

COMPUTERIZED ALGORITHMS FOR PARTIAL CUTS

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Abstract: Stand density, stand structure (diameter distribution), and species composition are all changed by intermediate treatments in forest stands. To use computer stand-growth simulators to assess the effects of different treatments on stand growth and development, users must be able to duplicate silviculturally realistic treatments in the simulator. In this paper, we review the computer algorithms for partial cuts associated with the FIBER, NETWIGS, OAKSIM, SILVAH and YIELD-MS computer programs. We assess these algorithms with respect to flexibility, comprehensiveness, and their ability to mimic cuts prescribed in management guides for timber production. The paper also suggests directions for developing a new algorithm that incorporates the strengths of several of the existing algorithms.

INTRODUCTION

One effect of the microcomputer revolution on forestry has been the development of computer-based growth simulators and their use to test the projected outcome of alternative treatments in forest stands. The utility of these tests is greatest if the computer can duplicate effects achieved on the ground with a minimum of user effort. This paper examines the partial-cutting algorithms in five forest growth simulators, and contrasts them with respect to flexibility, comprehensiveness, and ability to duplicate the kinds of treatments recommended by silvicultural research for the production of timber products. Our focus will be on the algorithm used to implement intermediate thinnings under even-aged silviculture, but we will indicate which of the programs make provisions for other partial cuts, such as those for stands being managed under uneven-aged silvicultural systems.

Among the principal effects of intermediate thinnings are changes in stand density, stand structure, species composition, the average quality of residual trees, and spacing and uniformity of the residual stand. Silvicultural guidelines for mixed hardwoods managed for timber production, including the central and northern hardwood types of the northeastern United States (Leak and others 1987, Marquis and others 1984, Roach 1977, Roach and Gingrich 1968), consistently recommend that intermediate treatments should remove poor-quality and high-risk trees and improve residual spacing and uniformity. Residual stand density is specified through either stocking guides or residual basal area, and may vary with

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stage of stand development. We will report how each of these parameters is controlled in the thinning algorithms of the different computer programs.

COMPUTER MODELS

The life cycle of a growth and yield model typically includes periods of data collection, data analysis, model development, and finally implementation of the model in computer program code. The data collected usually cover a long span of time, in stands that have been managed in various ways. The analysis strives to identify the factors that are most highly associated with tree growth. The mathematical representation of those processes are built into a computer program.

In these models, the processes of stand development (ie. growth, mortality, management) are simplified and stated as algorithms. These algorithms are the steps that are systematically followed to mimic each actual process, much like a recipe from a cookbook. The algorithms can then be translated into computer code for inclusion into the growth and yield simulator.

Model developers make several assumptions in developing the algorithms. For all the models described in this paper, there is an assumption that the stand is uniform throughout with respect to size, species composition, quality and spacing. If a user inputs data from a stand for which this assumption is not true, the results can be absurd. As an extreme example, suppose a user entered as a single stand data from an area that was predominantly pole timber in its eastern half and predominantly medium saw timber in its western half. The average stand characteristics such as diameter or volume are not appropriate to either half of the stand. Any recommendation for intermediate thinning would likely be inappropriate also. In such a stand, applying a cut that emphasizes removal of small trees or large trees may result in wiping out one half of the stand while leaving the other half untouched.

Another assumption is made about growth of residual trees. The data used in building these models come from carefully controlled experiments. If the user requests removals from stands in ways that were not tested, the predicted growth response may not bear any resemblance to reality. For example, in most even-aged research plots used to develop growth response models, the residuals after intermediate treatments are some of the biggest and best trees in the stand. A simulator developed from such data would likely do a poor job of predicting growth after a cut that removed all of the big trees, leaving suppressed and intermediate trees.

Intermediate management in even-aged stands is generally in the form of thinnings. Most computerized growth and yield models allow the user to interact in some way to specify thinnings. Options range from the very interactive (such as allowing the user to specify individual trees to be removed) through completely automatic procedures. The lowest levels are very tedious and require considerable specification by the user to implement a thinning. On the other hand, the automatic modes fully control density and structure, relieving the user

of making the detailed specifications. In this paper, we review the manual specifications in the next section, then progress to the more automatic procedures in the following.

The models explored in this paper were developed using data from mixed hardwood stands in the Eastern United States. The primary purpose of these models is to estimate growth and yield from forest stands of mixed hardwoods managed primarily for the production of wood products. Each contains at least one procedure for simulating partial cuts. The procedures range from manually selecting trees from an on-screen tree list to fully automatic procedures or algorithms that simultaneously control several important characteristics of the residual stand. The following sections describe the models and the associated thinning procedures.

