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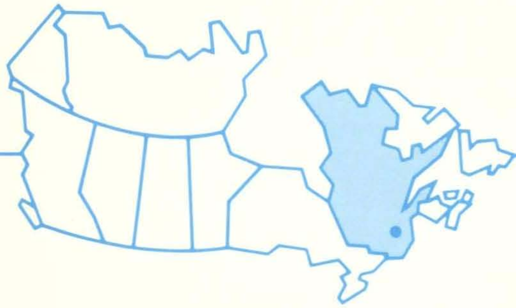
Computerized Data Acquisition for Radial Growth

Richard Zarnovican, Denis Ouellet, and
Sylvain Gendron



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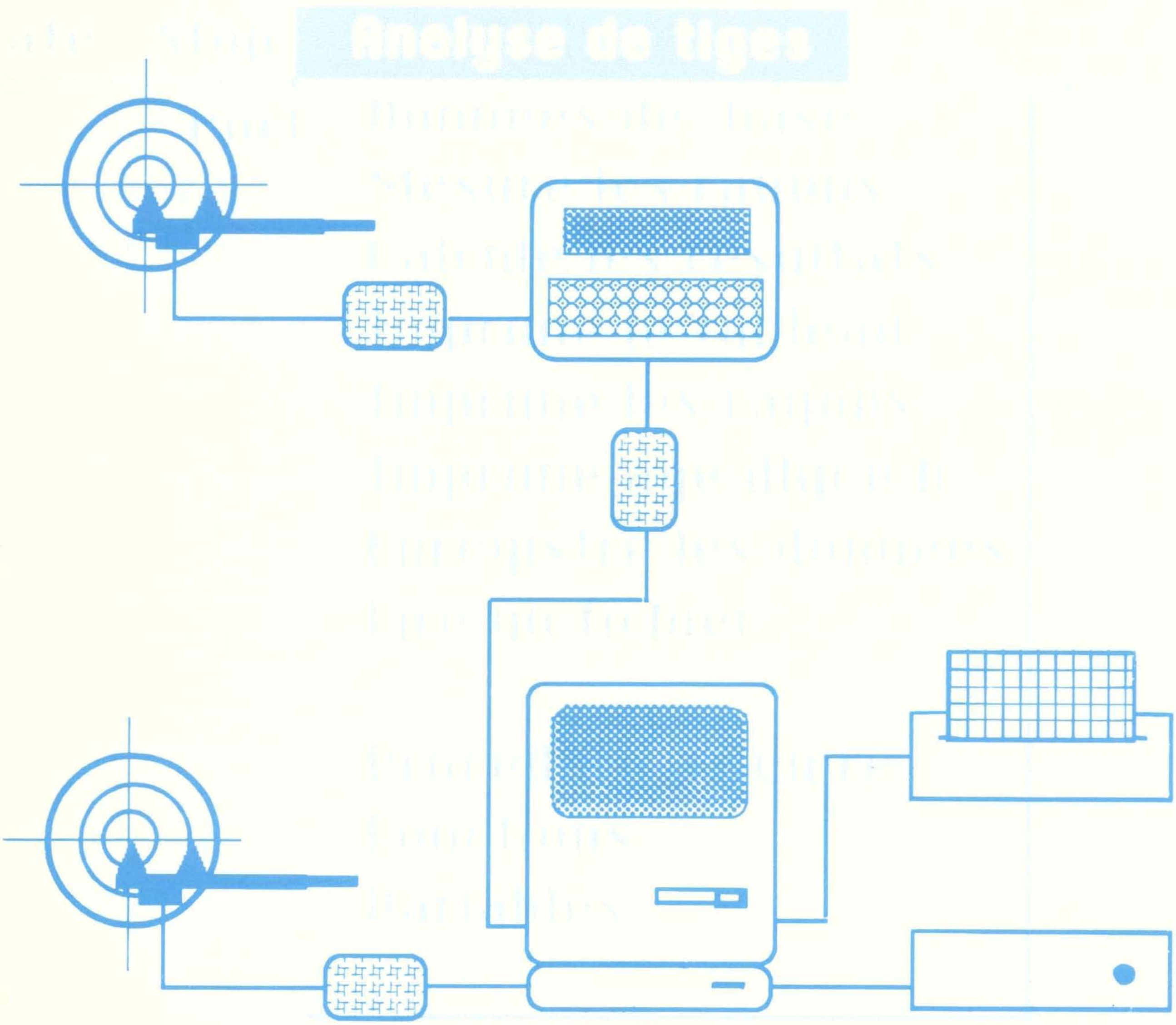

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TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

RÉSUMÉ

Une estimation précise de la croissance des arbres est la base fondamentale de toute étude dendrométrique sérieuse. Le présent rapport décrit la configuration et le fonctionnement des équipements utilisés pour l'analyse des tiges au laboratoire de croissance et de production du Centre de foresterie des Laurentides. Des résultats sous forme graphique et chiffrée ainsi que quelques exemples de l'application de l'analyse de tige en foresterie complètent le travail.

