This study is an attempt to systematically derive relationships between budworm defoliation and stand yield for a variety of stand types in New Brunswick. To our knowledge, it is one of the first budworm impact studies anywhere in which sample plots have been selected through stratification of existing forest inventory plots, on the basis of factors known to affect budworm damage levels (i.e., tree species, maturity, and protection). With the high cost of establishment and remeasurement of permanent sample plots, it would appear to make sense for research and management agencies to utilize the same network of plots, wherever possible. Further, it fosters a closer tie between management problems and research efforts, and is a step towards reducing some of the divergence which has been noted in the past (e.g., Carrow 1986).

A somewhat similar study to the one reported in this paper has been going on in Maine since 1975. The Maine Spruce Budworm Growth Impact Study was established as a cooperative effort among the CANUSA program, USDA Forest Service, Maine Department of Conservation, and 11 private forestry companies, and consisted of annual surveys of over 400 0.02-ha plots. Results from the study have indicated that softwood basal area accretion (survivor growth) decreased from 0.68 m^2/ha in 1975-76 to 0.45 m^2/ha in 1980-81, a loss of 35% due to budworm defoliation (Brann _et al_. 1983). In 1981, mortality increased over 1976 levels by 173% and 33% for fir and spruce in the softwood type.

Recent work in several regions has developed frameworks for including budworm effects in timber supply analyses (e.g., Seymour 1986, MacLean and Erdle 1984). One factor that has significantly enhanced the possibilities of using budworm impact data in forest management planning is the increased usage of computer-based Geographic Information Systems and supporting analytical software. These systems make it possible to manipulate and forecast data from each of the thousands of individual stands in a management area in formulating a management or protection plan, and to retain the spatial location of each stand in the forest.

Despite the emergence of such powerful tools, the success of any decision-support system will hinge on the degree to which forecasts of stand development match reality. The little information currently available on stand development under varying levels of budworm impact hampers our forecasting abilities considerably. This, in turn, severely constrains examining and evaluating alternative protection and harvesting measures, and inhibits improving them in the context of wood supply and operational forestry activities. The objective of our study is to partially address this problem by better defining the relationships between budworm defoliation and stand development.

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PREDICTING THE PROBABILITY OF SURVIVAL FOR BALSAM FIR, RED SPRUCE AND WHITE SPRUCE DURING A SPRUCE BUDWORM OUTBREAK IN MAINE

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Abstract--Survival models are a necessary component of a forest growth simulation. Equations are presented to estimate the probability of survival and the conditional probability of cause of death given that the tree has died, for red spruce (*Picea rubens* Sarg.), white spruce (*Picea glauca* Voss.) and balsam fir (*Abies balsamea* L.) during a spruce budworm (*Choristoneura fumiferana* Clem.) epidemic. Both individual tree (crown class and species) and stand variables (fir ba/a, spruce ba/a, hardwood ba/a, old defoliation and new defoliation ratings for the plot) were significant in explaining the variability of survival during the epidemic.

Keywords: Balsam fir, spruce, spruce budworm, logistic regression.

INTRODUCTION

A tree's likelihood of survival during a spruce budworm epidemic is essential information for forest management's decision to spray insecticides. Moreover, survival information along with a forest growth simulator make it possible to hypothesize what type of trees will compose the stand, during and following the epidemic.

Much literature exists on the occurrence, distribution and description of mortality patterns during a spruce budworm outbreak. Reports on the current outbreak in Maine are provided by Lawrence and Houseweart (1981) and Brann et al. (1981,1983). An excellent review and analysis of Canadian budworm mortality are provided by MacLean (1980).

Past budworm mortality studies have attempted to quantify budworm-caused mortality to a variety of stand characteristics, such as ba/a, volume/a and species composition. Usually these stand characteristics take the form of host species percent composition and host species ba/a, etc. The dependent variable in most studies is either percentage of host species dead (based number of trees/a or ba/a) or host species dead ba/a. The results of past analyses have been quite variable, partly because budworm density or amounts of feeding are not included in the model. Also previous studies have used stand level variables thus masking any within plot variation such as tree size or crown class.

The models presented in this paper predict the probability of survival and the probability of cause of death given that a tree has died, for balsam fir, red spruce and white spruce during a spruce budworm epidemic in Maine. Both stand level and individual tree variables are used to explain variability of survival during the epidemic.

DATA

These data represent 282 of an original 400 plots established in 1975 as a cooperative effort among the CANUSA program, the USDA Forest Service Northeastern Area State and Private Forestry, the State of Maine Department of Conservation Bureau of Forestry, and eleven private forestry companies (Boise Cascade Corp., Diamond International Corp., Georgia-Pacific Corp., Great Northern Paper Co., J.M. Huber Co., International Paper Co., J.D. Irving LTD, Prentiss & Carlisle Co., Scott Paper Co., St. Regis Paper Co.,and Seven Islands Land Co.) to document the effect of the spruce budworm, on the growth and mortality of the Maine forest. Plots are remeasured annually by field crews of the above stated cooperators.

Measurements are on 1/20 acre plots for all trees greater than 4.5 inches dbh. The following records are maintained for each tree.

1. tree species
2. dbh
3. crown position (suppressed, intermediate, codominant, dominant)
4. tree status (cull, merchantable, dead)
5. cause of death (budworm, blowdown, harvest, logging damage, other, unknown)
6. total height
7. crown length
8. defoliation of new foliage
   (a) none, trace (1-5%), light (6-20%), moderate (21-50%), heavy (>50%)
9. defoliation of old foliage where the classification is the same as in 8.
10. climatic zone as described by Lautzenheiser (1972).

METHODS AND RESULTS

Because only two causes of mortality (budworm or blowdown) were recorded in this study, a system of two equations can be used to predict the probability of mortality by cause of death. First an individual tree survival model (1) was fit using a logistic regression model. Similarly a second logistic regression model (2) was fit for the conditional probability of cause of death given that the tree has died. Thus the probability of budworm mortality is the product of the probability of mortality times the conditional probability of budworm death. The probability of blowdown mortality is computed in a similar manner, substituting the conditional probability of blowdown in place of the conditional probability of budworm caused mortality.

The parameter estimates for the survival model are given in equation (1), and the conditional probability of cause of death in equation (2).

(1) $P_1 = \exp(N)/(1 + \exp(N))$

where: N = 3.174 + .013298 (% FBA) + .030497 (FBA) + .00055908 (SBA) + .024185 (HBA) - .00016976 (FBA) (SBA) - .00027042 (FBA) (HBA) - .73906 (OD) - .0080368 (OD) (FBA) + REGION + SPEC + ND + CRWN + NDCRWN,

P_1 = probability of survival,
% FBA = percent of plot ba/a composed of balsam fir,
FBA = balsam fir ba/a,
SBA = spruce ba/a,
HBA = hardwood ba/a,
OD = mean of yearly old defoliation ratings from the plot,
REGION = -.5635 if southern climatic zone,
.5635 if northern climatic zone,
SPEC = -1.42381 if balsam fir,
.78337 if red spruce,
.64044 if white spruce,
ND = -.046781 if defoliation of new foliage >50% for at least one tree on the plot $\leq$ 5 years,
.046781 if > 5 years,
CRWN = .12809 if dominant crown class,
-.065878 if codominant crown class,
.042138 if intermediate crown class,
-.10435 if suppressed crown class,
NDCRWN = -.276431 if dominant crown class and level one of ND
.276431 if dominant crown class and level two of ND
.060793 if codominant crown class and level one of ND
-.060793 if codominant crown class and level two of ND
.077198 if intermediate crown class and level one of ND
-.077198 if intermediate crown class and level two of ND
.13844 if suppressed crown class and level one of ND
-.13844 if suppressed crown class and level two of ND

(2) $P_2 = \exp(N)/(1 + \exp(N))$

where: N = -1.1049 + .0067119 (FBA) + .013904 (SBA) - .00014513 (FBA) (SBA) + .37208 (OD) + REGION + SPEC + ND + CRWN + NDCRWN + NDOD (OD),

P2 = conditional probability of budworm mortality (conditional probability of blowdown mortality is 1 - P_2),
FBA = balsam fir ba/a,
SBA = spruce ba/a,
HBA = hardwood ba/a,
OD = mean of yearly old defoliation ratings from the plot,

REGION = .85607 if southern climatic zone
-.85607 if northern climatic zone
SPEC = .70619 if balsam fir
-.34290 if red spruce
-.36329 if white spruce
ND = 1.0008 if defoliation of new foliage >50% for at least one tree on the plot $\leq$5 years,
-1.0008 if >5 years,
CRWN = -.948104 if dominant crown class
.096604 if codominant crown class
.28829 if intermediate crown class
.56321 if suppressed crown class
NDCRWN = .18192 if dominant crown class and level one of ND
-.18192 if dominant crown class and level two of ND
-.31332 if codominant crown class and level one of ND
.31332 if codominant crown class and level two of ND
-.17581 if intermediate crown class and level one of ND
.17581 if intermediate crown class and level two of ND
.30721 if suppressed crown class and level one of ND
-.30721 if suppressed crown class and level two of ND
NDOD = -.39383 if level one of ND
.39383 if level two of ND

The coefficients of the survival equation (1) indicate that:

1. The probability of survival is greater in the northern climatic zone.
2. Balsam fir has a greater probability of mortality than red or white spruce which have essentially equal probabilities of mortality.
3. An interaction between crown class and new defoliation of $\geq$ 50% for at least one tree on the plot indicates that all crown classes except the dominant class have increased mortality rates with increasing number of years of new defoliation $\geq$ 50%.
4. The greater the mean of yearly old defoliation estimate the higher the probability of mortality.
5. An interaction effect of spruce and balsam fir ba/a indicates that high levels of spruce and fir ba/a increase the probability of mortality.
6. Increasing levels of hardwood ba/a increase the probability of survival except when high levels of fir are present on the plot. When high levels of fir and hardwood ba/a are present the survival probabilities decrease.
7. An interaction between mean old defoliation rating and balsam fir ba/a indicates that high levels of old defoliation and fir ba/a increase mortality rates.

The coefficients from equation (2) predict the conditional probability of whether the tree was budworm killed or blowdown. Interpretation of the coefficients indicates:

1. A tree has a greater probability of being budworm killed in the southern climatic zone than in the northern zone.
2. Balsam fir trees are more likely to suffer budworm mortality than either red or white spruce.

3. An interaction between spruce and fir ba/a indicates that high levels of spruce and fir ba/a increase the probability of a tree being blow-down mortality.
4. High levels of new and old defoliation increase the probability of budworm mortality.
5. The probability of budworm mortality increases as we progress from dominant to suppressed crown classes.
6. An interaction between crown class and new defoliation of $\geq$ 50% for at least one tree on the plot indicates that dominants and suppressed crown classes have increased probabilities of being blowdown for level 2 of ND, while for codominants and intermediates the probability of blowdown decreased for level 2 of ND.

As an example of how these equations can be used, assume we wish to estimate the probability of budworm mortality and blowdown mortality during the epidemic. Table 1 gives the estimates of P_1 and P_2 from equations (1) and (2) for three example trees.

Table 1. Predicted probabilities of survival (P_1) and conditional probabilities of budworm caused death (P_2) for some specific tree and plot characteristics.

Tree #1	Climatic Zone	Species	Crown Class	Defoliation New	Defoliation Old	Basal Area/Acre Fir	Basal Area/Acre Spruce	Basal Area/Acre Hardwood	Probability of Survival P_1	Conditional Probability of Budworm Mortality P_2
1	south	BF	codominant	2	4.5	50	50	50	.086179	.981676
2	north	BF	codominant	2	4.5	50	50	50	.225445	.906269
3	south	RS	codominant	2	4.5	50	50	50	.461568	.949404

The probability of mortality is $1-P_1$, the conditional probability of budworm death cause is P_2, and the conditional probability of blowdown death cause is $1-P_2$. Therefore the probability of budworm mortality for tree #1 is (1-.086179) x (.981676) = .897076, and the probability of blowdown mortality for tree #1 is (1-.086179) x (1-.981676) = .016745. The probability of budworm mortality for tree #2 is (1-.225445) x (.906269) = .701955 and the probability of blowdown mortality is (1-.225445) x (1-.906269) = .072599. The probability of budworm mortality for tree #3 is (1-.461568) x (.949404) = .511189 and the probability of blowdown death is (1-.461568) x (1-.949404) = .027243.

Comparing tree #1 to tree #2 we see that the probability of budworm mortality is higher in the southern climatic zone, and that the probability of blowdown is higher in the northern climatic zone. A comparison of tree #1 to tree #3 indicates that balsam fir has a much larger probability of budworm mortality than red spruce.

CONCLUSION

Previous budworm research has concentrated on volume or ba/a (percentages of volume or ba/a) losses due to budworm (blowdown mortality is rarely incorporated). Usually the independent variable(s) are host species ba/a or non-host species ba/a, thus the influence of differential feeding and individual tree variables are unknown. Results from our analysis indicate that the use of logit equations (1) and (2) provide a flexible approach to predicting mortality by cause for a wide variety of stand and individual tree characteristics. The analysis leads to much more informative interpretation of budworm and blowdown mortality by species during a budworm epidemic.

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DAMAGE SYMPTOMS ON TREE CROWNS AND GROWTH CHARACTERISTICS IN YOUNG STANDS OF NORWAY SPRUCE AFFECTED BY "WALDSTERBEN"

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The investigation was carried out in the catchment area "Lange Bramke" in the Harz mountains in North-West Germany which was completely planted at the same time with pure Norway Spruce after 1945 and which was used for several research projects of soil science, hydrology and ecology. Typical damage symptoms which did not occur before 1982 and their distribution within the stands and within the landscape were surveyed by means of CIR aerial photographs and field observation. At four selected places about 200 trees were cut for analyzing growth characteristics (height increment and diameter increment). Correlations between visible damage symptoms and growth were analyzed. Differences between north and south aspect and between steps of elevation are disussed with special regard.

DIAMETER INCREMENT LINE AND STAND DEVELOPMENT

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Abstract--A linear function, known as the diameter increment line, can be used to depict the relationship between stem diameters and their increments in a pure even-aged stand. The two coefficients of the function, constant at each age, predictably change in the course of stand development so as to uniquely identify four developmental stages.

Keywords: diameter increment, stand development, tree size.

INTRODUCTION

One of the major factors affecting tree and stand increment is the current size of trees, their accumulated increment. Tree size determines the amount of resources available for tree growth and also reflects tree age which slows growth. In a cohort of trees (group of trees of the same age and species), generally, there is a positive feedback between size and increment. Developmental processes in a forest stand, however, substantially modify this general relationship. These changes in response of increment to size provide a sensitive measure for distinguishing the stages of stand development.

The need for identification of the developmental stages arises in many situations. Most of the silvicultural treatments are stage-specific. Several important relationships between stand variables, for example, the self-thinning rule, or the 3/2-power law, (Yoda et al. 1963) and Reineke's (1933) equation, are applicable only to the intermediate stages of stand development. Nevertheless, such critical moments of development as the achievement of crown closure or the onset of stand decomposition are not yet defined quantitatively.

In this study the most accessible tree variable, stem diameter, is used as the representative of the size. Behavior of the coefficients of the relationship between diameter and its increment, known as the diameter increment line (Loetsch et al. 1973), will be related to stages of stand development.

MODEL

Initial Stage

The initial stage of development of even-aged stands lasts from stand origination until the onset of competition for light among trees and the achievement of crown closure. During this stage of free growth the increase in tree size is not inhibited by intraspecific competition and does not cause mortality. There are several ways to show that at the initial stage the diameter increment (at breast height or stem base level), i, is proportional to the diameter, d, itself:

$$i = pd \tag{1}$$

where p is a coefficient of proportionality which remains constant for a cohort but changes with age.

One of these ways is to suppose that the resources available for the increase of stem volume, i_v, which constitutes the major portion of tree growth, are proportional to the crown volume of a tree, cv, rather than to the crown surface, because, due to the small crown size, sunlight can spread throughout the crown. The crown length of young trees usually coincides with or is proportional to tree height, h, while the crown width is proportional to stem diameter (at base or breast height level). Therefore, one can assume that the crown volume and, consequently, the available resources, r, and the volume increment are proportional to the product of the height and squared diameter:

$$cv \propto r \propto i_v \propto d^2h \tag{2}$$

The average diameter increment of a stem can be found as the ratio between the volume increment and stem surface, s:

$$i = i_v/s \tag{3}$$

The surface is proportional to the produce of the height and diameter and, therefore,

$$i \propto d^2h/dh = d \tag{4}$$

The same result follows from observations that at the initial stage the change of tree dimensions in general, and diameter growth in particular, can be described by the elementary exponential function of age, t:

$$d = ae^{bt} \tag{5}$$

where a and b are positive coefficients. At this stage most of the growth equations are indistinguishable from the exponential function. Differentiation of this function provides equation (1).