The simulators in FIBER, NE-TWIGS, OAKSIM, SILVAH, and YIELD-MS are distance-independent, individual-tree or stand-table projection types of simulators. They all begin with an enumeration of trees by species and diameter, and all are capable of producing a similar enumeration after projection. All simulators are available for public use on IBM compatible microcomputers. Most are being used by forest managers in central and northern hardwood forest types. Further basic information about the simulators and associated programs follows.

FIBER Version 2.0 (Solomon and others 1987)

FIBER was developed for the spruce-fir and northern hardwood forest types of New England. It is based on data from 359 spruce-fir research plots in Maine and 48 northern hardwood research plots in New Hampshire. In addition, some 2,500 growth plots, mostly from forest industry, were utilized; these plots are scattered throughout Maine, New Hampshire, Vermont, and northern New York.

Variables used in FIBER growth and mortality equations include: d.b.h., initial stand basal area, residual stand basal area, percent hardwoods, and percent species (for ingrowth).

FIBER is a two-stage matrix model. One stage is a set of linear regression equations that predicts transition probabilities of tree growth and mortality as a function of stand density, tree size, and proportion of hardwoods. These predicted probabilities are the elements of stand projection matrices used to project the distribution of diameters over a 5-year period. Projection periods in FIBER are 5 years. Minimum tree size is 5 inches; maximum tree size is 30 inches. FIBER is the one of two programs tested that currently contains an ingrowth function.

A run of FIBER is defined at the outset, and thinning can be performed during a simulation either by specifying the interval between thinnings in years or by specifying a volume or basal area that will trigger a thinning.

Various thinning strategies can be specified with a few simple parameters. The user specifies when and how much to thin. The residual level for the partial cut is specified as a basal area,

a volume, or the B-level on northern hardwood, mixed-wood, or spruce-fir stocking guides reproduced in the FIBER documentation.

Thinning treatments can be specified as 1) no thinning, 2) thin-from-above, 3) thin-from-below, 4) diameter class removal, 5) uniform thinning, and 6) q-line thinning. The no thinning option continues to grow the stand. For the thin-from-above, -below, and uniform, a percentage of the total cut to remove from each species must be specified. If that specification results in removing more than is present, then the excess is distributed to other species in the priority that the user assigns to each species. With the thin-from-above option, the user specifies a beginning diameter and the program removes trees starting at that diameter and continues to smaller size classes until the amount specified has been removed. The thin-from-below is similar except that the program removes trees starting at the specified diameter and continues to larger diameters. The uniform thinning spreads the amount to be removed from each species evenly over all diameter classes of that species. The diameter class removal option is used interactively, and allows the user to specify the number of trees to remove from a given species and diameter class. The final option, q-line thinning, allows the user to specify the structure for an uneven-aged cut.

NE-TWIGS Version 2.0 (Hilt and Teck 1989)

NE-TWIGS was developed for general use throughout the Northeastern United States. It used the large data base of the Forest Inventory and Analysis Unit, which includes more than 4000 permanent 0.20 acre plots. Growth records on these plots cover an average of 12 years and include all forest types and species growing in the Northeast.

NE-TWIGS utilizes the computer shell developed by the North Central Forest Experiment Station for their Lake States and North Central TWIGS simulators (Belcher 1982). However, the growth and mortality equations in the NE variant differ in several ways from the NC and LS variants.

NE-TWIGS is a distance-independent, individual tree simulator. It works either from a tree list or a stand table, and is capable of handling fractional trees (it will accommodate a unit as small as 0.1 tree/acre).

Variables used in NE-TWIGS to estimate growth and mortality include: species, d.b.h., BAL (basal area in trees larger than the tree in question), and site index. As with the other TWIGS models, the NE variant calculates potential growth, then reduces that growth by competitive position (BAL). NE-TWIGS projects in growth periods of 1 year. Minimum diameter is 1 inch; maximum diameter is 30 inches. NE-TWIGS is one of two programs tested that currently contains an ingrowth function.

Runs of NE-TWIGS can be automatic, with user-defined interactive management at specified intervals, or highly interactive, with user specifications of reports, management activities, and additional projections at the end of each projection period. There is no mode in which

management occurs whenever simulated stand development reaches a threshold basal area or relative density.