Nous avons examiné les fondements de la croissance radiale des arbres, les méthodes pour la mesurer et nous avons décrit les différentes étapes de l'analyse de tige. Notre objectif principal était cependant d'informatiser la saisie, le traitement et la mise en mémoire des données de la croissance radiale servant à l'analyse de tige.

ABSTRACT

An accurate estimate of tree growth is a basic requirement in forest mensuration studies. This report describes the configuration and the operation of equipment used for stem analysis in the project group of growth and yield at the Laurentian Forestry Centre. The report is completed by some illustrations and applications of stem analysis in forestry.

We examined the fundamentals of analysing the radial growth of trees, the methods of measuring, and the various stages of stem analysis. Our main objectives were to computerize the acquisition of information and to process and store radial growth data for stem analysis.

BASICS OF RADIAL GROWTH

When we examine the cross-section of a tree, we observe concentric layers, known as growth rings or annual rings. The phenomenon of annual rings is related to climatic conditions, particularly alternating warm and cold periods. As soon as the buds open in the spring, the cambium, which is inactive in winter, starts to produce quite large, thin-walled cells; this is the earlywood or springwood. In summer, however, the cells produced by the cambium are small and thick-walled: this is the latewood or summerwood. Thus the radial growth for the year gives the distinct impression of a ring because of the variation in tree metabolism, reflected in the specific structure of the wood.

Using the contrast between springwood and summerwood, foresters measure radial growth in wood cores or disks. However, the analysis of wood cores does not give the necessary accuracy to establish such characteristics as the volume of a tree or its form quotient. Moreover, studies (Siostrzonek 1958; Abetz 1960; Smelko 1965) have shown that core analysis is subject to error and does not meet current requirements of research on tree growth.

To avoid, as much a possible, the problems of inaccuracy mentioned above, growth studies are making increasing use of stem analysis. Although this technique is destructive, complex to perform, and limited to species with distinct annual rings, it is the only direct forest measurement method available for studying growth in trees and the various aspects of their development.

Its main objective is to reconstruct the growth of a tree over time, faithfully and accurately, in its main forest measurement sizes. Stem analysis has two stages. The first covers the field work (felling and bucking the tree and obtaining the disks), while the second consists of identifying and marking the annual rings and measuring their width. Data acquisition and processing use the computer equipment described below.

FIELD WORK

In the field, a tree is carefully chosen, and on it stump height (generally between 0.3 and 0.4 m) and the 1.3 m height are marked using a steel tape; the tree is then felled. The usual morphological measurements are taken from the felled tree (Zarnovican 1982) and all trunk and branch sections having a small-end diameter greater than 7 cm are marked off. The sections are selected by the Huber method or the Smalian method, and disks between 2 and 6 cm thick are taken. In addition, the length of the leader and its diameter at the large end, with and without the bark, are recorded. The disks are identified, numbered, wrapped, and shipped as quickly as possible to the laboratory to prevent any contamination or deterioration of the wood.

LABORATORY WORK

Disk preparation

In the laboratory, the surface of each disk is prepared to make the growth rings distinct; this is relatively easy for the coniferous species, as the structure and size of the tracheids are remarkably different in early- and late-woods. Usually, a simple restoring of the cross-section with a properly sharpened electric plane is enough to allow measurement of the growth rings. However, recognition of the annual rings in deciduous species is more difficult. The arrangement of the pores does not always provide a marked contrast between the early- and late-woods; this is the case for species with ring-porous, such as oak, ash, hickory, and elm or semi-ring-porous, such as walnut or black cherry. The use of flourescence techniques is necessary in the case of diffuse-porous species, such as maple, birch, beech, hophornbean, poplar, willow, and basswood. The definition of annual rings is sometimes complicated by the presence of discontinuous rings and false rings. Their occurrence is caused by frost, defoliation, fire or, in certain cases, prolonged suppression of the tree. To avoid this problem, it is suggested that vigorous, dominant trees be sampled, that the surface of the disks be well prepared, and that a good fluorescence technique be chosen. Finally, it should be pointed out that it is better to work dry wood than wet wood.

Measurement

Radial growth is measured on a cross-section with a ruler. However, we can also measure the cross-sectional areas, using a planimeter or digital image measurement technique.

Measuring along the radii is currently more economical than the area method. However, the radii method inevitably involves errors, and we must determine the minimum number of radii and the method of measuring them to obtain a given degree of accuracy. This problem was thoroughly examined by Siostrzonek (1958). He concluded that, to obtain a satisfactory degree of accuracy, we must use the root mean square of at least four radii in the form of a cross, with the primary axis offset 22.5 degrees from the greatest diameter. The same question was recently dealt with by Weise (1982). On the basis of an analysis of a spruce tree, this author concluded that, to calculate the basal area and volume and the increments in these values with acceptable accuracy, it was sufficient to measure four radii in the lower part of the trunk and only two in the upper part.