Balancing Stage

A new powerful factor, competition for light, appears when trees close their crowns. Competition diminishes the increment of smaller, shaded trees creating a large number of suppressed trees. Suppression at this stage is not yet balanced by mortality. It is possible to predict that, instead of the proportionality of the initial stage, the diameter increment line, as a result of diminished increment of smaller trees, would become steeper and its projection on the y-axis would be below the coordinate origin. At this stage the simplest description of the line is a linear function with the negative y-intercept, q:

$$i = pd + q, \; q < 0 \tag{6}$$

Stage of Balanced Growth

The continuing action of the same factor, competition for light, brings about a relatively stable balance between tree growth and mortality which lasts as long as the canopy remains closed. This balance does not mean that the increase of biomass and its loss (due to mortality) are equal. During this stage the stand biomass increases while the number of trees decreases. This is possible because natural selection does not work at random among trees: survival and growth of larger trees are much greater than that of smaller ones. What does remain constant during this stage is the crown surface of trees on a unit area (Briegleb 1952, Mohler et al. 1978, Long and Smith 1984). In addition to the crown surface, according to the 3/2 power law of self-thinning (Yoda et al. 1963, White and Harper 1970), the relative rate of self-thinning with respect to biomass growth is also a constant, equal to two for all species and habitats.

It is expected that recurrent removal of small trees with lower increments would make the increment line flatter and $q > 0$. Thus, depending on its duration, the same factor (competition for light) would produce opposite signs for the intercept.

As a result of aging, the growth rate slows down in the course of time. Therefore, one can predict that the coefficient p would decrease during the balanced stage, as well as during the entire life span of a stand. $p = 0$ signals the end of the balanced stage and the beginning of stand decomposition.

Similar behavior of the coefficients could be detected when, instead of the age trend, one considers trends caused by the difference in density or tolerance. Probably, any factor affecting density, be it initial number of trees, thinning, or tolerance, would affect the coefficients p and q. For example, one can expect that the coefficient q would longer retain negative values in densely planted unthinned stands of tolerant species when compared with wider spaced plantations of intolerant species.

During the balanced stage the linear regression (equation 6) would become a less accurate picture of the diameter increment line, in particular, because the assumption about proportionality of volume increment to crown volume would no longer be valid. The volume increment of large trees is rather proportional to the crown surface, and, therefore, the actual line would be concave with respect to the diameter axis. The linear approximation (equation 6), perhaps unsuitable for exact increment predictions of large trees, might still be used for distinguishing developmental stages.

EMPIRICAL EVIDENCE

Materials and Methods

Two sets of data were used to calculate the coefficients of the diameter increment line. The first set includes three stands of Aleppo pine (Pinus halepensis Mill.) situated in the Judean Hills, Israel. Periodic annual increments of the two younger stands (Shaharia and Ariel permanent sample plots) were calculated using remeasurements performed by the Forest Department of Israel Land Development Authority. The third stand (at Ma'ale Hahamish) was measured by the author in March 1976. Diameter increments were obtained from coring.

The second set, published by Seth (1974), consists of periodic remeasurements of a sal (Shorea robusta Gaertn.) stand (plot 7, Porahat) in India. The sal stand is located in a more favorable environment for trees than the Judean Hills and has a potentially greater life span than the Aleppo pine stands.

The coefficients and other statistics of regressions were computed using the SYSTAT microcomputer package.

Results

The pine stands demonstrate the first three stages of stand development (Table 1).

Table 1. Statistics of linear regressions of past annual diameter increment (cm) on diameter (cm). see = standard error of estimate

Age, years	r2	see	Intercept	Slope
		Aleppo pine		
10	0.994	0.024	0.040	0.117
25	0.857	0.080	-0.354	0.053
35	0.932	0.028	0.122	0.007
		Sal		
42	0.966	0.035	-0.161	0.023
52	0.959	0.030	-0.145	0.016
62	0.726	0.029	0.039	0.005

The intercept of the 10-year-old stand is not statistically different from zero (the intercept's 95% confidence limits include zero). Two other intercepts do differ from zero, although, as expected, in the opposite directions. The slopes consistently decrease with age. Judging from these data, the stage of balancing growth started at about 12-15 years and ended at 30 years.

The data of the sal stand confirms its greater longevity: the same balancing stage lasted until about 60 years. Its beginning cannot be documented from the data which cover only the two intermediate stages of stand development.

CONCLUSION

Two groups of conclusions can be derived from the presented results. The first of these summarizes the effects of internal and external factors on behavior of the coefficients:

(1) It seems that, intrinsically, diameter increments of individual trees of the same age and species are proportional to the corresponding diameters. The coeffient of proportionality (slope) is independent of tree size.

(2) This coefficient decreases with age remaining at each age equal for all trees.

(3) Unlike the internal factors, the action of the external (environmental) factors depends on tree size which determines in a closed stand the amount of exposure to sunlight. Immediately after crown closure the difference in tree size results in decreased increment of smaller trees and is reflected by the negative y-intercept.

(4) The ensuing difference in mortality between smaller and larger trees brings about the opposite result - positive intercept.

Thus, it seems that the slope indicates the biological age of trees, while the intercept reflects the outcome of competition among trees. Therefore, in order to model the growth of an individual tree it is sufficient to consider only the coefficient p (which is the relative growth rate of diameter) and its change with age.

The second group of conclusions deals with the utilization of the values of the coefficients for identification of stages of stand development. Based on the presented theoretical considerations and empirical evidence, behavior of the coefficients during stand development can be summarized as follows (Table 2):

Table 2. Coefficients of diameter increment line and stand development.

Stage	p	q
1. Free growth	$p_1 = \max$	$q_1 = 0$
2. Balancing	$p_2 < p_1$	$q_2 < 0$
3. Balanced growth	$p_3 < p_2$	$q_3 > 0$
4. Decomposition	$p_4 < 0 < p_3$	$q_4 > q_3$

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TREE RING SCANNER: AN AUTOMATIC TREE-RING-MEASURING MACHINE

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Abstract--Accurate tree-ring measurement is essential in forest-growth experiments. The present paper reviews previous work in designing tree-ring-measuring devices and introduces an automatic tree-ring-measuring device: the Tree Ring Scanner.

Keywords: Tree-ring, increment core.

INTRODUCTION

For many years, forest researchers have used information acquired from annual-ring measurement to study effects of environmental influences on tree growth. A forest-growth experiment may require accurate measurements of thousands of ring widths from samples of increment cores or tree discs. Knowing that manual transcription of readings from a hand-operated measuring device is time-consuming, routine, repetitive, and error-prone, many mensurationists have directed their effort toward automating this laboratory-data-collection process. The purpose of the present paper is to review previous work in designing tree-ring-measuring machines and to introduce an automatic tree-ring-measuring device: the Tree Ring Scanner.

PREVIOUS ACCOMPLISHMENT

Graham (1980) described the configuration, capacity, and accuracy of the Addo-X electronic annual-ring-measuring machine, which - compared with field measurement - is fast and accurate; however, he was concerned about erroneous measurements resulting from faded light source, slack and backlash in the translation stage, and the slow speed of data-capture devices. Graham (1980) further pointed out that most Addo-X components require daily check for proper adjustment and have many inherent problems that seriously affect the system's accuracy. He, nevertheless, recommended it for tree-ring measurement because of the Addo-X system's cost effectiveness.

To improve accuracy in ring-width measurement, Johann (1977) first employed an electronic encorder in his design of the Digitalpositiometer System.[1] In this system, a photoelectrical transducer travels along a

[1]Trademark of Kutschenreiter.

glass scale and is capable of detecting its position against the scale. Readings of different positions are first displayed and stored in an electronic counter then later transmitted to a computer; a ring-width measurement is derived from the difference between two position readings. Using an electronic encoder, Johann not only eliminated slack in the translation stage but also improved measurement accuracy.

Jordan and Ballance (1983) reported their experience with the DIGI-MIC system. They found that, although the system allowed for rapid and accurate collection of tree-ring data, the use of a cassette recorder for data storage deferred reviewing, editing, and analysis of data. Like the Addo-X system, DIGI-MIC differentiates annual-ring boundary by using a conventional binocular microscope which, after prolonged use, causes eye fatigue.

Technology Dynamics, Inc. offers an optional video monitor to be used with its Annual Growth Ring Measurement System Model 1000.[2] With this option, a TV camera is mounted above the microscope's ocular tube to project the sample's magnified image - along with the measuring reticle - onto the video monitor. The quality of enhanced core, or disc images, of coniferous species is suitable for ring-width measurement.[3] Adaptation of a video display in lieu of a microscope will effectively eliminate the problem of eye fatigue, while increasing productivity and data accuracy.

TREE-RING-SCANNER SYSTEM

The Tree Ring Scanner system is an automatic tree-ring-measurement system consisting of two hardware subsystems and computer programs for data capture, retrieval, quality control, and analyses.

The first subsystem is a microcomputer system that comprises a system unit, data terminal, dot-matrix printer, and acoustic modem. Not only does this system capture and store ring-width data for subsequent analyses, it also can be used as an independent computing device.

The other subsystem is an electronic tree-ring-scanning device, called Tree Ring Scanner. Configured for automatic acquisition and handling of ring-width data, the Tree Ring Scanner contains three components: a sample-moving assembly, an imaging assembly, and a digital-display assembly.

The sample-moving assembly contains a sample carrier, a measuring translator (the X-axis), a positioning translator (the Y-axis), and a rotator (the Z-axis). A sample thus can be moved about any of the three mutually perpendicular axes. Motion along the X-axis is accomplished

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[2] Personal communication: Correspondence with Mr. James C. Hartl of Technology Dynamics, Inc., November 1, 1984.

[3] Personal communication: Telephone conversation with Ms. Jonalea Tonn of the Intermountain Forest and Range Experiment Station, U.S. Forest Service, September 17, 1985.

with a motor-driven translation stage: While scanning rings, the operator presses a button to activate the motor; the amount of linear displacement or, in this case the ring width, is obtained from a digital linear transducer with a 0.01 mm resolution. Motion about the Y-axis is created by turning a spindle on the Y-translator: The amount and direction of travel are sensed by an optical encoder with a resolution of 0.01 mm; the function of this translator is to adjust the sample's position for measurement. Circular motion of the sample about the Z-axis is achieved by rotating a turntable: This turntable incorporates a bidirectional shaft encoder that provides digital readings at a ± 0.5 degree interval; the sample carrier's circular motion permits tracing of missing rings. The sample-moving assembly can accommodate a disc of 76.2 cm (30 in) in diameter, or a core of 177.8 cm (70 in) in length.

Tree Ring Scanner's imaging assembly consists of a projection-stereo-zoom microscope with two attachments: illuminator and camera. The projection microscope provides high resolution and depth of field required for tree-ring measurement. Also, because the image is projected in natural color, an operator can easily detect sharp change in tone at the transition zone and more readily differentiate between earlywood and latewood. Unlike the conventional microscope, which requires precise location of the head to enable small light bundles to enter the eye, the projection microscope allows considerable head freedom in both the lateral and in-and-out positions. This freedom in head location, as well as the clarity of enhanced stereo-color image, eliminates eye fatigue completely. Magnification of the microscope with the 1X object lens is 7.5X to 50X; magnifications with supplementary lenses (2X, 1.5X, 0.7X, or 0.4X) are 7.5 to 50 multiplied by the power of the supplementary lenses. The camera attachment is capable of producing stereo pairs of the projected image.

The digital-display assembly consists of three up-and-down counters with 8-digit LED display. By pressing a button, binary coded decimal outputs from counters are transmitted to the microcomputer through an S-100 bus. Without handshaking with the microcomputer, the counters' output can be manually transcribed on paper or recorded on other storage media. This feature allows Tree Ring Scanner to be operated independently as a tree-ring-measuring device.

OPERATION PROCEDURES

Operation of the Tree Ring Scanner system is simple and straightforward: Initially, a sample is mounted on the sample carrier and placed on the carrier's seat. The operator then aligns the core with the scope's horizontal hairline by moving the two translators and by rotating the turntable. After initial setup, the operator runs the control program that will automatically set all counters to zero. The control program first requests for header information including file ID, core ID, date of sample collection, date of measurement, species code, core position, and other relevant information. While entering the header information, the operator can correct input errors as they are discovered. As soon as header information has been received, the control program is ready to receive data transmitted from the Tree Ring Scanner. By pressing a dual-button switch, the operator moves the sample carrier along the X-axis. When the vertical hairline is aligned with the latewood's outer edge, the operator presses a single-button switch to transmit readings from counters to the microcomputer. At the same time, the screen will display (1) the renewed ring count and (2) absolute and relative positions of the X, Y, and Z axes. The operator can verify these readings, continue ring measurement, or exercise any option offered by the control program; namely, (1) delete data point, (2) review the last 10 points, (3) start scanning line, (4) reset all counters, (5) store data and restart, and (6) quit. After ring-width measurements have been recorded, all readings are stored on a floppy diskette for later manipulation.

QUALITY CONTROL AND DATA ANALYSIS

Since Tree Ring Scanner can collect ring-width data fast and accurately, a core (or a line) on a disc is usually independently measured twice. While scanning, the operator makes on-line error corrections. Afterward, if more than one line has been scanned on a disc, the operator may execute a quality control program to check (1) the equality of ring counts and (2) the difference between the two readings of the same ring width on a given line. The maximum allowable difference may be attributable to program change; however, when errors are detected, the operator is asked to take remedial action. Because the sample is still on the carrier, delay in repeating the scanning process is minimal.

Some programs developed for tree-ring analyses can be executed on the microcomputer, while others can be run only on an IBM main-frame computer.

RELIABILITY

Tree Ring Scanner was designed and constructed at the University of Kentucky's Department of Forestry at Lexington and has been in operation since October 1982. Since that time, no repairs or servicing have been necessary.

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FIELD DATA COLLECTION USING A PORTABLE MICROCOMPUTER

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Abstract--A wide range of portable electronic data loggers currently on the market is suitable for use in a forest environment. Epson microcomputers are being used for entering, checking and summarising measurements from permanent sample plots. As prices fall and memory sizes increase, wider use of data capture devices can be expected in both research and management applications.

Keywords: Data capture, permanent plots, microcomputers.

INTRODUCTION

Paper, traditionally used for recording forest data, is not the most suitable medium for use in a forest environment since it is easily damaged and soon gets dirty. In recent years a wide range of portable data loggers and microcomputers has appeared on the market. These machines, developed principally for use in supermarkets for stock control, offer a real alternative to a printed form. In this paper, the use of such machines is discussed for data capture from permanent sample plots established for growth and yield studies.

FIELD APPLICATION

The Mensuration Branch of the Forestry Commission's Research Division manages a national network of about 800 sample plots which are individually assessed at intervals of about five years. At each assessment the diameter of each tree is measured together with heights and volumes of a sample of trees. These measurements form the basis of yield studies and are used to derive typical patterns and rates of tree growth on a range of sites. Within the network of sample plots there are experiments designed to determine the effects of planting trees at different spacings and to investigate the response of trees to different thinning and respacing treatments.

Until the early 1970s all data were collected and processed manually. Thus foresters visited sample plots, measured the trees, recorded the measurements on paper, and then, back in the office, summarised the data and worked out the results. If any errors were detected the forester would return to the plot to check and, if necessary, correct the measurements. The paper records were then sent to the main Research Station for storing. This procedure had a number of disadvantages. Foresters used to spend approximately half their time calculating results and made frequent errors. The paper forms were often damaged in the field and were difficult to read after many years of storage.

More recently the introduction of computers has allowed foresters to send their field measurement forms direct to the Research Station where the time-consuming calculations were performed by the computer. This procedure, however, still had its disadvantages. Although the calculations were carried out correctly, errors were sometimes introduced when data were copied from field forms on to the computer. Also, delays due to the postal service and data preparation meant that results were received by the forester long after he had left the sample plot, so that he was unable to check the data easily.

In recent years, the availability of portable computers has offered the prospect of radically changing these procedures. The ability to process results in the forest means that postal delays and copying errors can be eliminated. The specification for a suitable machine included the following requirements:

- minimum of 16K usable memory;
- a large, liquid crystal display;
- an easy-to-use keyboard;
- reasonable weather proofing;
- and, most importantly, programmable by research staff.

The machine that is being used by the Mensuration Branch to collect data in sample plots is an Epson HX-20 microcomputer. It is programmable in BASIC and comes with standard 16K RAM memory, a 20 character, 4 line liquid crystal display, a 24 column dot matrix printer, a built-in time and calendar clock, a full typewriter keyboard, a speaker for audible warnings, an RS232 interface, and as an option a microcassette drive. In its application for data collection in forestry experiments the memory has been expanded to 32K. The Epson weighs approximately 1.7 kg and measures 29.0 x 21.5 x 4.4 cm and is powered by nickel-cadmium rechargeable batteries with a 40 hour capacity. These various features of the machine offer great flexibility when it is used in the field. The built-in printer allows the forester measuring the tree to produce a hard copy of all data as they are entered, and to print intermediate results. The microcassette provides another medium for data storage. The transfer of information to and from the main sample plot database is achieved either by sending microcassettes in the post or by connecting the Epson to an acoustic coupler and transmitting the data via a standard British Telecom telephone through a modem at the main Research Station. This translates the signal into characters for input to the main computer.

In practical use the flow of information is as follows:

1. Collection of previous measurements.

In the office, the field forester dials the main computer. The previous measurements for the sample plot are transmitted over the telephone line to the Epson HX-20. Alternatively the data are recorded on cassette at the Research Station and the microcassette is sent in the post to the field forester who loads it into the Epson.