Thinnings are specified by creating a list of priorities from nine different removal procedures. Up to five procedures may be combined to generate the marking rules used by practicing foresters. Of the nine removal procedures, the first six specify the trees to be removed until the target residual-basal area is reached. The last three are procedures that override the target residual-basal area. The procedures are, 1) remove rough and rotten from size class, 2) remove smallest trees of all species not specified to leave, 3) remove largest trees of all species not specified to leave, 4) remove smallest trees of specified species, 5) remove largest trees of specified species, 6) shelterwood cut leaving the largest diameter and highest crown ratio trees, 7) reduce the number of trees to specified residual level, 8) remove overtopping trees, essentially a diameter limit, and 9) remove all trees of a user specified size and species.

OAKSIM (Hilt 1985a, 1985b)

OAKSIM was developed for oak-hickory forests of the upland central hardwood region. Growth and mortality data come from 20-year records on 77 permanent growth and yield plots in southern Ohio and southeastern Kentucky. White oak, black oak, and scarlet oak were the most common species on the plots, with other upland hardwoods represented in varying amounts. A single growth equation is used for all species, but there are four mortality equations; one each for black oaks, white oaks, other trees (primarily hickory), and understory trees. Adjustments are made to total stand growth by use of equations from GROAK (Dale 1972), a stand level simulator developed from the same data set.

Variables used in OAKSIM equations include: d.b.h., quadratic mean stand diameter (QMD), total stand basal area, site index, and species (mortality only).

OAKSIM is a distance-independent, individual tree simulator. It works from a tree list and treats each tree in that list (each sample) as an entity, either killing it or growing it in its entirety.

Runs of OAKSIM are defined at the beginning of a run. Thinnings are scheduled by the user, who specifies the age, residual density, the intensity codes for each species group, and the residual density (in percent stocking by the Oak Stocking Chart) for each thinning.

If a thinning is desired, the user specifies the residual density, and the entire distribution is done automatically. The distribution of cut is based on a mathematical model of actual thinnings. Application of this thinning algorithm ensures residual stands that duplicate as closely as possible the actual study plot residuals. The percentage to cut from any diameter class is a function of the residual density and the cumulative frequency of live trees in the stand. While this ensures that irregularities in the original stand are not increased, it does nothing to alter these irregularities.

The user can specify three options to control the species composition effects of this thinning algorithm. While the number of trees to cut within any diameter class is fixed by an equation, the user can specify the allocation of that cut across species within each class. The choices are to 1) maintain the same proportion in each species as in the unthinned stand, 2) double the cut for a species, or 3) eliminate a species.

There are no provisions for partial cuts under uneven-aged silvicultural systems or for user-designed cuts in the OAKSIM program. The research plots that were used to provide the data from which OAKSIM was developed were all even-aged.

SILVAH Version 4.04 (Marquis 1986)²

SILVAH was developed for use in hardwood forests of the Allegheny Plateau region of Pennsylvania, New York, West Virginia, Maryland, and Ohio. The SILVAH program is primarily a decision-support system used in making silvicultural decisions, but it includes a stand growth simulator as an important component.

Growth data in SILVAH comes from two major sources. Data on the cherry-maple and beech-birch-maple types came from approximately 370 tallies of long-term research plots in northwestern Pennsylvania, some of which span 55 years of continuous record. These data have been used to develop separate growth and mortality equations for black cherry, red maple, sugar maple, and American beech. Other non-oak species are calculated from the equations of one of these species. Equations for growth of species of the oak-hickory type in SILVAH came from OAKSIM. The equations were simply taken from OAKSIM, and used for all oak species. Growth adjustments included in OAKSIM based on the stand growth simulator GROAK are not included in SILVAH.

Variables used in SILVAH growth and mortality equations include: species, d.b.h., relative diameter (d.b.h./stand diameter), relative stand density (total basal area for oaks), and site index (oaks only). SILVAH is a modified stand table projection simulator. SILVAH works with per acre data, and permits fractional trees/acre to die or move in d.b.h. class.

SILVAH offers a range of run options, from interactive through automatic. In the most automatic mode, partial cuts are triggered by growth to a program-set threshold density. Volumes available for cutting must also meet user-specified levels for the program to implement an automatic cut. In the most interactive mode, a user selects any treatment(s), including customized ones, at the end of each growth period. SILVAH does not include a facility for editing the current stand table as one way of describing a partial cut.

²Marquis, David A. and Richard L. Ernst. In preparation. User's guide to SILVAH: a stand analysis, prescription, and management simulator program for hardwood stands of the Alleghenies. Available from the authors.