The problem of the length of the sections was researched by Korsun (in Korf 1953). He concluded that a length of one metre, in Huber's "section formula", is the most accurate, and that Huber's formula may be considered the reference formula for volume. With a view to making stem analysis more cost-effective, Weise (1982) looked into the use of sections of variable lengths. His research showed that section lengths between 4 and 6 could be used, for a saving of up to 40 percent of the total cost.

Finally, the matter of age interval for measurements has been discussed by Zarnovican (1981). The author concluded that the mean periodic increment is a valid estimator of the current annual increment from a mathematical view point. The accuracy of the estimate depends essentially on the length of this interval and the growth phase. For example, the error is negligible with an interval of two years in the full vigor and senescence phases. On the other hand, an interval of five years produces an acceptable error only for ages greater than that at the bend in the growth curve. Finally, an interval of 10 years can only be recommended for the senescence phase.

MEASURING EQUIPMENT

Since the first complete apparatus for measuring annual rings was built and marketed by Bo Eklund of Sweden and The ADDO and STALEX companies in 1949, several instruments have been developed (for example, Kennel 1968; Johann 1977; van der Beek and Maessen 1981; and Ulbricht 1981). A succession of very substantial improvements have facilitated the acquisition and processing of data, as well as the security and application of the results.

In the forest growth and yield laboratory at the Laurentian Forestry Centre, the first equipment for measuring annual rings was built in 1982. Intended for data acquisition and storage, this equipment incorporated four different