2. Field recording.

At the plot, the forester collects the new measurements in the sample plot. These are checked against the previous measurements as they are entered. If an apparent error is detected, such as a diameter being smaller than its previous measurement, the machine emits a bleep and displays a message on the screen asking the forester to check the measurements. The program calculates intermediate results as data are entered, for example, tree volumes.

3. Field processing of data.

The computer checks that all the measurements have been collected and processes the data. Any errors are displayed on the screen so that additional measurements or remeasurements can be done while the forester is still in the plot.

4. Transmission of data to the main computer.

Back in the office, the forester transmits the data over the telephone line to the main computer. If he experiences difficulty with transmission, he sends a microcassette containing the data in the post to the Research Station where it is read directly on to the computer.

Use of the Epson has a number of advantages over previous systems. Firstly, the machine can be programmed by research staff so that programs for data collection can be tailored to the users' requirements, and can be easily developed and maintained. Secondly, as the Epson is a computer, preliminary processing of data can be done in the field so increasing job satisfaction, greatly reducing delays in sending data to and from the Research Station, and allowing field teams to check and amend data before transmission for permanent storage. Thirdly, the built-in printer allows the forester to keep a permanent record of measurements and results. This is important during the early stages of introducing computerized data collection to staff who are used to working with paper forms. Fourthly, the computer power allows the forester to manipulate data, for example, to sort tree diameters into diameter classes. Finally, data can only be entered in a particular format and in a particular order, which ensures that data are consistent between measurements. The programme prompts the forester for information, and can check that all trees have been measured.

DISCUSSION

Complete with an acoustic coupler, and Epson microcomputer costs a little over 700 pounds Sterling.. The total annual cost of each machine including maintenance is unlikely to exceed 300 pounds Sterling. With agency rates for basic grade foresters in the region of 100 pounds Sterling per day, it is not difficult to justify the purchase of data collection devices when time savings can so easily be demonstrated.

With fast moving technology, new machines are continually appearing on the market. At some stage a choice has to be made. The Epson terminals described in this paper fulfill the requirements of the Mensuration Branch of the Research Division. Having created computer systems to deal with the data terminal, the machines are unlikely to be replaced in less than 3 to 5 years.

Costs of portable data capture devices are falling at the same time as processing capabilities and memory sizes are rising. It is expected that such machines will be used increasingly for data collection and manipulation in both research and management applications. Wherever large quantitites of data are collected on a regular basis, the use of these machines should be considered. A look into the future might reveal the following field applications:

1. Sawlog measurement.

   The forester enters measurements of length and top or mid diameter of sawlogs. The data capture device calculates the volume of the individual sawlogs and summary totals.

2. Standing volume measurement.

   The forester enters measurements of breast height diameter, length and mid diameter of volume sample trees, the breast height diameters of girth sample trees and a count of the total number of trees. The data capture device calculates and prints the total number of trees, the estimated volume (with confidence limits) and any other details that are required such as mean diameter and mean tree volume of the stand.

3. Forest inventory.

   The forester enters survey data such as forest name, grid reference, compartment number, species, age and yield class, and any other relevant information such as stocking, windthrow hazard classification and terrain class. The data capture device stores the data for transmission to a central computer where the data are analyzed and permanently stored. Portable data capture devices have been used by the Forestry Commission's Forest Surveys Branch to record and transmit the ground survey data for a recent national census of woodlands and trees.

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GROWTH DECLINE OF WIND-EXPOSED SUBALPINE TREES IN NEW HAMPSHIRE

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Wind stress is among the numerous natural or anthropogenic stress factors that may contribute to the reported decline in growth rate of spruce and fir at high elevations in the northeastern U.S. Subalpine sites in the Northeast are among the windiest forests in the world. Many overstory trees on exposed sites are eventually subjected to changes in wind exposure through mortality or windthrow of neighboring trees. Such changes in exposure may result in changes in growth rate. Overstory red spruce (*Picea rubens* Sarg.) and balsam fir (*Abies balsamea* (L.) Mill.) trees suddenly exposed to strong, turbulent winds along a ski trail cut in 1962 showed growth (increment of basal area) reductions during 1974 through 1983 of 82% and 63%, respectively, compared to growth during 1954 through 1963. Growth of comparable trees on the upwind side of the ski trail did not decline during this period. Mechanical damage to crowns and roots during tree sway is proposed as the primary cause of growth decline of the downwind trees. Downwind trees had smaller living crowns, fewer living fine roots, more abrasion wounds on woody roots, and more discoloration of root wood than did trees on the upwind side of the trail. Regression analyses were made using these 24 trees and 29 declining to healthy trees from two other poorly-stocked, wind-exposed stands in the White Mountains. Of the site, stand, and tree parameters tested, only root and crown damage parameters significantly correlated with reductions in growth rate. For fir, percent root discoloration and percent roots abraded explained 82% of the variation in growth decline. For spruce, crown loss explained 70% of the variation.

PREDICTED FOLIAGE PRODUCTION FOR DEFOLIATED BALSAM FIR TREES USING A MATRIX MODEL

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Abstract--A matrix model is developed to estimate foliage weight of defoliated and nondefoliated balsam fir (Abies balsamea (L.) Mill.) trees. Foliage weight in each of seven age-classes can be predicted by knowing the dbh and age of the tree. After defoliation by the spruce budworm (Choristoneura fumiferana Clemens), the maturation of each age-class of foliage is followed and compared with a sampled estimate of foliage from defoliated trees. Defoliation patterns followed annually are: (1) continued severe; (2) increasing; and (3) continuously light removal of the current-year foliage class. The model provides a basis for estimating the amount of foliage annually in each age-class.

Keywords: Balsam fir, foliage, models, defoliation.

INTRODUCTION

The total growth response of forest trees is a function of the many external influences that alter, positively or negatively, different tree functions. The annual growth of foliage is one of the tree's functions that may be influenced by environmental factors. Alterations in weather patterns, insect attacks, or removal of competing vegetation are examples of factors that have an effect on the foliage produced and eventual tree growth. To model the growth response of coniferous trees in the spruce-fir forests of the Northeast, foliage production and alteration of that production must be considered.

Balsam fir (Abies balsamea (L.) Mill.) and other coniferous tree species can retain foliage from 8 to 12 years, though the quantity and photosynthetic efficiency of that foliage decrease as the foliage grows older (Clark 1961). External influences, such as the attack of spruce budworm (Choristoneura fumiferana Clemens.) on spruce and fir trees, may change the amount of foliage retained in an age-class. The continued defoliation by the budworm results in reduced tree growth (Piene 1980). Thus, a matrix model was developed to describe the relationships that occur when foliage is disturbed by external influences such as the spruce budworm.

MODEL DEVELOPMENT

Hayslett and Solomon (1983) developed a time-independent matrix model to project foliage weight by age-classes:

$$\underset{\sim}{w}_{t+1} = A\,\underset{\sim}{w}_t ,$$

$$\text{where } A = \begin{bmatrix} ke_0 & ke_1 & \cdots & ke_{n-1} & ke_{n+} \\ P_0 & 0 & \cdots & 0 & 0 \\ 0 & P_1 & \cdots & 0 & 0 \\ \vdots & \vdots & & \vdots & \vdots \\ 0 & 0 & & P_{n-1} & P_{n+} \end{bmatrix}, \quad \underset{\sim}{w}_t = \begin{bmatrix} w_{0,t} \\ w_{1,t} \\ \vdots \\ w_{n+,t} \end{bmatrix}.$$

e_i = efficiency of i^{th} age-class of foliage, $i=0, 1, 2, \ldots, n-1, n+$;
P_i = proportion of i-year-old foliage that survives to become a year older, $i=0, 1, 2, \ldots, n-1, n+$;
k = constant; and
$w_{i,t}$ = weight of foliage in the i^{th} age-class at time t. The matrix A was called a foliage-weight projection matrix, and the vector $\underset{\sim}{w}_t$ was called a foliage-weight vector.

This paper is a modification and extension of that foliage-weight projection model including time-dependency and defoliation by the spruce budworm. The biological process is modeled more closely if the foliage-weight projection matrix A is thought of as a product of two matrices: $A_t = G_t S$, say, where S is a time-independent "survival matrix" and G_t is a time-dependent "growth matrix." Specifically,

$$S = \begin{bmatrix} 0 & 0 & \cdots & 0 & 0 \\ P_0 & 0 & \cdots & 0 & 0 \\ 0 & P_1 & \cdots & 0 & 0 \\ \vdots & \vdots & & \vdots & \vdots \\ 0 & 0 & \cdots & P_{n-1} & P_{n+} \end{bmatrix}$$

$$\text{and } G_t = \begin{bmatrix} k_t e_0 & k_t e_1 & \cdots & k_t e_{n+} \\ 0 & 1 & \cdots & 0 \\ \vdots & \vdots & & \vdots \\ 0 & 0 & \cdots & 1 \end{bmatrix}.$$

Beginning with a distribution $\underset{\sim}{w}_t$ of foliage, the foliage that survives until the next year is $S\underset{\sim}{w}_t$. This surviving foliage contributes to the growth of the new foliage and, after it is grown, the distribution of foliage becomes:

(1) $$\underset{\sim}{w}_{t+1} = G_t S \underset{\sim}{w}_t = A_t \underset{\sim}{w}_t$$

The model (1) can be modified by allowing for a "harvest" or removal of foliage by an insect attack, for example. We will denote the proportion of foliage lost or reduced in the i^{th} age-class in year t by $h_{i,t}$. The proportion of foliage remaining in the i^{th} age-class in year t is $1-h_{i,t}$, and we define the diagonal matrix

$$H_t = \begin{bmatrix} 1-h_{0,t} & 0 & \cdots & 0 \\ 0 & 1-h_{1,t} & \cdots & 0 \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ 0 & 0 & \cdots & 1-h_{n+,t} \end{bmatrix}$$

by which we multiply the foliage-weight vector, thus obtaining the vector of foliage remaining after defoliation, $\underset{\sim}{w}^*$:

$$\underset{\sim}{w}^*_{t+1} = H_t A_t \underset{\sim}{w}_t \; .$$

The foliage-weight vector at time t+q can be obtained from the foliage-weight vector at time t as follows:

$$\underset{\sim}{w}^*_{t+q} = H_{t+q-1} A_{t+q-1} \cdots H_t A_t \underset{\sim}{w}_t$$

We can find matrix A_t $(=G_t S)$, which is particular for balsam fir, by finding values for P_i, e_i (i=0, 1, ... 6+), and k_t.

We assume that the proportions (P_i) of needles on balsam fir that survive in each class remain constant regardless of defoliation history. These proportions (Table 1) are taken from Hayslett and Solomon 1983. Thus, the survival matrix S is

$$S = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ .965 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & .959 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & .909 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & .827 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & .726 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & .489 & .200 \end{bmatrix}$$

To obtain the growth matrix G_t, we begin by estimating the relative photosynthetic efficiencies, e_i. For each age-class of foliage, the efficiencies for May and June were read from Figure 23 of Clark (1961) and added together. The photosynthesis which occurs in the 1-year-old and older foliage in May and June, is that which contributes to the growth of the new foliage. Using the 1-year-old foliage as a standard, we obtained an estimated relative photosynthetic efficiency for each age-class of foliage (e_i, i = 1, 2, ... 6+). Because we had no data on the efficiency of foliage older than 6 years, we used the e_6 obtained from Clark (1961) as the efficiency for this entire class (w_{6+} is relatively small and any bias in e_{6+} is probably negligible) (Table 1).

Table 1. Portion of foliage surviving, relative foliage efficiency, and total foliage by age-class.

Age-class (i)	Surviving foliage (P_i)	Foliage relative efficiency (e_i)	Total foliage (r_i)
0	0.965	0.0	0.262
1	.959	1.000	.247
2	.909	.904	.207
3	.827	.763	.125
4	.726	.711	.072
5	.489	.674	.038
6+	.200	.585	.049

The determination of G_t (and, thus, of the foliage-weight projection matrix A_t for balsam fir) is completed by the derivation of an equation for k_t.

First, we use the following equation (equivalent to the equation for standing crop foliage on page 12 of Baskerville 1965) to compute the total foliage weight (W_t) in kg at time t:

(2) $$\hat{W}_t = 0.00126(dbh_t)^{3.21}$$

where dbh_t = diameter (cm) at 1.3 m at time t.

Then, using the proportions (r_i) (Baskerville 1965), the total foliage weight can be apportioned into age-classes (Table 1). The predicted foliage weight in the i^{th} age-class is:

(3) $$\hat{w}_{i,t} = r_i\hat{W}_t.$$

Specifically, the predicted amount of new foliage on a tree at age t+1 is

(4) $$\hat{w}_{0,t+1} = r_0\,\hat{W}_{t+1}$$

From equation (1), it follows that:

(5) $$\hat{w}_{0,t+1} = \sum_{i=0}^{5} k_t e_{i+1} P_i \hat{w}_{i,t} + k_t e_6 P_6 \hat{w}_6$$

Substituting (3) and (4) into equation (5), we have:

$$r_0\hat{W}_{t+1} = \sum_{i=0}^{5} k_t e_{i+1} P_i r_i \hat{W}_t + k_t e_6 P_6 r_6 \hat{W}_t$$

from which it follows that k can be determined by:

$$(6) \qquad k_t = \frac{r_0}{\sum_{i=0}^{5} e_{i+1}P_i r_i + e_6 P_6 r_6} \quad \frac{\hat{W}_{t+1}}{\hat{W}_t} .$$

Substituting the values of r_i and e_i from Table 1 into (6), we obtain

$$(7) \qquad k_t = .3560\ (\hat{W}_{t+1}/\hat{W}_t).$$

Thus k is time-dependent. Using equation (2), we can write equation (7) in the form:

$$k_t = .3560\ (dbh_{t+1}/dbh_t)^{3.21}.$$

A subset of trees was selected from several data sets over a range of dbh and age (age equals t), and values of k_t were calculated. These individual values of k_t varied considerably, and a quadratic curve was fitted through the average k_t values:

$$(8) \qquad k_t = .45917 - .00331t + .00003t^2.$$

Thus, we have the "growth matrix"

$$G_t = \begin{bmatrix} 0.0k_t & k_t & .904k_t & .763k_t & .711k_t & .674k_t & .585k_t \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

MODEL TESTING

The expansion of the foliage-weight model to include the prediction of annual foliage production on defoliated trees provides regular measures of the foliar biomass over time. To test the predictability of the model, we studied 45 plots from 35- to 65-year-old spruce-fir stands with different defoliation histories. In 1978, sixteen 0.01-ha plots were located on well-drained sites in predominantly fir stands in northern Maine and New Hampshire (Kleinschmidt et al. 1980). In 1980 and again in 1982, additional plots were selected in the same or similar stands in order to obtain a range in stand age, species composition, and defoliation history. Stands were selected on the basis of the annual defoliation reports of the Maine State Forest Service, combined with visual examination of branch samples.

Crown and dbh measures were taken on each tree. After felling, discs were taken at intervals along the bole, and, for each disc, bark thickness and radial increments were measured to the nearest 0.01 mm along an average radius. These measurements were used to determine bole diameter prior to defoliation and in preliminary bole-growth analyses (Kleinschmidt et al. 1980; Solomon 1983a, b).

One branch was sampled from the third, sixth and seventh, eighth, and, if it existed, the eleventh whorl from the top of the tree. For each branch, the foliage was separated by age-classes, dried (105°C), and weighed. The age at which the whorl was formed was determined by sectioning and aging the bole on either side of the whorl.

To estimate the actual foliage-weight by age class for each tree on the plots, an algorithm for balsam fir was used to predict the amount of foliage that would have been in each age-class on a branch had that branch not been defoliated (Kleinschmidt et al. 1980). The basic assumption was made that, for foliage in the ith age-class, the tree had been uniformly defoliated. That is, if any collection of branches had p percent of the foliage in the ith age-class on the non-defoliated tree, then, after defoliation, those branches still had p percent of the foliage remaining in the ith age-class. By this assumption, the ratio of the weight of the observed i-year-old foliage on the sampled defoliated branches (d_{it}) to the unknown weight of the i-year-old foliage on the entire defoliated tree ($\hat{D}_{it}$) equaled the ratio of the predicted weight (Kleinschmidt et al. 1980) of i-year-old foliage, which would have been sampled branches had they not been defoliated ($\hat{u}_{it}$), to the predicted weight of i-year-old foliage, which would have been on the entire tree had it not been defoliated (by equation (3)), this weight equals ($r_i\hat{W}_t$). That is,

$$d_{it}/\hat{D}_{it} = \hat{u}_{it}/r_i\hat{W}_t, \text{ which yields } \hat{D}_{it} = (d_{it}/\hat{u}_{it})r_i\hat{W}_t.$$

and the percentage of defoliation was determined by $100(\hat{u}_{it} - d_{it})/\hat{u}_{it}$.

By combining the proportion of foliage surviving from one year to the next, the relative foliage efficiencies, and the total foliage by age-class (Table 1) in equation 1, the annual foliage weight can be estimated by age-class for the following year for non-defoliated trees.

Using the model to predict the amount of foliage remaining after 5 years of defoliation, we selected 132 dominant and codominant balsam fir trees from six plots to depict three defoliation histories (light, increasing, and severe). In 1972, the dbh prior to defoliation was determined, and equations (2) and (3) were used to proportion the total foliage weight into age-classes. After solving equation (8) for k, the model was run on the data for these three defoliation histories. The defoliation was determined for each tree, and the plot percentages were averaged for each year.