The thinning algorithm in the SILVAH programs is described in detail elsewhere³. For even-aged partial cuts, the distribution procedure uses a negative exponential function to ensure that a specified proportion of the cut density is removed in trees smaller than the medial stand diameter (MD). The medial stand diameter represents the point where half the basal area is below and half the basal area is above. This distribution procedure does not account for any irregularities in the existing diameter distribution, however, and can result in severe cutting in some size classes in stands with irregular distributions. For all-aged cuts, an idealized inverse J-shaped curve, based on q , is transformed into the equivalent relative density. All density in excess of this curve is removed. If the original stand is deficient with respect to the target density in any size class, additional density is left in smaller classes to compensate. The automatic thinning algorithm assigns a cut proportion to each diameter class, and maintains the species composition of each diameter class as it was in the unthinned stand.

In addition to the automatic prescription generation option, users may either select a standard silvicultural prescription (alternatives include precommercial, combined precommercial/commercial, and commercial thinnings, thin-harvests, shelterwood seed cuts, and selection system cuts). Users may also design a partial cut by combining information about species, density, and structure. For each of these criteria, a single value, or a range of values can be specified; trees that simultaneously meet all three conditions are removed. In addition, this option allows the user to specify the priority for each removal; the user specifies those trees that are to be removed unconditionally, or subject to a minimum residual density.

YIELD-MS Version 1.1 (Hepp 1988)

YIELD-MS is the timber yield and planning module of the Tennessee Valley Authority's (TVA's) package of inventory, analysis, and economic analysis programs for timber managers working in mixed species stands. The YIELD-MS component is where the user has the opportunity to impose management procedures, such as partial cuts, and obtain stand growth projections.

Growth projections in YIELD-MS are stand table projections. Each species group and diameter class has a d.b.h. growth rate and a survival probability. Users may enter d.b.h. growth rates from a file, from increment core data particular to a stand, or by direct user entry. However, the preferred mode of growth projection is use of growth and survival probability equations from any of four other stand-growth simulators. These are OAKSIM, SILVAH, TWIGS (Shifley 1987), and G-HAT (Harrison and others 1986a, 1986b). The growth projection routine in YIELD-MS uses these equations but does not use any modifiers from the original programs. So, the results of simulating the growth of a stand with YIELD-

³Ernst, Richard L. and Susan L. Stout. In preparation. A computerized method for developing marking guides for forest stands. Available from the authors.

MS, using the OAKSIM equations, for example, may not be the same as simulating the growth of that stand using OAKSIM.

Data entry and inventory processing are accomplished in other programs in the TVA package. Diameters must be in 1-inch classes. Minimum diameter is 1 inch; there is no apparent maximum diameter.

Runs of YIELD-MS are interactive. Selecting trees for thinning can be in manual or automatic tree marking modes. The automatic tree marking mode allows the user to specify a percentage of a species, product, and size to remove. The program calculates the basal area in all trees that meet the three criteria, then removes the proportion of those trees as specified by the user. The product criteria consists of specifying grades 1 through 5 and pulpwood. The size criteria allows the user to specify that the removals occur equally across all diameters, from the biggest trees, from the smallest trees, from the most valuable trees, or from the least valuable trees.

The manual marking mode allows the user to edit the contents of the individual cells of a stand table on-screen. Although tedious, this method allows the most flexibility. The stand table is displayed on the screen, and it can be in any of the units supported such as number of trees, volume, value, and so on. The user changes the value in the cell, and the tables for cut and leave are adjusted.

SUMMARY OF PARTIAL CUT ALGORITHM OPTIONS

Tables 1 and 2 summarize the partial-cut options in these computer programs. In Table 1, the options for automatic partial-cut implementation are summarized. These are the options that allow the user to specify a few characterizing parameters, from which the computer program develops a comprehensive description of the cut. Table 2 summarizes the tools each program provides for users to develop customized partial cuts. The array of possibilities is extensive, as these tables and this summary show. There are uniquely advantageous features in each program, but no program includes all features.

Our assessment of the flexibility and comprehensiveness of the partial-cut procedures in these programs is necessarily subject to our own biases, experience, and computer use styles. We suggest that those programs with many customizing features in Table 2 are the most flexible. Those with many automatic features in Table 1 are the most comprehensive. Mastering any of these computer programs requires a learning period. While this period may be shorter for programs with the fewest options on both tables, those with many automatic features are easiest to use if many alternatives are to be tested. It is possible to construct most common silvicultural treatments with FIBER, NE-TWIGS, SILVAH, and YIELD-MS.