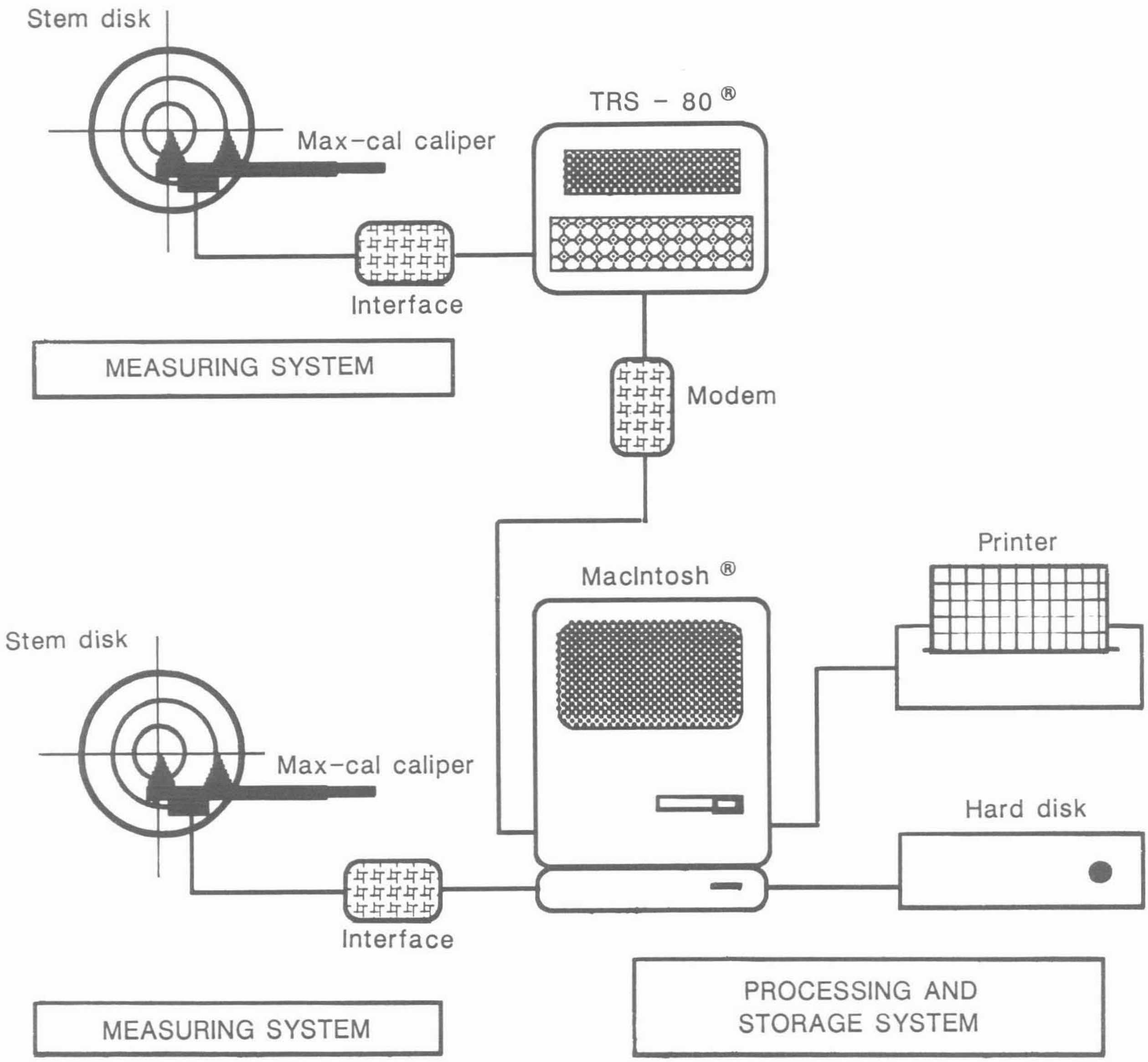

Figure 1. Computerized data acquisition for radial growth: diagram of components.

modules: the module for recognizing and identifying annual rings, the measuring module, the programable interface, and the module for controlling and recording data. Data processing has been done on mainframe system.

For two years now, efforts have been aimed at consolidating all stem analysis operations: data capture, data processing, and storage of the results in a microcomputer data base. The configuration of the equipement is shown diagrammatically in Figure 1.

To make data acquisition flexible, even in the field, we developed two measuring systems. The first consists of electronic caliper, an interface and a TRS-80® model 100 microcomputer from Radio Shack® (Figure 2). The advantage of this system lies in its self-sufficiency, low cost, and battery-operated components. The second system

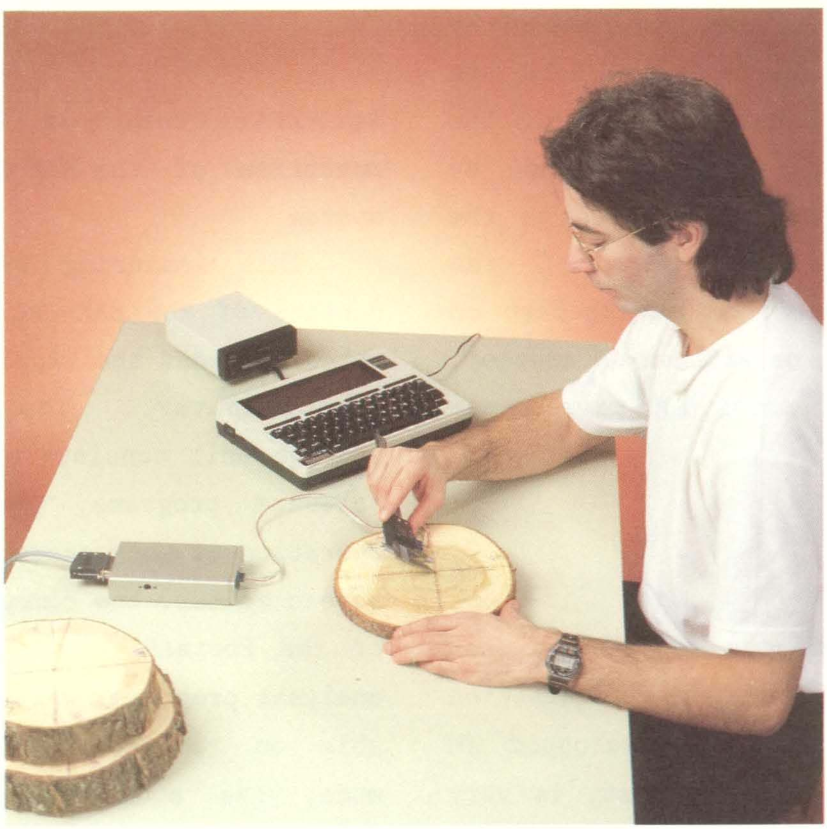

Figure 2. Measuring system using a TRS-80® model 100.

consists of the electronic caliper, the interface, and a Macintosh 512® microcomputer from APPLE®, with a hard disk. This is an integrated system (Figure 1): it not only acquires and processes data, but also stores the results in files.

Specifications of components and operation of the MAX-CAL/TRS-80® measuring system

The MAX-CAL® electronic caliper, made by Fowler digitally displays measured radii to within a hundredth of a millimeter. The caliper is powered by two silver oxide batteries. Data are transmitted by a connecting cable to the NSK model HMI-101® interface, made by Japan Micrometer MFG®, and then to the RS-232C® communication port of the TRS-80®. The interface can operate on four AA batteries, or with an AC adapter, as can the TRS-80® model 100 microcomputer.

Acquisition of the radii data uses the link protocol and a data acquisition program. This program, developped in BASIC and available on request, is very versatile and flexible. In addition to data acquisition, it allows printing, control, and transmission. Designed in conversational mode, the software requires no computer knowledge on the part of the user, and is accessible through menu bar keys. The data to be stored in a file are entered by keyboard (information of stems) or, through the caliper, by the acquisition button (radii lengths for each stem disk).