The estimated actual and predicted amounts of total foliage by age-classes are presented in Table 2. There are no entries for actual current foliage in 1978 because the foliage had not completed growth at the time the data were collected. The model follows the general form of foliage development through time and age-classes of foliage. The magnitude of differences seems to be large when comparing the estimated actual and predicted foliage weights. However, the values follow the defoliation pattern after 5 years.

For light defoliation, the model under-predicted the 1-year-old class and over-predicted the others (Table 2). As might be expected, the

Table 2. Estimated actual and predicted foliage weight (kg) by age class for three defoliation histories from 1972-78.

Foliage age-class	Light (n=42)			Increasing (n=47)			Severe (n=43)		
	1972 Est. Act.	1978 Pred.	1978 Est. Act.[a]	1972 Est. Act.	1978 Pred.	1978 Est. Act.	1972 Est. Act.	1978 Pred.	1978 Est. Act.
Current	2.51	3.72	--[b]	1.97	1.30	--	1.78	0.15	--
1	2.19	3.06	3.61	1.72	0.54	0.69	1.57	0.00	0.02
2	1.88	2.88	2.56	1.48	0.69	0.52	1.35	0.01	0.02
3	1.51	2.26	1.98	1.19	0.84	0.60	1.10	0.00	0.00
4	1.18	1.89	1.45	0.93	1.05	0.63	0.87	0.03	0.02
5	0.83	1.27	1.02	0.66	0.88	0.57	0.62	0.08	0.04
6+	0.41	0.75	0.34	0.33	0.59	0.24	0.30	0.54	0.13

[a]Actual is estimated from branch samples.
[b]The current foliage was not completely developed at the time of observation.

6+ age-class had the largest difference when compared to the actual estimate. The difference between the 1978 predicted and estimated actual foliage weights is probably due to the amount of variation that occurs in the estimates of relative efficiencies, the probability of retention from one age-class foliage to the next older class, and proportioning of foliage within age-classes.

The model under-predicted the 1-year-old class and over-predicted the other age-classes of foliage, for increasing defoliation (Table 2). The levels of defoliation had more variation as the intensity of attack increased. The difference between the predicted and estimated actual for increasing defoliation was larger than that for the light defoliation. However, the model did follow the changes in the proportion of foliage in each of the age-classes after 6 years.

For trees with heavy defoliation, the model under-predicts the first four age-classes and over-predicts the older age-classes. The 6+ age-classes had the largest difference due to the variation from tree to tree and the magnitude of the numbers.

CONCLUSION

The foliage-weight model, as developed to incorporate defoliation by the spruce budworm, provides a method of predicting annual foliage production. Thus, forest researchers are provided with a means of estimating the amount of foliage biomass that will be annually produced and retained for tree growth. Relationships between the amounts of foliage, age, photosynthetic efficiency, and tree growth can be utilized to quantify the impact of external stresses on our forest environment.

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KRONENPARAMETER ZUR SCHADENSERMITTLUNG IN NADELHOLZBESTÄNDEN

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1. Einleitung

Im Hinblick auf die immissionsbedingten großflächigen Waldschäden ist es eine wesentliche Aufgabe der ertragskundlichen Forschung, Zusammenhänge zwischen dem äußeren Schadbild der Bäume und ihrem Zuwachsgang zu prüfen. Bei Zusammenfassung größerer Gruppen von Fichten mit gleicher Schadstufe konnten relativ gute Korrelationen festgestellt werden, allerdings unter der Voraussetzung, daß die Bäume sich in ihren sonstigen Dimensionen sehr ähnelten (ATHARI 1983). Neuere Untersuchungen am Institut für Forsteinrichtung und Ertragskunde zeigen jedoch, daß der Zuwachsgang von Fichten gleicher sozialer Stellung und gleicher Schadstufe im einzelnen sehr unterschiedlich sein kann. Auch die im Anhalt an frühere Untersuchungen (KRAMER 1966) durchgeführte Prüfung des laufenden Zuwachses je Quadratmeter Kronenmantelfläche in Abhängigkeit von der Schadstufe brachte zunächst keinerlei Ergebnisse. Dieser Sachverhalt bestätigt die Vermutung von POLLANSCHÜTZ (1984), daß die augenblicklich übliche Einordnung der Schadstufen nach dem geschätzten Nadelverlust viel zu ungenau und zumindest für wissenschaftliche Untersuchungen unzureichend ist. Unterstützt wird diese Aussage durch die Untersuchungen von NAGEL (1984), bei denen er große Unterschiede zwischen der Luftbildinterpretation und der terrestrischen Schadansprache feststellen konnte.

Im Rahmen eines größeren Forschungsprojektes über die Auswirkungen von Umweltbelastungen auf das Wuchsverhalten verschiedener Nadelbaumarten im Nordwestdeutschen Küstenraum, sollen Zusammenhänge zwischen dem langjährigen Wachstumsgang von Einzelbäumen und ihren Dimensionen sowie dem äußeren Schadbild untersucht werden. Besonders wichtig hierfür ist die möglichst genaue Ermittlung der Kronenparameter. Über die wichtige und offenbar sehr aussagefähige aerophotogrammetrische Messung der Fichtenkrone hat AKÇA 1983 und 1984 berichtet.

Die folgenden Ausführungen befassen sich mit der terrestrischen Bestimmung der Baumkrone an Probebäumen, die für Stammanalysen vorgesehen waren.

2. Zur Methodik der Baumkronenerfassung

2.1 Kronenprojektion

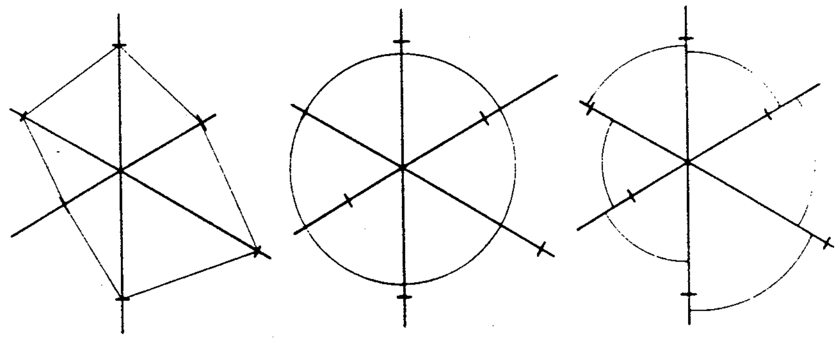
Bei dieser Untersuchung wurde zunächst eine Kronenprojektion aller in der Probefläche stehenden Bäume durch Ablotung der Kronenränder mit einem Dachlot an 6 verschiedenen Punkten durchgeführt. Die 6 Meßpunkte waren systematisch von der Nordrichtung ausgehend in einem Winkel von 60 verteilt. Gemessen wurde im einzelnen an den zu diesen Winkeln nächstliegenden Ästen. Zu jedem Aufnahmepunkt wurde dann der tatsächliche Winkel zur Nordrichtung sowie die Entfernung zum Stamm (Kronenradius) ermittelt.

2.2 Kronenschirmfläche

Aus der Kronenprojektion wurde dann die Kronenschirmfläche berechnet. Hierzu wurden drei verschiedene Berechnungsmodelle angewendet (s. Abb. 1):

Verschiedene Berechnungsmodelle

Abb 1 *der Kronenschirmfläche*



- Das Dreiecksmodell, bei dem die Meßpunkte zwischen 2 benachbarten Radien durch eine Gerade ausgeglichen und die Teilschirmfläche mit der Dreiecksformel ermittelt wird. Die gesamte Kronenschirmfläche entspricht der Summe der 6 Teilflächen.

- Das Mittelkreismodell, bei dem die Kronenschirmfläche über die Kreisformel und mit dem arithmetischen Mittel der 6 Radien berechnet wird.

- Das Teilkreismodell, bei dem jeweils das arithmetische Mittel zweier benachbarter Radien als Eingangsgröße zur Berechnung der Teilkreisflächen herangezogen wird. Die Kronenschirmfläche ergibt sich als Summe der 6 Teilkreisflächen.

Um die Aussagefähigkeit dieser 3 Modelle prüfen zu können, wurde an 50 Bäumen (je 10 ältere Tannen, Fichten, Douglasien, Lärchen und Kiefern) die Kronenschirmfläche durch Abloten von 18 Radien besonders genau ermittelt. Die Kronenschirmfläche wurde hierbei nach dem Dreiecksmodell und dem Teilkreismodell berechnet. Im Durchschnitt der 50 Bäume sind die Kronenschirmflächen nach dem Teilkreismodell lediglich um 3 % größer als nach dem Dreiecksmodell. Bei Berechnung der Kronenschirmfläche mit Hilfe von lediglich 6 der insgesamt 18 gemessenen Radien können für jeden Probebaum durch Verschiebung der Meßpunkte (1, 4, 7, 10, 13 und 16; 2, 5, 8 ... usw.) drei verschiedene Schirmflächen ermittelt werden. Für die 50 Probebäume stehen somit 150 Kronenschirmflächenberechnungen zur Verfügung. In Tabelle 1 werden diese 6 -Radien-Schirmflächen mit Hilfe der genaueren 18-Radien-Schirmfläche getestet.

Die Ergebnisse lassen deutlich erkennen, daß bei einer Schirmflächenermittlung mit 6 Radien das Dreiecksmodell unabhängig von der Baumart immer zu einem systematisch niedrigeren Wert führt. Der Mittelwert der Kronenschirmflächen beträgt hier nur 81 % bzw. 79 % der genauen Kronenschirmfläche.

Tabelle 1

Aussagefähigkeit von 6 Radien-Schirmflächen bei verschiedenen Berechnungsmodellen im Vergleich zur Kronenschirmfläche aus 18 Radien (KrSchFl 18)

Berechnungsmodell aus 6 Radien	Anzahl	Baumart	Mittelwert % (100 % KrSchFl 18 Dreiecksmodell)	Standardabweichung %	Variationskoeffizient %
Dreiecks-	30	Tanne	83	5,7	6,9
	30	Fichte	83	5,8	7,0
	30	Dougl.	82	8,4	10,2
	30	Lärche	81	8,3	10,2
	30	Kiefer	79	8,7	11,0
Σ	150		81	7,6	9,4
Mittelkreis-	30	Tanne	99	7,1	7,2
	30	Fichte	100	7,3	7,3
	30	Dougl.	99	10,2	10,3
	30	Lärche	95	12,5	13,1
	30	Kiefer	93	10,5	11,3
Σ	150		97	10,0	10,3
Teilkreis-	30	Tanne	102	6,8	6,7
	30	Fichte	102	7,0	6,9
	30	Dougl.	102	9,9	9,7
	30	Lärche	101	9,9	9,8
	30	Kiefer	100	10,6	10,6
Σ	150		101	8,9	8,8
			(100 % KrSchFl 18 Teilkreismodell)		
Dreiecks-	30	Tanne	80	5,5	6,9
	30	Fichte	81	5,7	7,0
	30	Dougl.	79	8,2	10,4
	30	Lärche	78	8,0	10,2
	30	Kiefer	76	8,4	11,0
Σ	150		79	7,4	9,4
Mittelkreis-	30	Tanne	97	6,9	7,1
	30	Fichte	97	7,2	7,4
	30	Dougl.	96	9,9	10,3
	30	Lärche	91	12,1	13,3
	30	Kiefer	89	10,1	11,3
Σ	150		94	9,9	10,5
Teilkreis-	30	Tanne	99	6,6	6,7
	30	Fichte	99	6,9	7,0
	30	Dougl.	98	9,6	9,8
	30	Lärche	98	9,5	9,7
	30	Kiefer	97	10,2	10,5
Σ	150		98	8,6	8,8

Das Mittelkreismodell liefert einen Mittelwert der Kronenschirmflächen von 97 % bzw. 94 % der genauen Kronenschirmfläche. Dieses Verfahren erscheint aufgrund der häufig auftretenden Exzentritität der Kronenausformung jedoch zur Berechnung der Kronenschirmfläche weniger geeignet. Standardabweichung und Variationskoeffizient sind bei diesem Modell am höchsten.

Das Teilkreismodell ergibt für alle Baumarten gute Resultate. Die durchschnittliche Kronenschirmfläche beträgt hierbei 101 % bzw. 98 % der Vergleichsschirmfläche. Auffallend ist dabei, daß die Mittelwerte der einzelnen Baumarten sehr weitgehend übereinstimmen. Dieses Verfahren hat außerdem den niedrigsten Variationskoeffizienten. Es kann daher als geeignete Berechnungsart betrachtet werden.

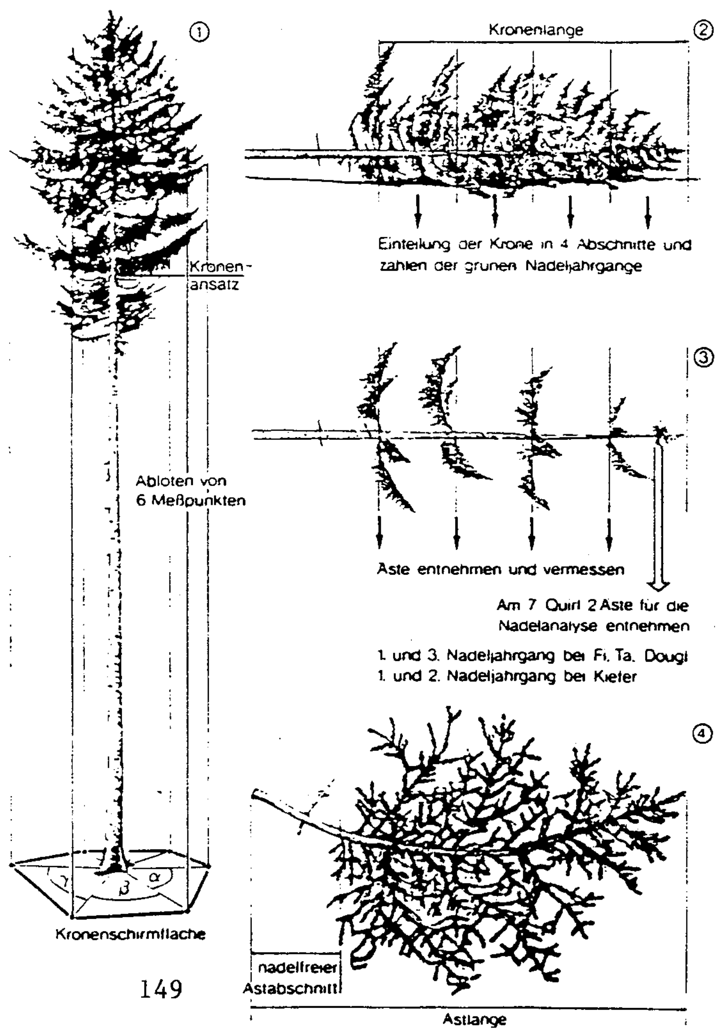
Diese Feststellung entspricht gut den von RÖHLE (1983) bei der Eiche gewonnenen Ergebnissen.

2.3 Kronenmantelfläche

Die Kronenmantelfläche der Probebäume wurde möglichst genau an den gefällten Stämmen ermittelt. Bei Bestimmung der Kronenlänge von Fichte, Douglasie, Tanne und Lärche diente als Kronenansatz der unterste Quirl mit mindestens drei grünen Ästen (Kiefer - erster grüner Ast). Die gesamte Krone wurde in 4 Abschnitte gleicher Länge eingeteilt. In diesen Sektionen wurden jeweils die Äste des untersten Quirls abgeschnitten und die horizontalen Astlängen wurden gemäß Abbildung 2 (4) gemessen.

Abb. 2

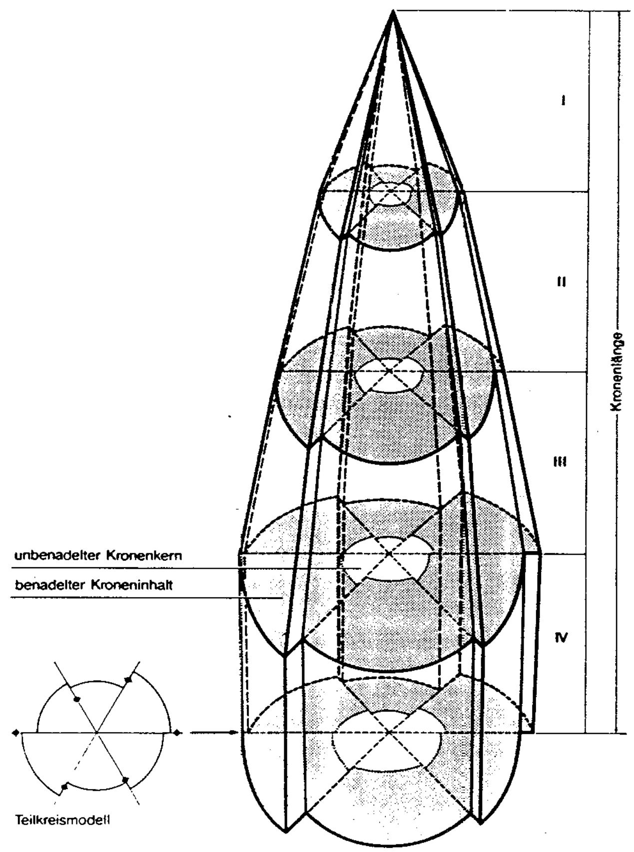
Arbeitsschritte zur Ermittlung der Kronenparameter



Mit diesen Werten wurde für jeden Kronenabschnitt die mittlere horizontale Astlänge gebildet. Die nach Abschnitt 2.2 am stehenden Baum ermittelte Kronenschirmfläche (Teilkreismodell) wurde entsprechend dem Verhältnis der mittleren horizontalen Astlänge an den Grenzen der vier Kronenabschnitte zu demjenigen der Kronenprojektionsfläche in die vier Kronenabschnitte transformiert. Bei den untersuchten älteren Nadelbaumarten entsprach der mittlere Radius des Kronenansatzes weitgehend dem durchschnittlichen Radius der Kronenprojektionsfläche.