Table 1.--Automatic cut generation features

Simulator	Thinning timing ¹	Density control ²	Even-age structure control ³	Uneven-age structure control ⁴	Other ⁵
FIBER	A, Y, T, I	BA, V, ST	D	Q, MX	Q
NE-TWIGS	Y, I	BA	-	Q, MX	Q
OAKSIM	A,Y	ST	F	-	Q, S
SILVAH	Y, T, I	RD	P	Q, MX	Q, N
YIELD-MS	I	BA	-	-	Q

¹A = Thin at given age, Y = thin after given number of years, T = thin when stand reaches threshold, I = interactive

²BA = basal area, V = volume, NT = number of trees, RD = relative density, ST = stocking guide level

³D = default quality and species removal priorities, P = power function, F = fitted function to research data

⁴Q = quotient, MX = max tree size

⁵Q = quality adjustment, S = species adjustment, N = select treatment by name

Table 2.--Customized cut generation features.

Simulator	Density control ¹	Cut from above	Cut from below	Cut uniform	Cut species	Save species	Cut dia class	Cut poor quality	Combine	Tree list edit	Other ²
FIBER	BA, V, ST	.	.	.	.		.
NE-TWIGS	BA	.	.		.	.	.	.	.
OAKSIM	ST				.		.				
SILVAH	RD			.	.		.	.	.		N
YIELD-MS	BA				.		.	.	.	.

¹BA = basal area, V = volume, NT = number of trees, RD = relative density, ST = stocking guide level

²N = select treatment by name

AUTOMATIC CUTS FOR EVEN-AGE STRUCTURE CONTROL

Three of the programs considered in this paper offer automatic structure control when applying even-aged thinnings. These automatic cutting options are important for a variety of reasons. The first is that these automatic cutting algorithms usually represent the model developer's best effort to mimic the kind of thinnings implemented on the research plots from

which the model was developed, and the model should most closely mimic the growth of real stands cut in these ways. The second is that because these options are often the easiest to implement, users take advantage of them, and a fuller understanding of their consequences improves use of the models. As we will show in this paper, the algorithms act in different ways on stands with different structures. An understanding of these differences also improves use of the models. Finally, a discussion of the algorithms actually used in different programs will enable those working on future model development to draw on the best of several existing algorithms.

Users of FIBER may request a thinning to the B-line of any of the stocking guides reproduced in the FIBER documentation (Solomon and others 1987), but this documentation does not describe the implementation of this procedure. Both OAKSIM and SILVAH use mathematical functions to distribute removals among diameter classes and species.

We will show the effects of these two procedures on two different oak stands, with quite different original structures. The first example is based on Schnur's (1937) yield table for 90-year-old oak on a site index 70 site (Figures 1a and 1b). This stand is typical of the structure and species composition of stands used to develop the OAKSIM model. The second stand is from a transition oak stand in northwestern Pennsylvania (Figures 2a and 2b), and is typical of the stand structure, density, and species composition found in that region and other areas in which stands of northern red oak and northern hardwood species are common (Stout in press). It is similar in structure to the stands used to develop the growth and yield model in SILVAH.

The OAKSIM procedure is described in detail in the OAKSIM documentation (Hilt 1986b). The function used was developed to describe the removals on the research thinning plots that yielded the data used to develop OAKSIM. Users may adjust the application of this procedure by species and residual density, but may not adjust the minimum cutting diameter, which is set at the smallest diameter class in the stand. The function determines the cut frequency in each diameter class as a function of the cumulative frequency from the smallest class and of the residual thinning density. This procedure automatically ensures that in irregularly small classes, the cut will be small, and in irregularly large classes, the cut will be large, still ensuring that the designated total cut is achieved. Nothing is done to smooth such irregularities. Figures 1a and 2a show the diameter distribution of Schnur's SI 70, 90-year-old oak stand and the Pennsylvania oak stand, respectively, with each diameter class separated into cut or leave trees according to the OAKSIM thinning function.