The file is then tranferred from the TRS-80® to the Macintosh 512®, using the PortaAPL® link protocol, and into a file in APL for processing.

Specifications of components and operation of the MAX-CAL/Macintosh 512® system

This measuring system (Figure 3) consits of the MAX-CAL caliper, the NSK interface and the Apple Macintosh 512® microcomputer. The processing and storage unit consists of the Macintosh®, software programs, and a hard disk. Operation of this assembly uses the full-screen editor, the communication protocol of the PortaAPL® software and the stem analysis programs, written in APL (available on request). In conversational mode, the stem analysis software is accessible to those familiar with stem analysis but knowing only a few basics of Macintosh operation.

Figure 3. Measuring system using a Macintosh 512®.

In our concern for simplicity, we tried the modular approach for performing the various steps to make the work both flexible and rational. In fact, choosing the stem analysis icon is all that is needed to access the workspace, executing a latent expression that automatically sets up the communications parameters protocol.

Then it is only a matter of selecting the menu bar for stem analysis (Figure 4) and executing the basic functions to acquire stem data, measure the radii with the MAX-CAL caliper, calculate and print the results, and store and retrieve the results. Furthermore, all relevant information is given under the "Procedure" function.

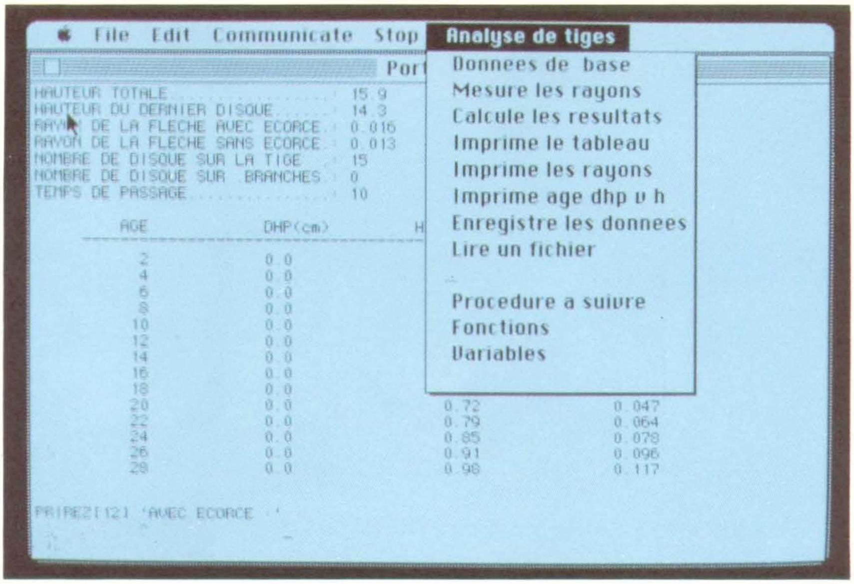

Figure 4. Workspace system commands for stem analysis.

Our observations after analysing 245 coniferous stems and 153 deciduous stems indicate that up to 4 000 radial growth measurements can be done in a day using this equipment.

RESULTS OF STEM ANALYSIS AND ITS APPLICATION IN FORESTRY

With the equipment and software, we can establish the main forest mensuration characteristics of a tree in chronological order. To illustrate the results of a stem analysis, we have reproduced the data from a basswood tree (*Tilia americana* L.) in Table 1. The table shows age, dbh, basal area, volume, height, form factor, and form height of the tree, as well as the increments for each of these.

An illustration of a number of temporal relationships, established by stem analysis for basswood and Norway

Table 1. Main forest measuration characteristics of a basswood tree (*Tilia americana* L.) as established by stem analysis