Mit Hilfe des Umfangs der Schirmflächen an den Sektionsgrenzen konnte die Kronenmantelfläche für die einzelnen Kronenabschnitte und für die gesamte Krone bestimmt werden.

Abb. 3 **Schematische Darstellung einer Baumkrone**



2.4 Kroneninhalt

Die Kroneninhalte sind früher vielfach als Kegel mit der Kronenschirmfläche als Grundfläche und der Kronenlänge als Höhe berechnet worden. Die hierbei verwendete Kronenformzahl von 0,33 ist jedoch nach der Feststellung von BURGER (1939) und nach den Ergebnissen dieser Arbeit zu klein. Für diese Untersuchung sollte daher der Kroneninhalt und insbesondere der benadelte Kroneninhalt genauer bestimmt werden.

Zusätzlich zu der Ermittlung der horizontalen Astlänge in den verschiedenen Kronenabschnitten wurden auch die nadelfreien Astabschnitte vermessen (Abb. 2(4)) und die grünen Nadeljahrgänge für jeden Kronenabschnitt gezählt (Abb. 2(2)).

Die Berechnung des Kroneninhaltes erfolgte gleichfalls für die 4 Kronenabschnitte, wobei der gesamte Kroneninhalt, der unbenadelte Kronenkern sowie der benadelte Kroneninhalt berechnet werden konnte.

Nach HARTMANN (1984) sind im norddeutschen Küstenraum Fichten, Tannen und Douglasien als gesund anzusprechen, wenn sie 7 grüne Nadeljahrgänge besitzen und Kiefern, wenn sie im Sommerhalbjahr 3 grüne Nadeljahrgänge mit normal langen Nadeln vorweisen. Von dieser Unterstellung ausgehend wurde durch Zählung der grünen Nadeljahrgänge der Nadelverlust im Ganzen sowie aufgegliedert nach Kronenabschnitten eingeschätzt.

3. Vergleich der verschiedenen Kronenparameter - Berechnungen

Nachdem die Kronenparameter mit Hilfe der Kronenanalyse ermittelt worden waren, wurde eine Prüfung des laufenden jährlichen Volumenzuwachses in der Periode 1979-1983 je Quadratmeter Kronenmantelfläche unter Berücksichtigung der Schadstufen durchgeführt (s. Tab. 2). Der Volumenzuwachs für jeden einzelnen Probebaum wurde hierzu mit Hilfe der Stammanalyse ermittelt. Die Ergebnisse der Tabelle 2 zeigen deutlich, daß bei den drei

Tabelle 2

Laufender jährlicher Volumenzuwachs je m^2 Kronenmantelfläche in der Periode von 1979 - 1983

i_v 1979-83	Anzahl	Nadelverlust %	i_v / m^2 Kronenmantelfläche m^3	%
Fichte	1	11-20	0,00019	100
	5	31-40	0,00014 (0,00011-0,00018)	74
	3	41-50	0,00011 (0,00007-0,00014)	58
Kiefer	1	11-20	0,00024	100
	3	31-40	0,00018 (0,00014-0,00024)	75
	4	41-50	0,00014 (0,00010-0,00020)	58
Tanne	1	0-10	0,00023	100
	1	21-30	0,00016	70
	3	31-40	0,00014 (0,00009-0,00018)	61
	1	41-50	0,00007	30

Nadelbaumarten Fichte, Kiefer und Tanne eine eindeutige Tendenz der Abnahme des jährlichen Volumenzuwachses je Quadratmeter Kronenmantelfläche zwischen gesunden und geschädigten Bäumen besteht. Dies liegt daran, daß bei den gesunden Bäumen je Quadratmeter Kronenmantelfläche mehr Nadeln vorhanden sind und somit auch mehr Zuwachs geleistet wird als bei den geschädigten Bäumen.

Um die Aussagefähigkeit der mit Hilfe der neu entwickelten Kronenanalyse ermittelten Kronenparameter zu bekräftigen, wurden ihre Werte mit entsprechenden Werten verglichen, die nach der vielfach verwandten Kegelformel berechnet worden waren. Dazu wurden die Werte der nach der Kegelformel berechneten Kronenparameter ins Verhältnis zu denjenigen nach der Kronenanalyse (= 100 %) gesetzt. Die Ergebnisse sind in der Tabelle 3 zusammengefaßt. Sie zeigen deutlich, daß bei der Kronenschirmfläche keine so großen Abweichungen auftreten, während bei der Kronenmantelfläche und dem gesamten Kroneninhalt deutliche Abweichungen zwischen den beiden Methoden zu verzeichnen sind. Betrachten wir die Rahmenwerte von Kronenmantelfläche und Kroneninhalt nach der Kegelformel, so wird deutlich, daß alle vorhandenen Abweichungen negativ sind; im einzelnen streuen hierbei die Werte von Krone zu Krone in einem erheblichen Maße.

Tabelle 3

Vergleich der Kronenparameter - Berechnungen nach der Kegelformel und nach der Kronenanalyse (= 100 %)

	Anzahl	FICHTE	Anzahl	KIEFER	Anzahl	TANNE	Anzahl	LÄRCHE
Kronenschirmfläche	21	98 % (90-100 %)	16	94 % (86-99 %)	7	98 % (96-100 %)	8	92 % (78-98 %)
Kronenmantelfläche	21	77 % (46-96 %)	16	77 % (54-100 %)	7	68 % (63-76 %)	8	88 % (80-98 %)
gesamter Kroneninhalt	21	68 % (48-100 %)	16	66 % (46-100 %)	7	53 % (48-63 %)	8	77 % (67-95 %)

Um zu zeigen, inwieweit sich die fehlerhafte Berechnung der Kronenparameter nach der Kegelformel und die unzulängliche Einschätzung der Nadelverluste auf den laufenden jährlichen Volumenzuwachs je Quadratmeter Kronenmantelfläche auswirkt,wurden diese Schätzwerte mit den entsprechenden aus der Kronenanalyse gewonnenen Werten verglichen (s. Tabellen 4, 5 und 6).

Die Anwendung dieser gröberen Schätzmethode führt bei allen drei Baumarten zu großen Abweichungen und damit zu zum Teil sinnlos erscheinenden Ergebnissen.

Besonders bei der Kiefer fällt auf, daß die geschädigten Bäume bei Anwendung der Kegelformel mit einer Ausnahme je Quadratmeter Kronenmantelfläche einen höheren Zuwachs leisten als die gesunden Bäume. So hat danach z.B. eine Kiefer mit dem geschätzten Nadelverlust von 70 % einen um 13 % höheren Volumenzuwachs je Quadratmeter Kronenmantelfläche als eine Kiefer mit nur 20 % Nadelverlust.

Tabelle 4

Laufender jährlicher Volumenzuwachs je m² Kronenmantelfläche in der Periode 1979-1983

i_v 1979-83	Anzahl	Nadelverlust %	i_v / m² Kronenmantelfläche m³	%
nach der Kronenanalyse und dem berechneten Nadelverlust				
Fichte	1	11-20	0,00019	100
	5	31-40	0,00014 (0,00011-0,00018)	74
	3	41-50	0,00011 (0,00007-0,00014)	58
nach der Kegelformel und dem geschätzten Nadelverlust				
Fichte	1	0-10	0.00024	100
	2	11-20	0,00025 (0,00021-0,00029)	104
	3	21-30	0,00017 (0,00013-0,00022)	71
	3	41-50	0,00014 (0,00010-0,00016)	58

Tabelle 5

Laufender jährliche Volumenzuwachs je m² Kronenmantelfläche in der Periode 1979-1983

i_v 1979-83	Anzahl	Nadelverlust %	i_v / m² Kronenmantelfläche m³	%
nach der Kronenanalyse und dem berechneten Nadelverlust				
Kiefer	1	11-20	0,00024	100
	3	31-40	0,00018 (0,00014-0,00024)	75
	4	41-50	0,00014 (0,00010-0,00020)	58
nach der Kegelformel und dem geschätzten Nadelverlust				
Kiefer	1	11-20	0,00023	100
	4	21-30	0,00024 (0,00017-0,00034)	104
	1	41-50	0,00010	43
	2	61-70	0,00026 (0,00017-0,00035)	113

Tabelle 6

Laufender jährlicher Volumenzuwachs je m² Kronemantelfläche in der Periode 1979 - 1983

i_v 1979-83	Anzahl	Nadel-verlust %	i_v / m² Kronenmantelfläche m²	%
rach der Kronenanalyse und dem berechneten Nadelverlust				
Tanne	1	0-10	0,00023	100
	1	21-30	0,00016	70
	3	31-40	0,00014 (0,00009-0,00018)	61
	1	41-50	0,00007	30
nach der Kegelformel und dem geschätzten Nadelverlust				
Tanne	1	0-10	0,00034	100
	1	11-20	0,00023	68
	2	21-30	0,00025 (0,00023-0,00026)	74
	1	41-50	0,00013	38
	1	51-60	0,00010	29

4. Flächenbezogener Zuwachs

Um flächenbezogene Zuwachswerte für einen geschädigten Bestand zu gewinnen, wurde im Forstamt Neuenburg (Reg.Bez. Oldenburg), Revierförsterei Upjever, Abteilung 244 ein "Kleinst-Kahlschlag" durchgeführt. Außer den 20 gefällten Stämmen wurden zusätzlich die dazwischen stehenden Stubben analysiert.

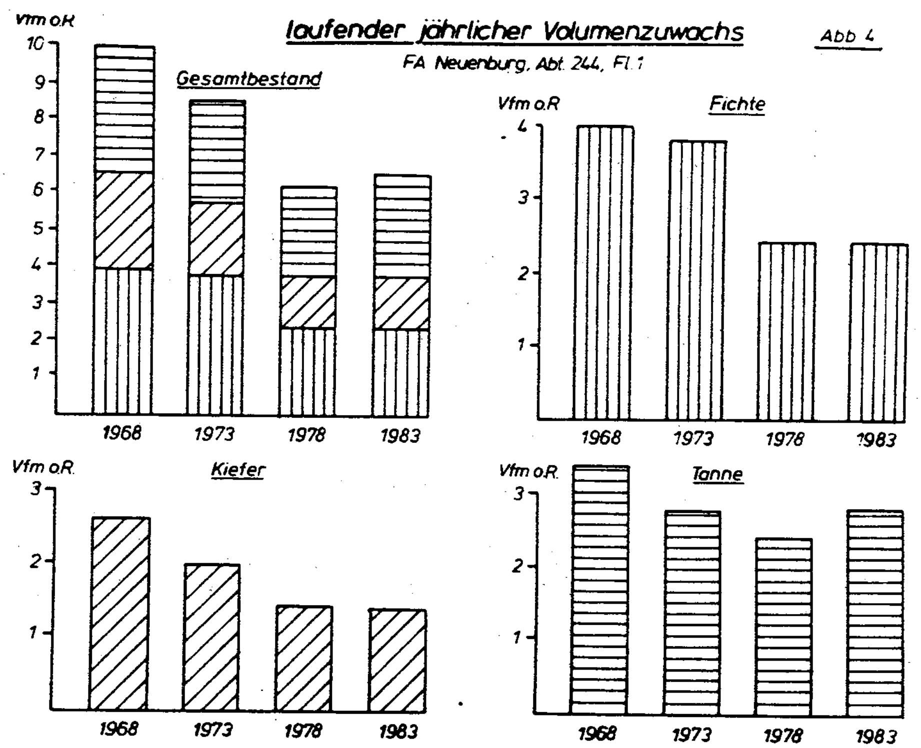
Mit Hilfe der Stammanalysen war es möglich, die Gesamtentwicklung der Probebäume dieses "Kleinstbestandes" zu erfassen. Durch die zusätzlichen Stubben-analysen konnte darüber hinaus für einen Zeitraum von 20 Jahren die Entwicklung von Stammzahl, Grundfläche, Höhe, Durchmesser und Volumen je ha ermittelt werden. Tabelle 7 und Abbildung 4 zeigen die Gesamtentwicklung der untersuchten Probefläche.

Die Ergebnisse der Tabelle 7 weisen auf, daß der laufende jährliche Volumenzuwachs von 10 Vfm Schaftholz o.R. im Jahre 1968 auf 6,6 Vfm Schaftholz o.R. im Jahre 1983 zurückgegangen ist. Die Zuwachsminderung ist bei der Fichte und der Kiefer am stärksten, bei der Tanne etwas geringer. So beträgt der laufende jährliche Volumenzuwachs bei der Fichte im Alter 70 (1968) 4,0 Vfm und sinkt bis zum Alter 85 (1983) auf 2,4 Vfm Schaftholz o.R. ab. Bei der Kiefer fallen die entsprechenden Werte von 2,6 Vfm im Alter 130 (1968) auf 1,4 Vfm Schaftholz o.R. im Alter von 145 Jahren (1983). Die Tanne leistet 1968 im Alter von 72 Jahren 3,4 Vfm und 1983 im Alter 87 2,8 Vfm Schaftholz o.R.

Tabelle 7:

FA Neuenburg - Rfö Upjever - Abt. 244 - Fläche 1

			Verbleibender Bestand					Ausscheidender Bestand		Laufender jährlicher Zuwachs an	
Jahr	Baumart	Alter	Stammzahl	Mittelhöhe m	Mitteldurchmesser o.R. cm	Kreisfläche o.R. m^2	Schaftholzmasse o.R. Vfm	Kreisfläche o.R. m^2	Schaftholzmasse o.R. Vfm	Keisfläche o.R. m^2	Schaftholzmasse o.R. Vfm
1963	Fi	65	251	15,7	17,5	6,1	58	-	-	-	-
	Kie	125	205	18,4	24,8	9,9	98	-	-	-	-
	Ta	67	137	19,2	21,3	4,9	52	-	-	-	-
			593			20,9	208				
1968	Fi	70	251	17,4	19,6	7,6	78	-	-	0,30	4,0
	Kie	130	205	19,0	26,0	10,9	111	-	-	0,20	2,6
	Ta	72	114	21,3	24,9	5,6	66	0,5	3	0,24	3,4
			570			24,1	255	0,5	3	0,74	10,0
1973	Fi	75	251	18,7	21,4	9,0	97	-	-	0,28	3,8
	Kie	135	183	19,5	26,6	10,1	106	1,3	15	0,10	2,0
	Ta	77	114	22,4	27,1	6,6	80	-	-	0,20	2,8
			548			25,7	283	1,3	15	0,58	8,6
1978	Fi	80	251	19,2	22,5	10,0	109	-	-	0,20	2,4
	Kie	140	183	19,9	27,3	10,7	113	-	-	0,12	1,4
	Ta	82	114	23,3	29,1	7,6	92	-	-	0,20	2,4
			548			28,3	314			0,52	6,2
1983	Fi	85	228	19,7	23,8	10,2	111	0,8	10	0,20	2,4
	Kie	145	183	20,1	27,8	11,1	120	-	-	0,08	1,4
	Ta	87	114	24,0	30,9	8,5	106	-	-	0,18	2,8
			525			29,8	337	0,8	10	0,46	6,6



In der Tabelle 8 wird nun der laufende jährliche Volumenzuwachs je ha der Aufnahmefläche den entsprechenden Angaben der Ertragstafel gegenübergestellt, um bei allen berechtigten Vorbehalten gegenüber diesem Vergleich (Ertragsniveau, Mischbestand, bisherige Pflege usw.) näherungsweise den Alterstrend aus den Werten der Ertragstafel für die einzelnen Baumarten einzuschätzen, der ja in den zuvor angesprochenen Zuwachsrückgängen enthalten ist. Um die witterungsbedingten jährlichen Zuwachsschwankungen auszugleichen, wurde eine längere Zuwachsperiode von 10 Jahren ausgewählt.

Tab. 8 Laufender jährlicher Volumenzuwachs

FA Neuenburg, Abt. 244, Fl. 1

Baum-Art	Ertragsklasse	Periode I 1963-1973 Vfm	i_vI- Alterstrend Vfm	Ertragsklasse	Periode II 1973-1983 Vfm	i_vII:i_vI-Alterstrend %	Zuwachsminderung %	Nadelverlust %
FICHTE	III,4	3,9	3,6	III,5	2,4	67	33	31
ET		9,9			9,2	93		
KIEFER	III,8	2,3	2,0	III,7	1,4	70	30	39
ET		2,8			2,5	89		
TANNE	II,5	3,1	3,1	II,3	2,6	84	16	25
ET		10,6			10,5	99		

Es zeigt sich, daß bei Fichte und Kiefer Zuwachsminderungen von ca. 30 % und bei der Tanne von 16 % auftreten, die nicht durch den Alterstrend oder durch Klimaschwankungen zu erklären sind. Sie lassen den vorsichtigen Schluß zu, daß hier auch Zuwachsverluste durch Schadeinwirkungen im Spiel sein können.