The SILVAH procedure uses a modified negative exponential function, which guarantees that for cuts from below (those in which more than half the cut will come from trees lower than MD), the largest proportion of the cut will come from the smallest class for cutting, and each successive class will have a slightly smaller cut. After the equation is applied to 1- or 2-inch diameter classes, the cut from several adjacent classes (the 6- through 11-inch classes for poletimber, for example) is accumulated into a class proportion. This reduces the smoothness of the cut, but yields a more realistic marking guide for woods use. Users may adjust the residual relative density and the proportion of the cut to be made in trees less than MD. Users have some control over the minimum diameter in which cutting is to occur. The

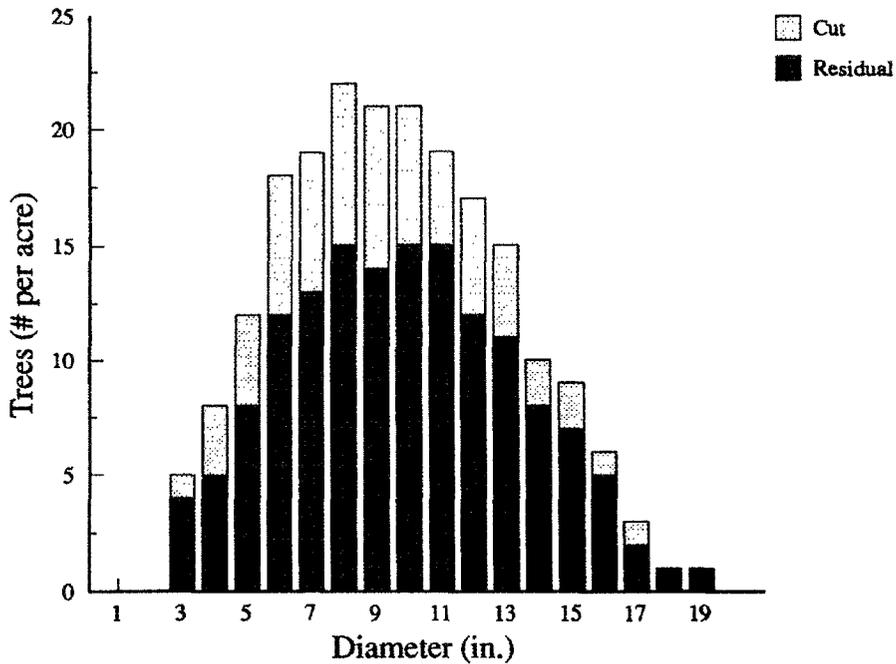


Figure 1a. Cut and residual trees in Schnur's SI 70, 90-year-old stand after a thinning as prescribed by OAKSIM.

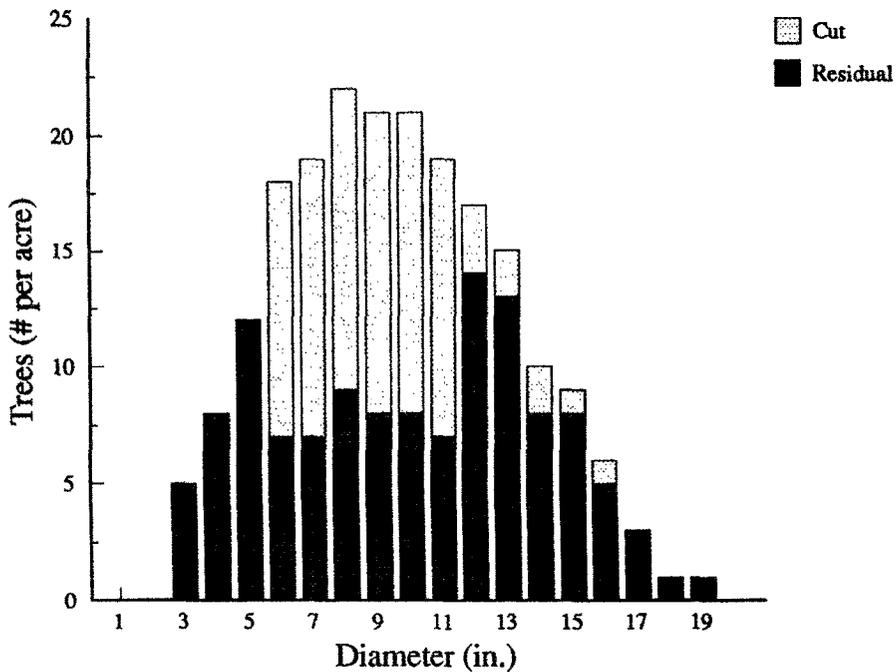


Figure 1b. Cut and residual trees in Schnur's SI 70, 90-year-old stand after a commercial thinning with 75 percent of the density removed in trees smaller than MD as prescribed by SILVAH.