Age	DBH	c.a.i.	m.a.i.	BA	c.a.i.	m.a.i.	Vol.	c.a.i.	m.a.i.	Ht	c.a.i.	m.a.i.	Form factor	Form Height
2	0.0		0.00	0.000		0.000	0.00		0.000	0.27		0.13	0.000	0.00
		0.00			0.000			0.021			0.29			
4	0.0		0.00	0.000		0.000	0.04		0.011	0.85		0.21	0.000	0.00
		0.43			0.003			0.117			0.72			
6	0.9		0.14	0.006		0.001	0.28		0.046	2.30		0.38	2.068	4.76
		0.90			0.025			0.573			1.00			
8	2.7		0.33	0.056		0.007	1.42		0.178	4.30		0.54	0.591	2.54
		0.88			0.049			1.510			1.00			
10	4.4		0.44	0.154		0.015	4.44		0.444	6.30		0.63	0.459	2.89
		0.89			0.075			2.940			0.50			
12	6.2		0.52	0.303		0.025	10.32		0.860	7.30		0.61	0.467	3.41
		0.82			0.090			4.094			0.50			
14	7.8		0.56	0.484		0.035	18.51		1.322	8.30		0.59	0.461	3.83
		0.64			0.085			4.741			0.33			
16	9.1		0.57	0.654		0.041	27.99		1.750	8.97		0.56	0.478	4.28
		0.70			0.108			6.225			0.67			
18	10.5		0.58	0.869		0.048	40.44		2.247	10.30		0.57	0.452	4.65
		0.83			0.147			8.830			0.50			
20	12.2		0.61	1.163		0.058	58.10		2.905	11.30		0.57	0.442	4.99
		0.62			0.124			10.040			0.50			
22	13.4		0.61	1.411		0.064	78.18		3.554	12.30		0.56	0.451	5.54
		0.70			0.154			12.966			0.50			
24	14.8		0.62	1.719		0.072	104.11		4.338	13.30		0.55	0.455	6.06
		0.52			0.124			10.611			0.50			
26	15.8		0.61	1.968		0.076	125.34		4.821	14.30		0.55	0.445	6.37
		0.66			0.172			14.167			0.33			
28	17.2		0.61	2.311		0.083	153.67		5.488	14.97		0.53	0.444	6.65
		0.52			0.145			13.201			0.42			
30	18.2		0.61	2.602		0.087	180.07		6.002	15.80		0.53	0.438	6.92
		0.54			0.160			17.230			0.50			
32	19.3		0.60	2.923		0.091	214.53		6.704	16.80		0.53	0.437	7.34
		0.53			0.166			17.340			0.42			
34	20.4		0.60	3.255		0.096	249.21		7.330	17.63		0.52	0.434	7.66
		0.54			0.176			19.785			0.33			
36	21.4		0.60	3.607		0.100	288.78		8.022	18.30		0.51	0.437	8.01
		0.64			0.221			20.669			0.33			
38	22.7		0.60	4.049		0.107	330.12		8.687	18.97		0.50	0.430	8.15
		0.61			0.224			19.834			0.33			
40	23.9		0.60	4.497		0.112	369.79		9.245	19.63		0.49	0.419	8.22
		0.51			0.195			16.831			0.33			
42	24.9		0.59	4.886		0.116	403.45		9.606	20.30		0.48	0.407	8.26
		0.43			0.171			16.436			0.50			
44	25.8		0.59	5.229		0.119	436.32		9.916	21.30		0.48	0.392	8.34
		0.41			0.170			17.700			0.25			
46	26.6		0.58	5.568		0.121	471.72		10.255	21.80		0.47	0.389	8.47
		0.35			0.148			15.669			0.25			
48	27.3		0.57	5.865		0.122	503.06		10.480	22.30		0.46	0.385	8.58
With bark														
48	29.0			6.611			585.00			22.30			0.397	8.85

N.B. DBH in cm, Ba in Dm^2, Vol in dm^3 and height in m.

DBH: diameter at 1.3 m. BA: basal area. VOL: volume without bark. Ht: height. Form. factor: form factor. c.a.i.: current annual increment. m.a.i.: mean annual increment