Eine Gegenüberstellung der Zuwachsminderung mit dem durch die Kronenanalyse ermittelten Nadelverlust erlaubt eine vorläufige Aussage über Ausmaß der Schäden bei verschiedenen Nadelbaumarten in einem untersuchten Mischbestand und darüberhinaus eine gewisse Beziehung zwischen Zuwachs und Schäden zu geben.

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Abstract:

The paper deals with the exact quantitative measurement of crown parameters.
Close correlations between volume increment per square meter crown surface area and the vitality of the trees can be determined with help of the described crown analysis.

THE INFLUENCE OF TIME AND WEIGHING CONDITIONS ON THE DETERMINATION OF FOLIAR BIOMASS AND ITS DYNAMICS

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Abstract--35 lots of 10 leaves each were collected from the bottom and 35 lots from the top of five 70 years old sample trees (Q. Robur L.) in the Romanian Plain. Re-weighed after dehydration, one noticed that the loss in water content varies in accordance with air temperature and relative humidity: it is more rapid when the leaves are kept in the open air (by 5-6% after one hour and by 13-14% after 3 hours) and slower when the leaves are kept in plastic bags (by 4-5% after 3 hours and by 9% after 12 hours). This is very important both for a correct determination of foliar biomass and its dynamics.

Keywords: Biomass, determination, foliar biomass, foliage weighing, Quercus Robur L.

INTRODUCTION

As a result of the research carried out intermittently during the past 20 years, on various species' foliar biomass, we found out that in order to obtain correct results it is important to know the influence of environmental conditions on determinations and the rigorous observance of the working method. We found out this mainly when we tried to find an explanation for the important differences between measurements made by various authors (Decei 1984, Dissescu 1974) for the same species and especially when we analyzed the possibilities of determining the dynamics and increase of tree and stand foliar biomass (G. Dissescu 1977, Dissescu-Stoiculescu 1983).

One of the most important remarks refers to the influence of the time and weighing conditions of foliage, either wholly collected or as samples; on the accuracy of the measurements (Atwill-Ovington 1968).

As our experience showed that once detached from the shoots the tree leaves start to lose weight (the more unfavourable air temperature and humidity are, the sooner they lose weight), we started a detailed investigation of the phenomenon when oak (Quercus Robur L.) foliar biomass determinations were made.

The aim of the experiment was to establish the influence of the delay of weighing and thermohydric conditions on the possible errors in the determination of foliar biomass and its dynamics.

MATERIAL AND METHOD

Pedunculate oak leaves were gradually collected from five trees in the forest Cornetu (18 km SW of Bucharest) between July 6-18, 1983 when they were fully mature.

In order to facilitate the collection the trees were selected at the stand skirt. Three branches were cut from each tree, from the superior and inferior thirds of their crowns. This was carried on between 10-11 a.m., after the evaporation of dew, and air temperature was not beyond 27-28°C. The branches were placed in buckets full with water (without soaking the leaves) and taken to the laboratory. Seven lots of 10 leaves from the first growth were collected at random, from each tree, at different heights; as they were collected they were weighed with an accuracy of 0.0001 g. The first 10 leaf lot was placed in a closed plastic bag, according to the working method often used for the determination of foliar biomass. The other six lots were left in the open. Thus, for each tree there were two ten leaves lots kept in plastic bags and 12 lots kept in the open air (6 lots from the crown superior level and 6 from the inferior level). On the whole, we worked with 35 lots of leaves from the crown superior level and 35 lots from the crown inferior level.

Once prepared for storage, each lot was weighed again, as far as possible, with the same accuracy, first 10-15 minutes after the collection, then every hour for 28-30 hours from the beginning of the experiment. The study extended over 68-72 hours for some trees and the leaves were last weighed at longer intervals, in accordance with the loss of weight of the lot. At the end of the study the leaves were gradually introduced in a thermostat and dried for 48 hours at 100°C, then were weighed again. At the same time, air temperature and relative humidity were noted.

RESULTS

The Ratio Between Anhydrous Leaf Weight and Green Leaf Weight

The weighing showed that the mean ratio between anhydrous leaf weight and green leaf weight was 41.5% (with a variation between 39.6 and 44.5%) for the superior part of the crown and 40.9% (with a variation between 39.5 and 44.4%) for the inferior part of the crown (Table 1).

Significant differences appeared in 2 out of 5 cases between the proportions determined for the two levels (tree no. 3 - very important difference; tree no. 4 - significant difference) (Table 2). This emphasizes the fact that although the lots of leaves from the inferior level of the crown lost by total drying more weight than the leaves at the crown top, the difference is not often statistically significant (II - Table 2).

Table 1. The ratio between leaf anhydrous and green weight (in %) at the pedunculate oak (*Q. Robur* L.).

Tree No.	Crown Level	N	$\bar{x} \pm s_{\bar{x}}$	s	$s_{\bar{x}\%}$	$s_{\%}$
1	Top	7	39.57 ± 0.24	0.6390	0.6	1.6
	Bottom	7	39.47 ± 0.17	0.4586	0.4	1.2
	T+B	14	39.52 ± 0.14	0.5371	0.4	1.4
2	Top	7	41.08 ± 0.25	0.6703	0.6	1.6
	Bottom	7	40.68 ± 0.26	0.6848	0.4	1.7
	T+B	14	40.88 ± 0.18	0.6848	0.4	1.7
3	Top	7	41.72 ± 0.17	0.4535	0.4	1.1
	Bottom	7	40.01 ± 0.17	0.4561	0.4	1.1
	T+B	14	40.86 ± 0.26	0.9883	0.6	2.4
4	Top	7	40.86 ± 0.30	0.8069	0.7	2.0
	Bottom	7	40.00 ± 0.23	0.6104	0.6	1.5
	T+B	14	40.43 ± 0.22	0.8203	0.5	2.0
5	Top	7	44.49 ± 0.20	0.5218	0.4	1.2
	Bottom	7	44.24 ± 0.44	1.1594	1.0	2.6
	T+B	14	44.36 ± 0.23	0.8737	0.5	1.9
Total	Top	35	41.55 ± 0.29	1.7551	0.7	4.2
	Bottom	35	40.88 ± 0.32	1.8740	0.8	4.6

Table 2. The importance of the difference between the means of the percentage ratio between anhydrous and green weight.

Trial ctg.	Tested lots	t	l	α%	Signific.
I	$V_1 > B_1$	0.3	12	76.8	n.s
	$V_2 > B_2$	1.1	12	29.1	n.s
	$V_3 > B_3$	7.1	12	< 0.1	+++
	$V_4 > B_4$	2.2	12	4.8	+
	$V_5 > B_5$	0.5	12	62.6	n.s.
	V B	1.5	68	13.2	n.s.
II	$V_1 < V_2$	4.3	12	< 0.1	000
	$V_1 < V_3$	7.3	12	< 0.1	000
	$V_1 < V_4$	3.3	12	< 0.65	00
	$V_1 < V_5$	15.8	12	< 0.1	000
	$V_2 < V_3$	2.1	12	5.8	n.s.
	$V_2 > V_4$	0.6	12	56.0	n.s.
	$V_2 < V_5$	10.6	12	< 0.1	000
	$V_3 > V_4$	2.5	12	2.8	+
	$V_3 < V_5$	10.6	12	< 0.1	000
	$V_4 < V_5$	10.0	12	< 0.1	000
III	$B_1 < B_2$	3.9	12	0.21	00
	$B_1 < B_3$	2.2	12	4.8	0
III	$B_1 < B_4$	1.8	12	9.5	n.s.
	$B_1 < B_5$	16.5	12	< 0.1	000
	$B_2 > B_3$	2.1	12	5.8	n.s
	$B_2 > B_4$	2.0	12	84.1	n.s
	$B_2 < B_5$	7.0	12	< 0.1	000
	$B_3 < B_4$	0.03	12	>93.7	n.s
	$B_3 < B_5$	8.9	12	< 0.1	000
	$B_4 < B_5$	8.6	12	< 0.1	000
IV	$A_1 < A_2$	5.8	26	< 0.1	000
	$A_1 < A_3$	4.5	26	< 0.1	000
	$A_1 < A_4$	3.5	26	0.18	00
	$A_1 < A_5$	17.6	26	< 0.1	000
	$A_2 > A_3$	0.06	26	92.0	n.s.
	$A_2 > A_4$	1.6	26	12.2	n.s.
	$A_2 < A_5$	11.7	26	< 0.1	000
	$A_3 > A_4$	1.3	26	20.7	n.s.
	$A_3 < A_5$	9.9	26	< 0.1	000
	$A_4 < A_5$	12.3	26	< 0.1	000

Comparing the mean data by levels, we found out that the variation is more significant and frequent for the top leaves than for the leaves at the basis (II, III - Table 2).

As far as general means by trees are concerned the difference was distinctly significant in 7 out of 10 testing situations (IV - Table 2). Insignificant differences were noticed at trees no. 2, 3, and 4 which were defoliated to various degrees during spring time, but we used only leaves from the first growth.

Variation of the Ratio Between Weight of Leaves at Different Hours and Their Initial Weight

For the determination of initial weight, sometime called "green weight", we should know its variation according to the time that passed from the collection of the material because the immediate weighing of the leaves meets practical difficulties. Thus in order to collect the whole foliage 2-3 hours' work are necessary for a medium sized tree. If the foliage is weighed soon after its collection, the weight determined is already erroneous due to leaf withering between the time of felling, that of collecting and the time of weighing.

Our studies revealed that after leaf removal from the shoots and their keeping in the open air, there follows a rapid loss of weight. After one hour the weight represents 94-95% of the initial weight (with variations by trees and levels of collection between 92.9 and 96.1%) and after 3 hours 86-87% (with variations between 83.1 and 88.4%). The loss of weight is relatively high during the first 10 hours after the collection, then it gradually decreases and after 24-25 hours when the leaf weight is 49.7-52.2% of the initial weight, the decrease ratio is very low (figure 1). Under the working conditions of relative temperature and humidity, 68-70 hours after the collection, the leaves were as dry as air drying allows, their weight being 44.1-45.8% of the initial weight. By the further keeping the leaves in the open a variation of weight is noticed according to atmosphere humidity.

As far as the variation of the ratio for the leaves from the two levels is concerned, we noticed that the leaves from the inferior level show more visible loss in weight 15-20 hours after the collection, according to the trees. The loss in weight is greater than for the leaves at the crown top.

Comparing this variation together with that of the lots of leaves kept in plastic bags we noticed an important difference. Three hours after the collection, when the weight of the leaves kept in the open air was 86-87% of the initial weight the weight of the leaves kept in plastic bags was 95.8-96.7% of the initial weight (with variations between 95-97.4%); 6 hours after the collection the weight of the leaves in the plastic bags was 94.9-95.2% (with variations between 92.9-95.8%) as compared to 77.6-78.8% for those kept in the open air; 12 hours later, the weight of the leaves in plastic bags decreased to 90.7-90.6% (with variation by lots between 87.7-93.7%) in comparison with the loss of weight of the air kept leaves: 62.5-65.2%. This shows that by keeping the leaves in plastic bags the loss of weight can be slowed but not stopped.

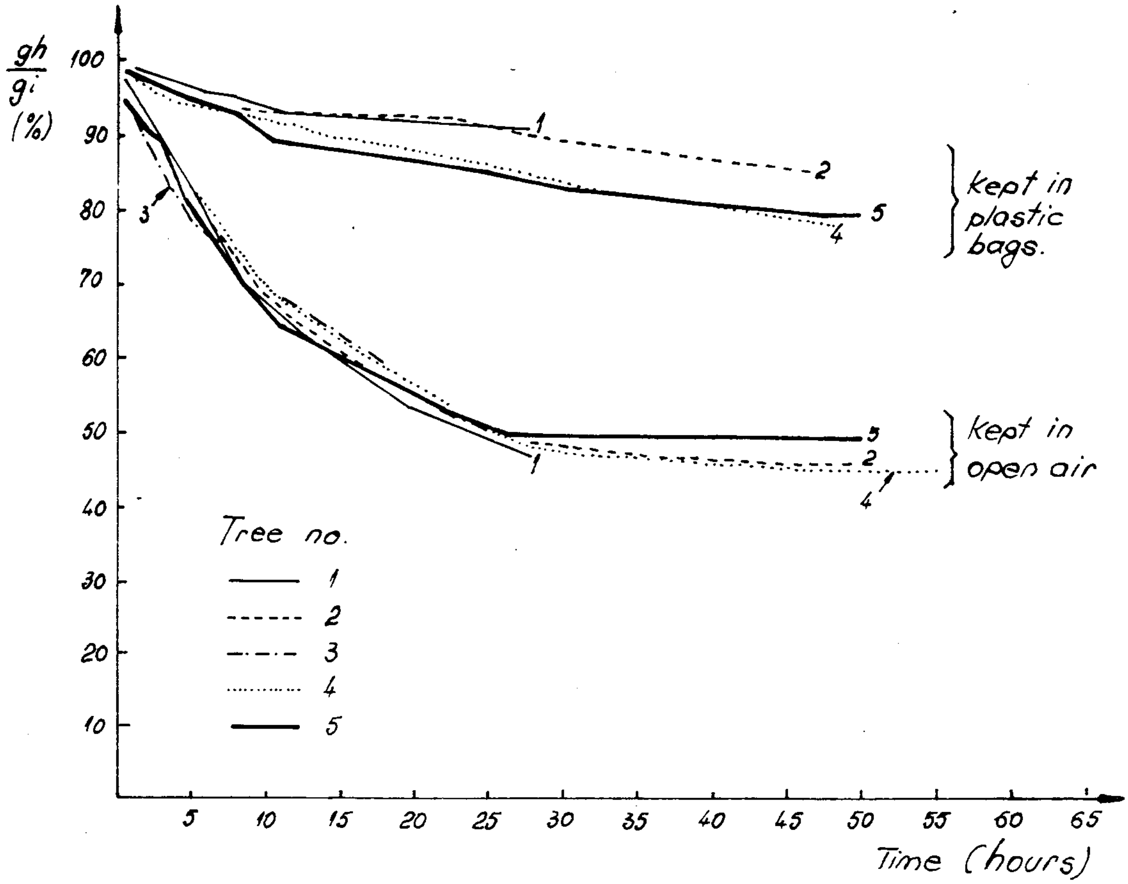


Figure 1. Ratio variation between hour weight (g_h) and initial weight (g_i) of leaves collected from the crown superior part, according to the time elapsed since they were collected and the way they were kept.

The Water Content of Leaves and the Rhythm of Evaporation

At the time of collection the water content (expressed in the percentage difference between initial weight and anhydrous weight) varied in the leaves between 55.7% - tree no. 5 - and 60.5% - tree no. 1 - with an average of 58.8%. Although leaves at the inferior part of the crown were richer in water content as compared to those at the superior level, the values were almost similar (58.5% on an average for the top leaves and 59.2% for the leaves at the basis).

The rhythm of water loss depended on the preservation method, air temperature and relative humidity and the water content of the leaves. The influence of air currents' speed was eliminated due to the laboratory conditions under which the experiment took place.

As an illustration we shall present the data obtained for trees no. 1 and 4 (with the highest water content: 59.6 and 60.5%) and tree no. 5 (with the lowest water content: 55.7%). The other trees had intermediate values.

Mention should be made of the existence of the so called "residual water", which does not yield by evaporation, although the leaves in the open air were kept in thin layers of 1-2 leaves each, periodically winnowed. The residual water, eliminated only by introducing the leaves in the thermostat represented 6.8-8.0% of the water weight. Even after 70-72 hours of drying in air this residual water maintained in the leaves and its content even increased, together with temperature decrease and air relative humidity increase. A rapid increase of leaf weight was noticed after taking them out of the thermostat, which can be explained by the absorbtion of water vapors in the atmosphere. Therefore, in order to establish the anhydrous weight of leaves, we should work as quickly as possible and weight them right after taking them out of the thermostat.

Comparing the results obtained we drew the conclusion that by keeping them in the air the leaves with a higher water content (trees no. 1 and 4) showed a slower evaporation in the first hours (differences of 6.2-6.3 during two consecutive readings) than the leaves with a lower water content (differences of 8.4-9.2% during two consecutive weighings). But evaporation was more active in the first case for a longer period of time, even 26-27 hours after the collection being 1.2-1.6% of the total weight of the water initially contained. Tree no. 5 showed an intense initial evaporation (7-8 hours 5.5-9.2% per hour) which then first decreased to similar values and then to lower values as against those of trees no. 1 and 4. The difference between the evaporation process at the two categories of leaves gradually increased during the first 14-15 hours after the collection (differences of 13.1-13.5%) and later on decreased (after 30 hours the difference was 3.1%) (Table 3).

Table 3. Hour loss water at the leaves kept in the open according to environment accumulated temperature.