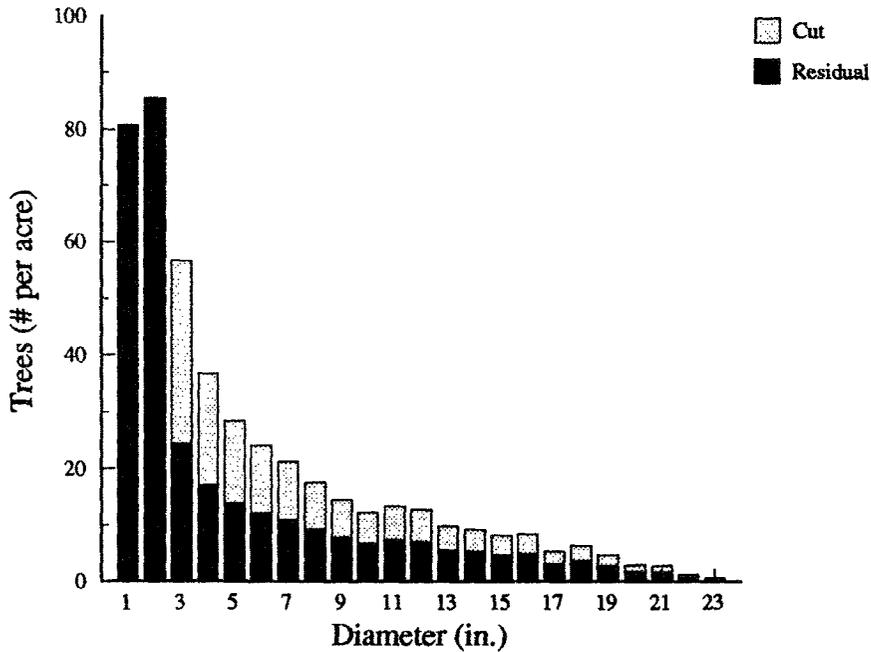


Figure 2a. Cut and residual trees in a Pennsylvania oak stand after a thinning as prescribed by OAKSIM.

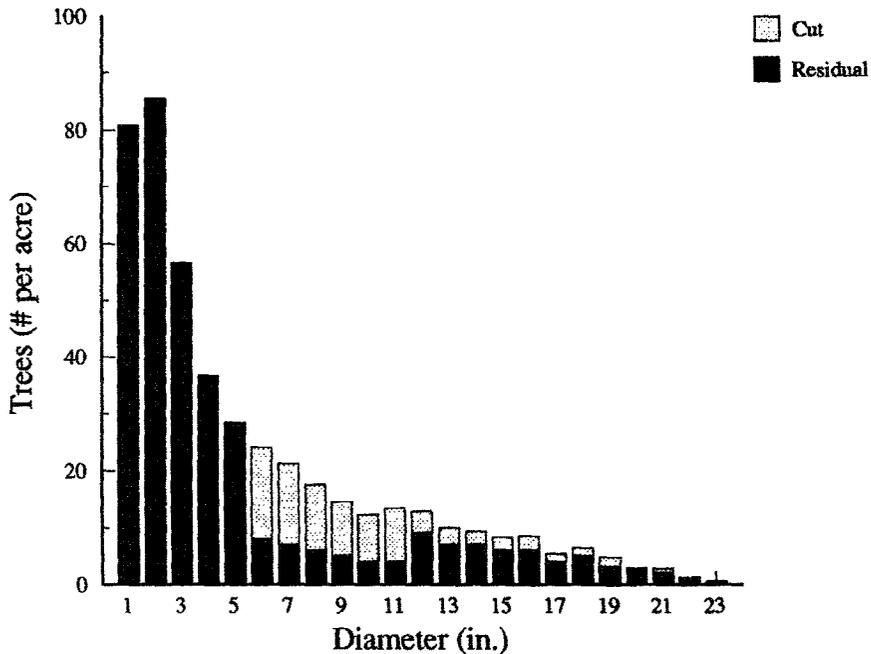


Figure 2b. Cut and residual trees in a Pennsylvania oak stand after a commercial thinning with 75 percent of the density removed in trees smaller than MD as prescribed by SILVAH.

procedure largely ignores irregularities in the original diameter distribution, although adjustments are made when the procedure calls for removal of more trees than are present in a diameter class.

Figures 1b and 2b show the same stands as Figures 1a and 2a, with each diameter class divided into cut or leave trees according to the SILVAH default function for a commercial thinning. The two procedures have quite different effects on both of these stands. In each stand, there are differences in the smallest size classes and differences in the overall structure of the residual stand. Each of these differences is a consequence of the thinning algorithm and its constraints.