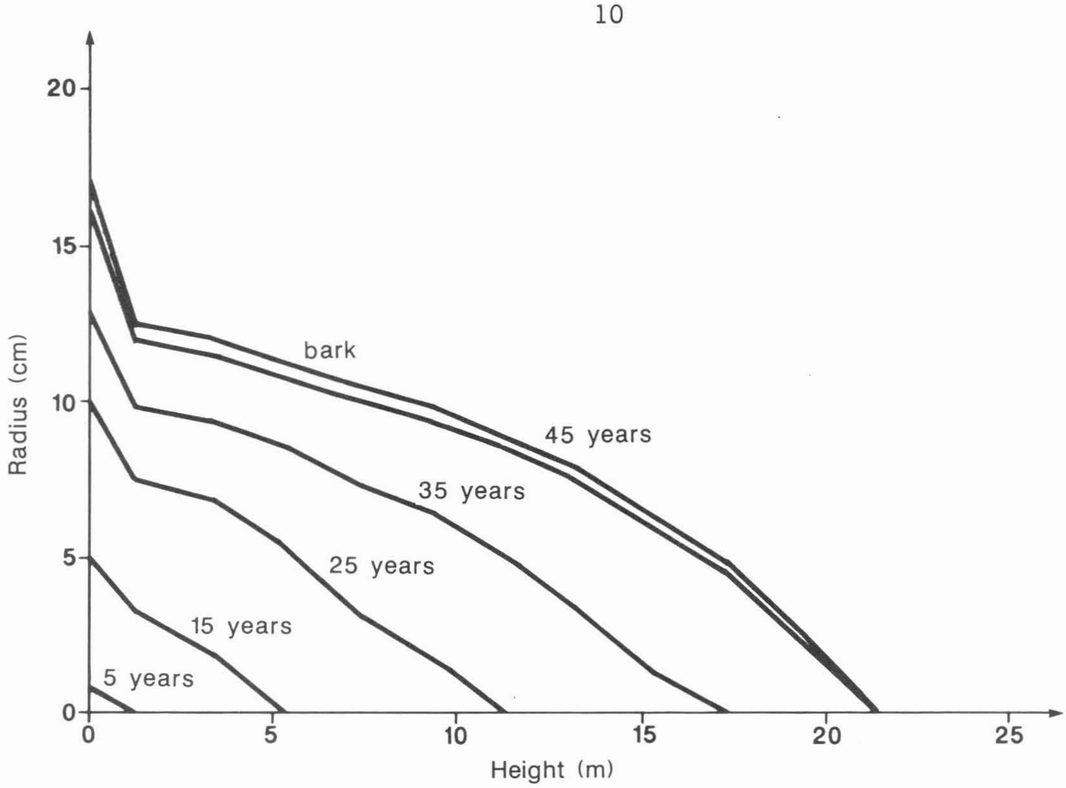

Figure 5. Stem profile of a spruce in relation to age.

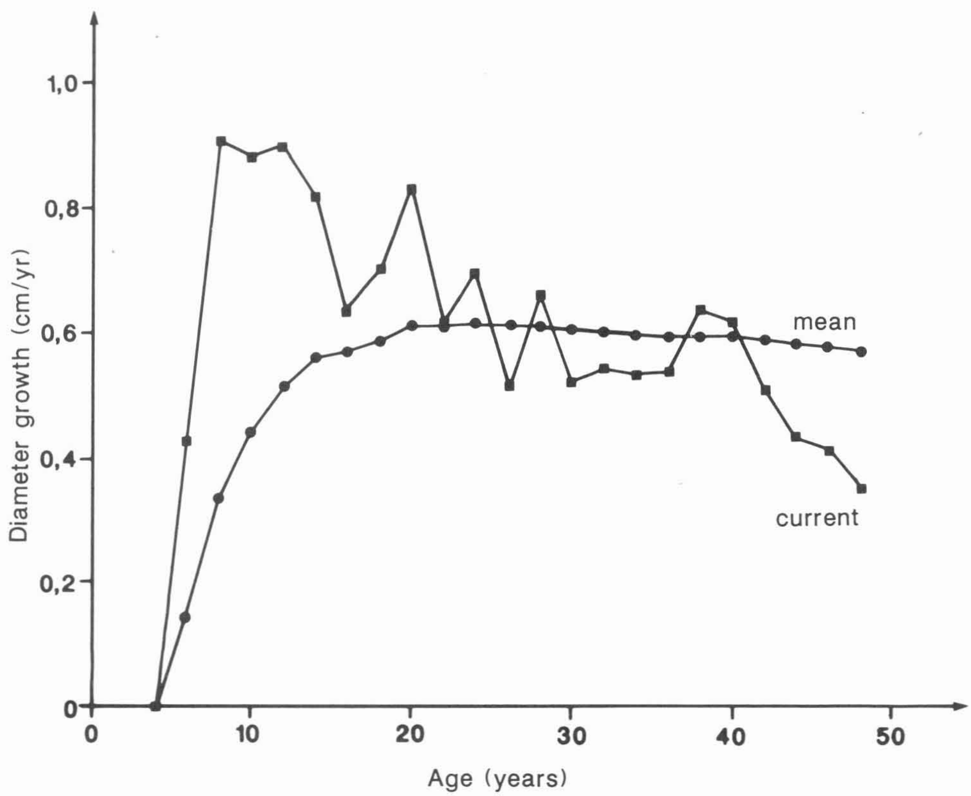

Figure 6. Diameter growth of a basswood tree.