Hours	t (C)		w_1/w_t (%)			Hours	t (C)		w_1/w_t (%)		
	at the trees no.						at the trees no.				
	1-4	5	1-4	5	diff.		1-4	5	1-4	5	diff.
1	27	28	9.4	8.7	- 0.7	16	430	453	67.4	80.3	+12.9
2	54	57	15.7	17.9	+ 2.2	17	456	479	69.2	81.5	+12.3
3	81	86	21.9	26.3	+ 4.4	18	481	506	71.5	82.7	+11.2
4	108	115	27.7	32.9	+ 5.2	19	507	533	74.5	83.8	+ 9.3
5	135	144	32.3	39.0	+ 6.7	20	532	560	75.8	84.9	+ 9.1
6	162	174	37.1	45.0	+ 7.9	21	558	588	77.5	85.9	+ 8.4
7	189	204	42.7	51.4	+ 8.7	22	584	616	78.9	86.8	+ 7.9
8	216	233	46.2	57.9	+11.7	23	610	645	80.6	87.7	+ 7.1
9	243	272	49.8	61.7	+11.9	24	637	674	82.2	88.6	+ 6.4
10	271	290	53.0	65.5	+12.5	25	663	703	83.3	89.3	+ 6.0
11	298	318	56.0	68.8	+12.8	26	691	732	84.5	89.9	+ 5.4
12	325	346	58.3	71.0	+12.7	27	718	761	86.1	90.5	+ 4.4
13	351	374	60.2	73.2	+13.0	28	745	791	86.7	91.1	+ 4.4
14	377	400	63.2	76.7	+13.5	29	772	820	88.0	91.6	+ 3.6
15	404	427	65.0	78.1	+13.1	30	799	850	88.9	92.0	+ 3.1

w_1 = weight of lost water; w_t = water total weight.

We believe this difference was greatly determined by the combined influence of air temperature and relative humidity. For the first category, air temperature was lower (mentioned as sum in Table 3) and air relative humidity higher (80.7%, with variations between 75 and 95%); air temperature for tree no. 5 was constantly higher and relative humidity was lower (75.1%, with variations between 67 and 82%).

For the leaves kept in plastic bags, although evaporation was slower, a constant loss of weight was noticed as a result of loss of the water contained (Table 4).

Table 4. Hour loss of water at the leaves kept in plastic bags, according to accumulated temperature.

Hours	t (C) at the trees		w_1/w_t (%) at the trees		
	1-4	5	1-4	5	diff.
1	27	28	1.8	2.3	+ 0.5
2	54	57	3.5	4.3	+ 0.8
3	81	86	5.4	6.3	+ 0.9
4	108	115	6.8	7.5	+ 0.7
5	135	144	7.4	9.0	+ 1.6
6	162	174	8.3	10.9	+ 2.6
7	189	204	9.2	12.4	+ 3.2
8	216	233	9.9	14.0	+ 4.1
9	243	272	10.6	16.0	+ 5.4
10	271	290	11.4	17.1	+ 5.7
11	298	318	12.1	18.2	+ 6.1
12	325	346	12.8	19.5	+ 6.7

w_1 = weight of lost water; w_t = water total weight.

Thus, after 6 hours for the leaves kept in plastic bags, we observed a loss of water equivalent to 8.3-10.9% of the initial weight, as compared to 37.1-45.0% for the leaves kept in the open air. After 12 hours the loss of water was 12.8-19.5% for the leaves in plastic bags and 58.3-71.0% for the other category. During the first 12 hours after the collection (when the leaves may be kept in bags without physical modifications) the differences between the two categories gradually increased from 0.5 to 6.7%. Due to these differences it is difficult to determine a unique coefficient for water loss, holding true for all the trees.

The Variation of the Ratio Between Leaf Hour Weight and Their Anhydrous Weight

As a result of the drying process, the variation of leaf weight can be expressed in the ratio between their weight at different moments after the collection and their anhydrous weight.

By means of the ratio (K ratio) we can indirectly determine with a tolerable accuracy, the anhydrous weight according to the leaf weight at a given time. The practical importance of the problem is underlined as anhydrous weight is the most precise form of expressing foliar biomass. As compared to the ratio presented in a preceding chapter, ratio K has a more marked variation due to the lower value of the referential term (anhydrous weight vs. leaf initial weight). At the same time individual differences among the trees studied appear more obvious (Figure 2).

The first 12 hours after the collection, when the weighing is necessary and supposedly carried on, the curves showing K ratio variation can be linearized by transforming $y = 10/K$ (Figure 3).

We noticed for both categories of leaves the congruence between the regression equations established for the first four trees and separately for tree no. 5 (Table 5).

It is now adequate to mention that the leaves collected from both levels of tree crown, correlation between the time when they were collected and K ratio can be expressed through distinct regression equations, where the correlation coefficient (r) has slightly higher values than if the level of collection is not considered.

For example, Table 5 shows the equations determined for the leaves kept in the open air. This specification is only theoretically of interest because practically we collect the whole foliage of a tree, with no distinction as to the crown levels.

Table 5. Correlation and regression of the ratio between the hour weight of leaves and their anhydrous weight with time.

Tree no.	Keeping method	Level of collection	r	Regression equation $y = 10/K$; x = no. of hours
1-4	open air	sup. + inf.	0.978+++	$y = 4.1655 + 0.1693\ x$
5		sup. + inf.	0.945+++	$y = 4.4656 + 0.2533\ x$
1-4	plastic	sup. + inf.	0.667++	$y = 4.0081 + 0.0177\ x$
5	bags	sup. + inf.	0.939+++	$y = 4.2808 + 0.0444\ x$
1-4	open air	superior	0.985+++	$y = 4.2152 + 0.1685\ x$
		inferior	0.977+++	$y = 4.1156 + 0.1701\ x$
5	open air	superior	0.999+++	$y = 4.4465 + 0.2153\ x$
		inferior	0.997+++	$y = 4.4847 + 0.2913\ x$

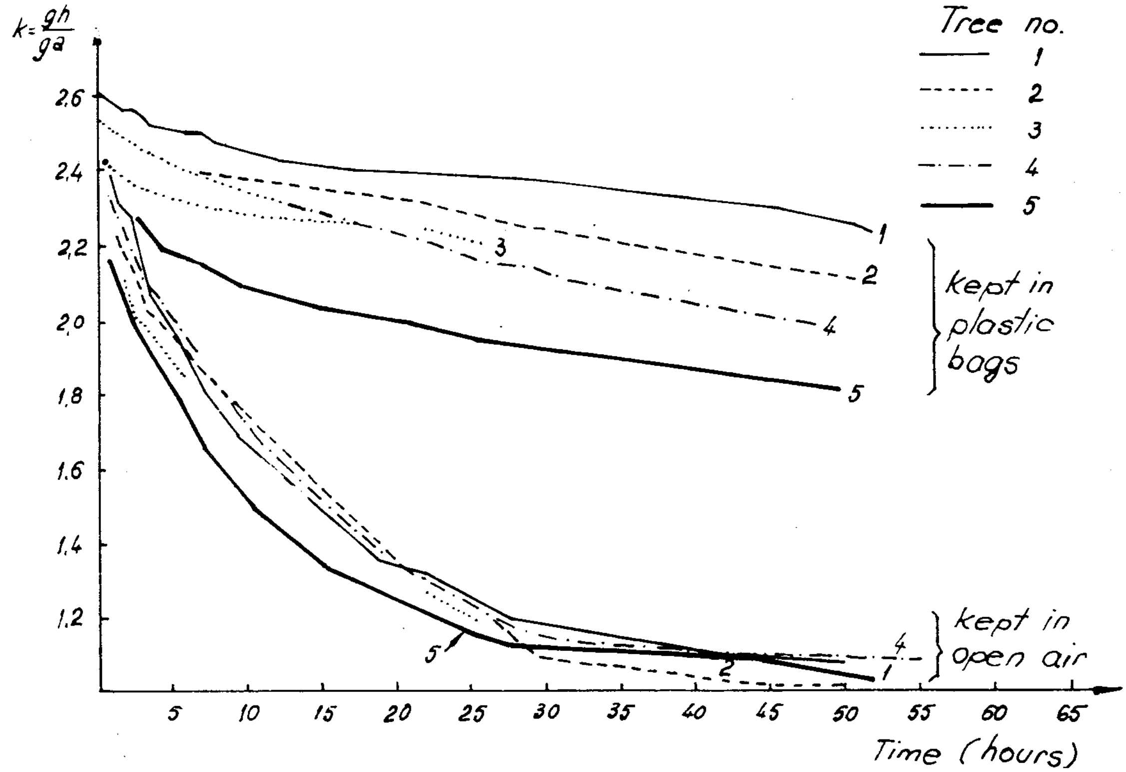
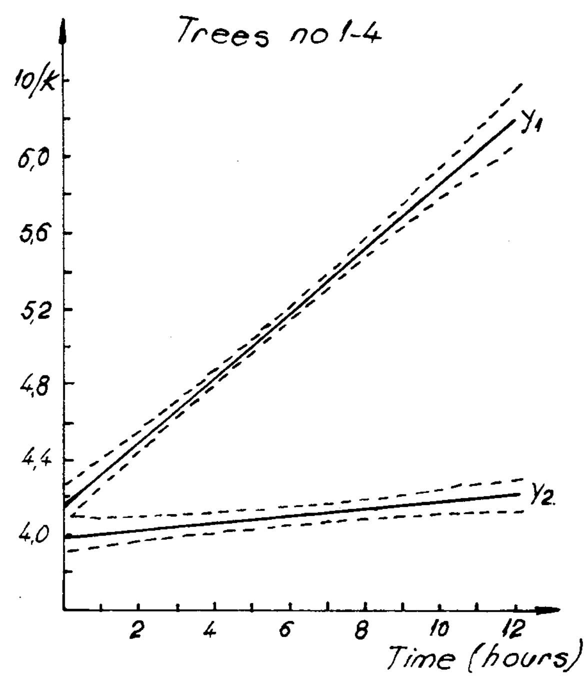


Figure 2. K ratio variation between hour weight (g_h) and anhydrous weight (g_a) of leaves collected from the superior part of crown according to the time elapsed since they were collected.

Figure 3. Regression of the ratio 10/K according to the time elapsed since leaves were collected and to their keeping in the open air (y_1) or in plastic bags (y_2) at the sample trees no. 1-4.



From our results we came to the conclusion that there might sometimes appear significant differences from tree to tree, as the case for trees 1-4 and tree no. 5.

CONCLUSIONS

The research carried out led to important conclusions for the precise determination of foliar biomass and its dynamics:

- Leaf water content, expressed in the percentage difference between their initial and anhydrous weight varies between 55 and 60%;

- According to air temperature and relative humidity the loss of water is more rapid or slower, following a decreasing curve, asymptote to the level of residual water - between 7 and 8% - which is eventually regained from the atmosphere even though the leaves had been introduced in the thermostat. Kept in plastic bags the leaves slowly lose water, nevertheless they also gradually lose weight;

- The mean ratio between leaf anhydrous and fresh weight varies distinctly and significantly in 7 out of 10 trials. The level of this ratio oscillates considerably between the leaves from the superior part (41.5%) and those from the inferior part of the tree crown (40.9%);

- The ratio between the weight of leaves at different times and their initial weight decreases by 5-6% one hour after the collection and by 13-14% after 3 hours, up to 50-52% after 24 hours, if leaves are kept under room temperature and humidity conditions. Keeping them in plastic bags means an obvious decrease of the loss (4-5% after 3 hours and 9% after 12 hours);

- The ratio between leaf hour weight and anhydrous weight also varies following a decreasing curve; the variation is stronger for the leaves kept in the open air; by means of the regression determined between this ratio and the time that passed from the collection, their anhydrous weight can be accurately enough determined; this represents, through its stability, the only correct way of expressing foliar biomass;

- The determination of foliar biomass without considering the loss of water throughout the time of collection and that of weighing is erroneous (the longer the time after collection, the bigger the errors). The errors are negative and influence the difference in foliar biomass from stage to stage, and its dynamics respectively. Moreover, a comparison between the results of two or more determinations is possible only if the same weighing methods are applied under the same air temperature and humidity conditions;

- The determination of foliar biomass using the leaf anhydrous weight can also lead to quantitative errors if it is not done right after taking them out of the drying thermostat. These are positive errors and the longer the time, the bigger the errors.

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THE HYSTERESIS PHENOMENON EMPHASIZED BY THE INFLUENCE OF GRAZING ON THE RADIAL GROWTH OF THE SESSILE OAK (QUERCUS PETREA LIEBL) TREES

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Abstract--The obtained results show that the decennial current mean increments in the diameter in the grazed variants are 96.7 - 100% from the control value. These insignificant values in terms of their transgression probability of 5% (Table 2) suggest a phenomenon of "hysteresis". This means that the interval of the edaphic reestablishment is longer than that of the edaphic degradation. This result shows that grazing in the forest affects its stability.

Keywords: Grazing in forest, hysteresis, influence of grazing, radial growth, forest stability, *Quercus petraea* Liebl.

The researches on the grazing-impact on the stability of the oak forests made obvious the influence of grazing on the diameter current growth in sessile oak. Investigations were made in two experimental ranges, in Gaesti and Tirgoviste. In each range a stand was chosen considered as representative with regard to the grazing practice. The ecological characteristics and the stand ones of the experimental plots are shown in Table 1.

In each experimental range, researches were carried out in a plot continually pastured (fig. 1) and in a fenced plot, outer the influence of grazing 10 years before beginning of the present study. During the ten years anterior to our researches and two research-years no perturbant incidental factors occurred.

The results of our auxometrical researches are sintetically shown in Table 2, in the present work. From these data, following can be deduced:

- in the experimental range Gaesti, the mean values of the diameter current growth in the last ten years, in the control variant and in the pasture one, are identical (x = 6.765 mm);

- in the experimental range Tirgoviste, the same biometrical indicator represents 6.019 mm in the control variant confronted by 5.803 mm (96.7%) in the pasture variant. The statistical tests we applied show that by the transgression probability of 5%, the mean value of the diameter current growth, in the last decade, for the trees of both variants are statistically unsignificant.

This result has a particular ecological significance because it demonstrates that after 12 years from the complete ceasing of the forest grazing, the diameter growth of the trees in these stands does not differ from the diameter growth of the trees in the neighbour stands, continuously pastured. It is the confirmation that the soil is not an inexhaustible and inert reserve, but an extremely complex and permanently changing medium. Far of being invulnerable, the soil can be destroyed when its equilibrium is broken or when it is - simply - swept by water and winds. It is in a continuous formation processus, and at the same time, submitted to degradation, a natural or an artificial one. The sun energy and the atmosphere allow its normal restoration, but the "processus is extremely slow (4 - 10 centuries for 3 cm depth), while man and weather can destroy it in several years, even in several hours (Bonnefous, 1976).

Given the fact that after 12 years of complete ceasing of the pasture, the stand not yet reacts positively, our researches show the long lasting character of the quality restoration of the forest soil in the pastured forest. This fact, obvious from the auxometrical data statistically granted, demonstrates that the restoration of the edaphic quality, even after abolition of the pasture, can last for decades and centuries, but the degradation of the edaphic quality is fast. The difference between these two antagonistic processes suggests that "hysteresis" phenomenon by which the duration of the regeneration lasts longer time than the degradation period.

The obviousness of the phenomenon in the results of the present researches, justifies the estimations advanced in the Italian ecologic literature (Susmel, 1955) emphasized later in the Romanian sylvicultural literature (Stoiculescu, 1971), according to which the sole superficial restructuration of the soil, after the grazing abolition, can last 50 years.

In conclusion, the grazing practice in the forest leads to the degradation of the soil and of the forest vegetation, and, under certain conditions, can lead to their definitive ruin (Botnariuc, 1982; Giurgiu, 1982; Tkacenko, 1955). This evolution is due to the edaphic phenomenon of hysteresis, suggested by the auxometrical researches carried out, in the present work, in the sessile oak stands.