The Schnur stand has the even-aged stand structure, or diameter distribution, traditionally associated with forest types in which the species are similar in growth rate and tolerance to shade. In this stand, the OAKSIM algorithm identifies trees for cutting from the 3-inch through the 17-inch class, all in proportion to their presence in the existing stand (Figure 1a). SILVAH's algorithm includes no cutting in the sub-merchantable size classes in this stand. In addition, SILVAH's algorithm stipulates that 75% of the density to be removed will be in trees with diameters smaller than MD. In this stand, this results in a much heavier cut in the poletimber classes and somewhat lighter cut in the sawtimber classes (Figure 2a). Both residual stands have a bell-shaped distribution in the merchantable classes. In the OAKSIM distribution this bell-shape extends into the sub-merchantable classes.

The Pennsylvania transition oak stand has the inverse-J shaped diameter distribution frequently found in even-aged hardwood stands with a mix of species of different growth rate and tolerance for shade. Once again, differences in threshold diameter for cutting are apparent in the residual stands, although in this stand, the fact that trees less than 3 inches in diameter are not processed by OAKSIM is apparent. SILVAH's algorithm concentrates the cut in this stand in the 6-, 8-, and 10-inch classes, and establishes a bell-shaped distribution, particularly in the 10- through 24-inch classes. The residual from the OAKSIM thinning algorithm retains its original, inverse-J shape.

A comparison of the effects of thinning algorithms on different stands is made more difficult by the absence of a universal measure of relative density. Both algorithms use relative density to control the total amount of removals, but the density measure is different. OAKSIM uses the Oak Stocking Guide (Roach and Gingrich 1968), while SILVAH uses a tree-area ratio based measure with three species groups (Marquis and others 1984, Stout and Nyland 1986).⁴ In stands with species from more than one species group, similar basal areas may represent different densities, and similar densities may represent different basal areas (Stout and others 1987). It is very difficult to impose thinnings that leave residual stands that are similar in both absolute and relative density across the two measures. For the purposes of focusing on the thinning algorithms, we have concentrated on the structure of the cuts, rather than on the absolute amounts removed.

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Both procedures allow the user to specify the residual density for thinnings in the density measure associated with the model. OAKSIM uses the residual density in the cumulative cut function and varies both the absolute amount to be cut in each class and the proportion of the cut assigned. SILVAH maintains the same proportions for the cut, but increases or decreases the absolute amount in each size class according to the selected residual densities. Users may, however, specify the proportion of the cut to be assigned to diameter classes below MD, and hence the proportion of the cut in each size class.

CONCLUSIONS

This examination of the computerized procedures for implementing partial cuts in computerized forest stand-growth simulators points to an opportunity to develop a new procedure for implementing even-aged thinnings automatically. OAKSIM uses a cumulative distribution function, but is inflexible with respect to structure. While SILVAH is flexible, its procedure is relatively insensitive to the original stand structure. Both procedures are tightly tied to the structure of the stands in the data bases from which they were developed. Neither procedure alters the prescribed residual to compensate for irregularities in the existing distribution, and the SILVAH procedure actually can worsen these irregularities if applied blindly.

One new approach would be to use a distribution function for the cut, as SILVAH does, and then to distribute it on a cumulative basis as OAKSIM does. This would eliminate the shortcomings of both methods. Such a function could include built-in flexibility to handle different structures for thinnings or shelterwood cuts near stand maturity, for example.

Another approach would be to develop automatic procedures for partial cuts under even-age systems that mimic the procedures in wide use for partial cuts under uneven-age systems. The procedures for distributing partial cuts under uneven-age systems involve description of a target residual distribution by size class and removal of those trees that exceed the target distribution. Some procedures include a step to modify the target distribution to compensate for deficiencies in the present stand. The various silvicultural guides in use throughout the Central Hardwood region suggest that even-age thinnings should be applied to increase the stand diameter (shorten the rotation length), and favor the biggest and best trees. Some guides specify narrowing the range of diameters. These characteristics could be translated to a target residual structure for even-aged stands and a procedure used that would prescribe cutting the trees in excess of the target distribution.

This examination of the computerized partial cut procedures available in commonly used computer stand-growth simulators has demonstrated the wide range of alternatives available, and can form the basis for development of an integrated, flexible, comprehensive and user-friendly set of procedures for future versions of existing simulators or new decision support programs, such as that being developed under the auspices of the Northeastern Forest Experiment Station (Marquis 1990). All programs examined here control density, quality, and structure in the residual stands either directly or indirectly. A complete partial cutting module

could be derived by using the best components of each of the individual procedures. Such a module should allow for totally automatic distribution of cut that controls density, quality, and structure. It should also allow complete and flexible manual intervention.

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