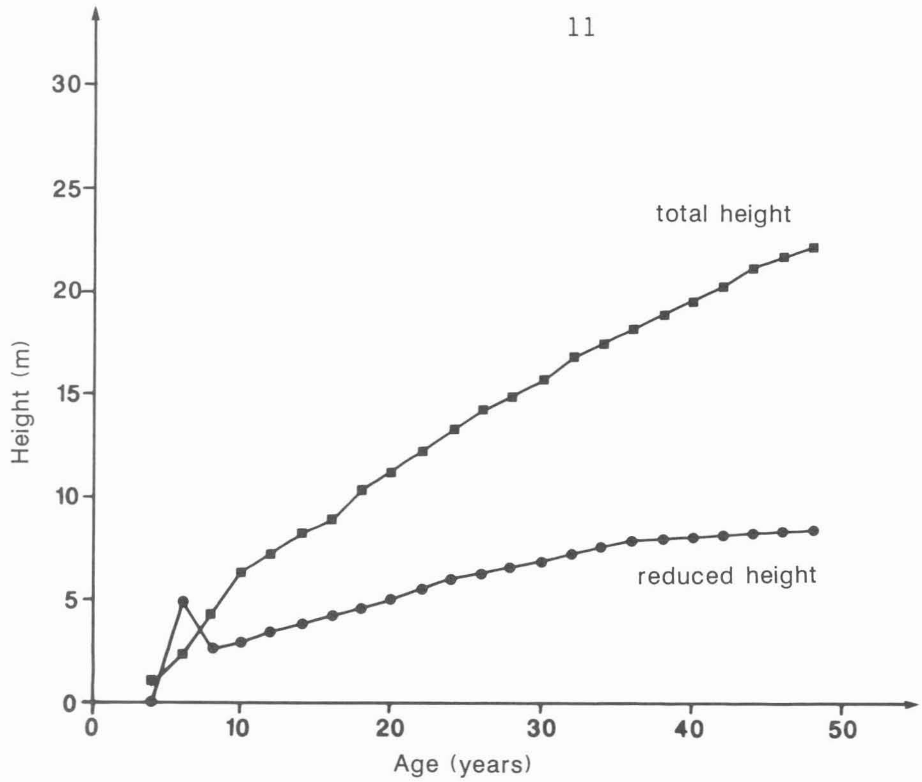

Figure 7. Height growth of a basswood tree.

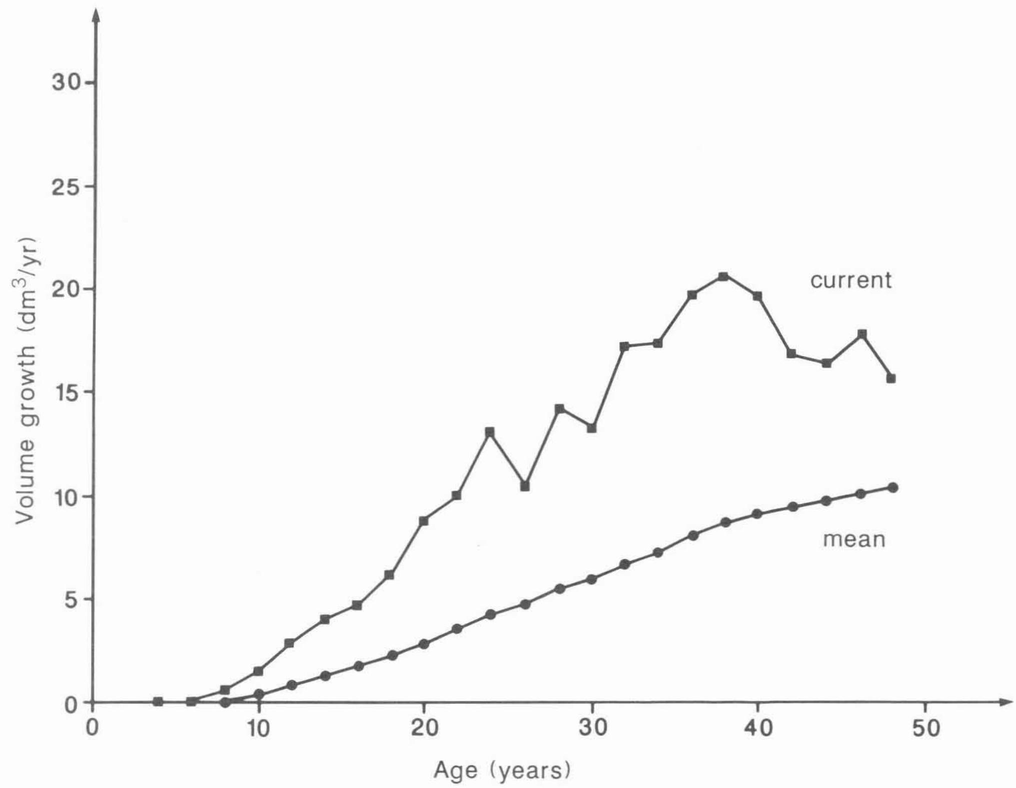

Figure 8. Volume growth of a basswood tree.

spruce (*Picea abies* Karst) appears in Figures 5, 6, 7, and 8.

In forestry, stem analysis is often applied in establishing of the site index curves (for example, Turnbull 1958; Curtis 1964; Beck 1971; and Zarnovican 1983). It is also a basic method for studying volume and volume increments in trees and for estblishing volume tables (for example, Siostrzonek 1958; Prodan 1965; Zarnovican 1981, 1982a; Nagel and Athari 1982).

It appears that stem analysis can enable us to evaluate the effects of thinning, drainage, and fertilization on volume growth or on change in tree form with a sufficient degree of accuracy and (Johann 1980; Sterba 1980; Zarnovican, Trencia 1987).

Finally, stem analysis has proven to be the ideal technique for accurately assessing the volume loss caused by disease and insects (Vins 1967; Zarnovican 1982b; Archambault 1983).

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