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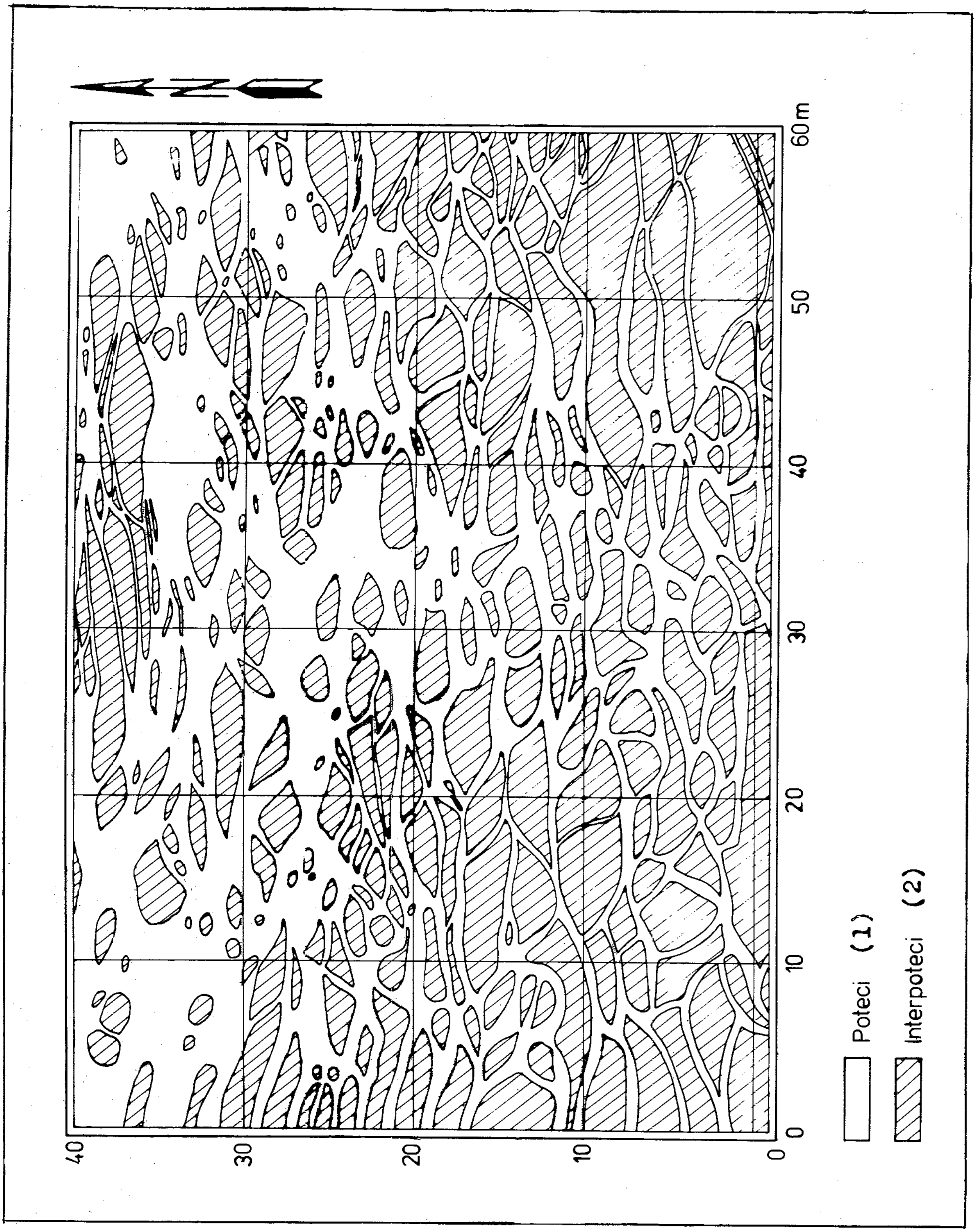

Figure 1. Path network made by cows in the grazed stands (Ranger-district Caesti): 1-Paths; 2-Inter-paths.

Table 1. Ecologic and biometric characteristics of the investigated stands.

Experimental range	Sample plot	G.u.[1]	Altitude, m	Slope, %	Soil type	Texture	pH	Humus %	Forest type	Composition	Age, years	dg cm	hg m	Site index	Source
Gaesti	control	plateau	280	3	Bfgs[2]	loam-clay soil	5.8	2.5	Sop[3]	10 so[4]	60	24	15	IV	Coppices
	grazed	plateau	280	3	Bfgs[2]	loam-clay soil	5.8	2.5	Sop[3]	10 so[4]	60	24	15	IV	Coppices
Tirgo-viste	control	plateau	300	5	Bfgs[2]	loam-clay soil	5.5	3.5	Sop[3]	8 so[5] 2 Eo	60	20 20	17 17	IV IV	Coppices Coppices
	grazed	plateau	300	5	Bfgs[2]	loam-clay soil	5.5	3.5	Sop[3]	8 so[5] 2 Eo	60	20 20	17 17	IV IV	Coppices Coppices

1 Geomorphological unit
2 Brown forest gley soil
3 Sessile oak plate stand on gley soil
4 100% sessile oak
5 80% sessile oak, 20% European oak

Table 2. The value of same statistical indicators settled for differentiating diameter current growth in sessile oak trees in the last decade, for control and grazed variants.

Experimental range	Sample plot	Diameter current growth mm	Mean %	Variance	Cases	Liberty degree	Test Fisher experimental	Test Fisher theoretic	Test t experimental	Test t theoretic
Gaesti	control	6.765	100.0	7.857	31	30	--	--	--	--
	grazed	6.765	100.0	2.608	34	33				
Tirgo-viste	control	6.019	100.0	7.209	32	31	1.33	$F_{0.05}$ = 1.87	0.163	2.000
	grazed	5.803	96.7	9.759	29	28				

THE LIGHT WITHIN THE FOREST GROWTH HYPERSPACE MEANING

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Abstract--The author outlines an interesting prognosis illustrated by exhibits and photographs which include an original contribution to the scientific literature. Finally a dendrochronology research network in three steps is highly sketched.

PROGNOSIS

The hyperspace is the fourth spatial dimension that modern biology identifies as the "Environment of Perpetuity".

Historically, the human being has been evolved by the different thinking schools in sustaining sensitiveness towards the "production philosophy of space".

Physics creates the vocabulary to name this universal meaning; Biology prescribes its significance and Ecology profiles its prospection for each organism and its proper growth environment categorization.

So, we have in our feelings the enormous succeeding of organic variability upon the Planet. Humans, from ancient time, have had the valuable concession by their intuitive thinking to enhance comprehensive using of life's dimension.

Without "the light fluxes" it would be impossible to conceive changeableness of the "perception" and much less to process the "conceptualization". Also it would never have been possible to recognize the importance of "competitiveness" as an internal impulse component of the "motivation" in human's living; the same is true for the "dominance" trend into the remaining organisms in the world.

The abiotic content in the "Planetary limiting layer" has its environment too. The "light" builds the linking massive cycling of geochemical, geophysical and the complex responses of fluctuations of its "weathering". This is the "scenario" displaying the endless continuity and harmony of biogeocenological forces of life. (Exhibit II).

The "tree" renders the "wood" which depicts a "perdurable expression" that the author defines as "an efficient entering in the plant's body of the Hyperspace. If Man disrupts this pooling, the tree loses part of its encroachment values."

The "growth" is the cosmovision of "polarity" in the new paradigm: "the cybernetic forces in the art to meet compatibleness of the neighbouring resources". The trees continue their growing process during the night and the arborescent ferns anchor themselves in the site where the "Hyperspace" offers silent and meshy light.

Diagram as Exhibit I, let us draw attention to frequently disregarded time-space scale coupling: "The affective domain on the vegetable typological taxonomy". From this platform the forest types' ordinates will be evaluated by a "biocenic productivity curve design" which is similar to that based on the circadian rhythms of an animal behaviour within an indoor environment.

The tree grows creating stratification and structuration of its asocies and consocies both having a leading role within "forestry stability". Constancy, Persistence and Cyclical Stability are established by the presence of "light" as a main overriding factor in the "Hyperspace".

"Maturity of forest growth" - a pristine achievement - occurs within a "Climate of Light" (Braun-Blanquet, 1956) and we know that scientific literature reflects a great measure of analysis to this process into different life forms, but it leaves for our "Educational backgrounds" a steady-state of dependence from the fourth universal dimension: "The Perpetuity".

The author's thesis from an ecological understanding of Bioclimatology for buffering detrimental influences of the forestry management is being depicted by exhibits, herein enclosed.

Finally, the author's proposal underlines a dendrochronology research network in three steps illuminated by photographs attachment:

Step 1: the light in the micrometeorological distribution pattern fostering the natural regeneration....."near ground hyperspace" (15,16)

Step 2: the ecobiological significance of light in the trees' growth asymetry..."stem and branchiness hyperspace" (17,18)

Step 3: the forest growth as a remote sensing Indicatology of the Hyperspace (the environment of Perpetuity). "canopy hyperspace" (6,7,8)

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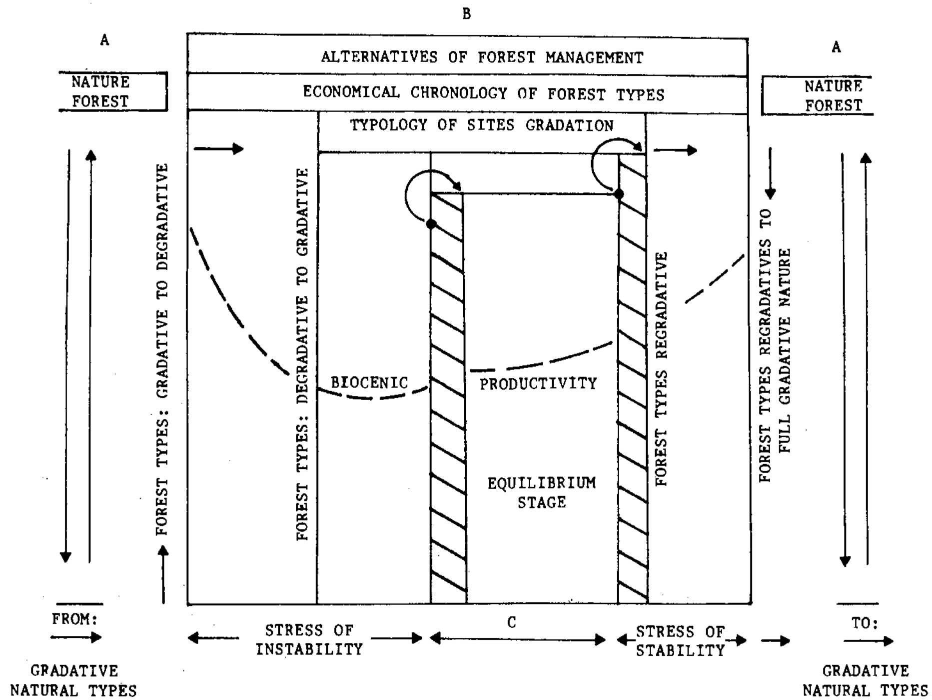
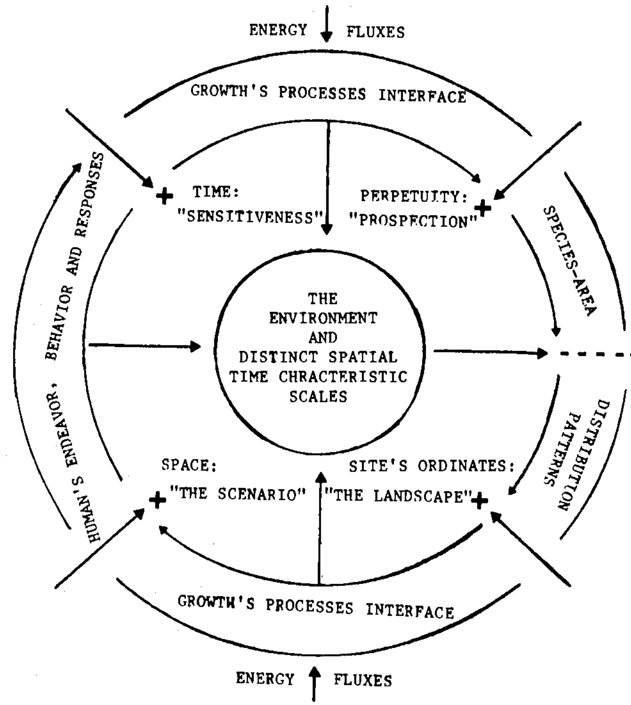
EXHIBIT I: HYPERSPACE MEANING WITHIN FOREST GROWTH TYPOLOGY IN RENDERING A BIOCENIC PRODUCTIVITY CURVE



A: SUCCEEDING EXTREMES OF UNPERTURBED SITE STAGE.
B: CHRONOLOGY WITHIN THE MAN-MADE MANAGEMENT OF FOREST STANDS.
C: DYNAMIC EQUILIBRIUM BUILT BY THE COUPLING OF CLIMATE-SOIL AND LIFE FORMS BIOLOGY.
: TREND OF DEVELOPMENT REGULARITY CONDITIONED BY LOCAL FACTORS FRAMEWORK(LEFT - WITHOUT CONTINUITY; RIGHT - WITH CONTINUITY).

EXHIBIT II: COSMOVISION RADEX OF THE HYPERSPACE-"THE LIGHT WITHIN THE FOREST GROWTH"



LIGHT(EVER MORE INTIMATE WITH EARTH'S PROCESSES)

FIG. 1 - "HYPERSPACE" ON LIVELY PROMOTION OF NATURAL REGENERATION OF THE MOST PRIZED WOODED SPECIES AND WIDELY SPREAD HERE.

FIG. 2 - A NON-USED FOREST SPECIES LUXURIANT RESPROUTING AFTER ONE MONTH OF TREE CUTTING.

FIG. 3 - "CLIMATE OF LIGHT WITHIN FOREST GROWTH UNDER HYPERSPACE MEANING". PRODUCTION OF NATURAL SEEDLINGS OF ONE HIGHLY PRIZED REPRESENTATIVE AT THIS LATITUDE.

FIG. 4 - REGROWTH OF ONE HEAVIEST REPRESENTATIVE TOGETHER WITH TACUAPY FOR THE WEEDING CONTROL INTO THE ENRICHMENT BELTS.

FIG. 5 – JUSTIFICATION AND EARLY REGULATION OF MIXTURE.

FIG. 6 – REMOTE SENSING INDICATOLOGY UPON RESILIENCE AND FLEXIBILITY.

FIG. 7 – STAND DEPENDENT UNDER SYSTEMATIC [illegible] OF FOREST STABILITY AND [illegible] PERIOD OF ADAPTATION OR [illegible] FROM THE [illegible].

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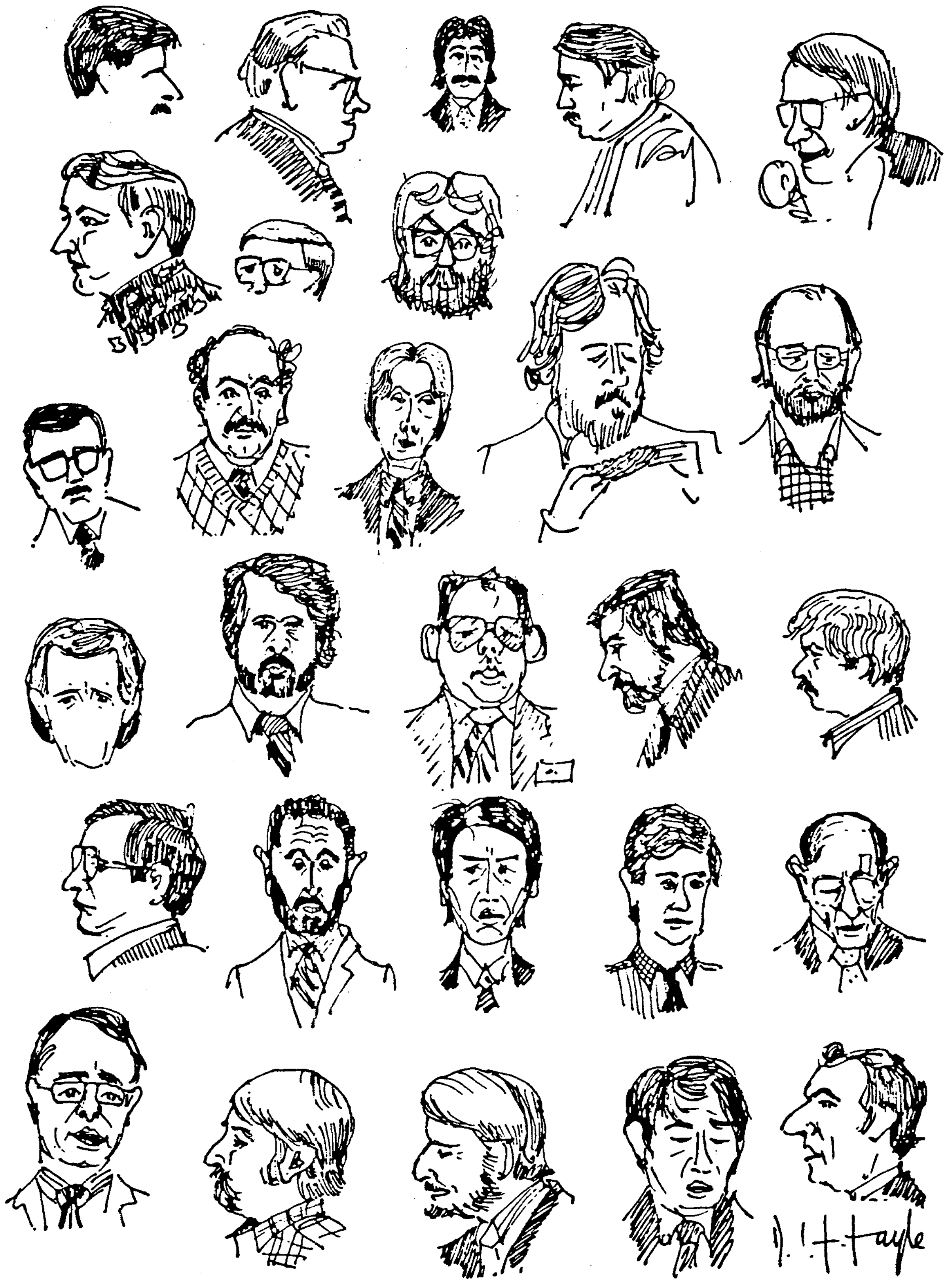

Sketches of some of the participants, drawn by David Fayle.

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