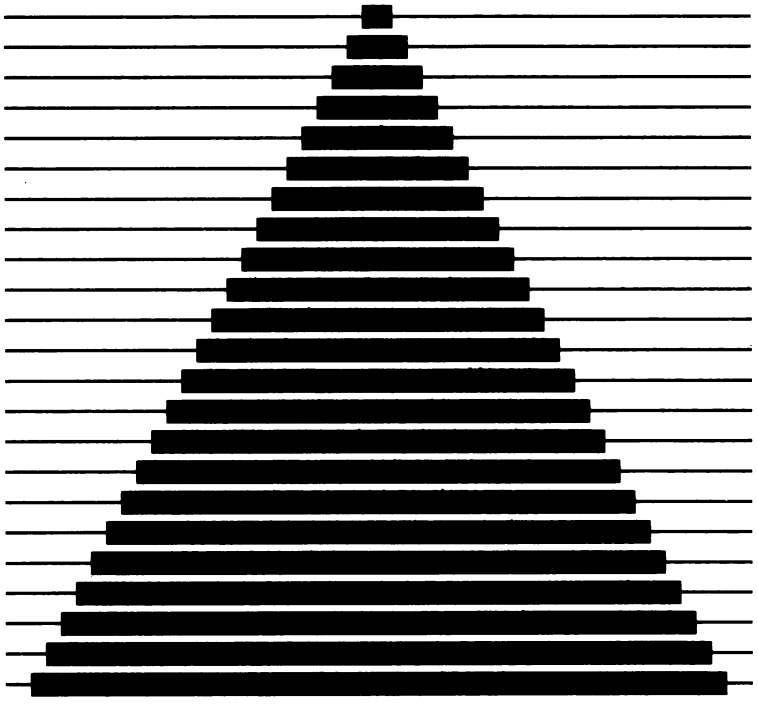
USDA FOREST SERVICE
GENERAL TECHNICAL REPORT **NC-69**

SIMULATING TIMBER MANAGEMENT IN LAKE STATES FORESTS



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Manuscript approved for publication: August 7, 1979

1981

SIMULATING TIMBER MANAGEMENT IN LAKE STATES FORESTS[1]

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Tree growth models are useful tools in projecting the growth of forest stands. If a growth model is programmed for use on a computer, the growth of a stand can be quickly and inexpensively projected. Rapid and inexpensive projections are important in a regional analysis, where there are many stands to evaluate. However, unless tree cutting can be simulated, the model is limited to predicting what will happen to unmanaged stands.

A Stand and Tree Evaluation and Modeling System (STEMS) has been developed at the North Central Forest Experiment Station (Leary 1979, Leary *et al.* 1979)[2,3] for the Lake States region (Michigan, Minnesota, and Wisconsin) of the United States. This computerized system simulates the changes in the forest as trees grow, die and are cut. This paper describes the part of the system, the management subsystem, that simulates tree cutting and explains how it can be modified to simulate many different tree cutting strategies.

To better understand the management subsystem, a brief description of STEMS is needed. STEMS is designed to grow any mixture of tree species or sizes in the Lake States. Growth equations were developed for 27 Lake States' species or groups of species. The equations for different species differ only by having different numerical coefficients. The stand that will be grown is represented in the computer by a tree list containing tree species, diameters, and crown ratio codes and values for stand characteristics. If available, tree quality codes are also used. The stand characteristics are age, site index, basal area, number of trees, and average diameter. These characteristics provide the only information available for growing trees, deciding on a management prescription, and selecting trees to cut. As trees grow, die, and are cut the tree list is altered (fig. 1).

There are two approaches which could be used in the management subsystem to simulate tree cutting. One is to have the *user* prescribe and implement cutting; the other is to have the *computer* prescribe and implement cutting. The first approach is impractical when hundreds of stands must be evaluated, as is the case when using STEMS for a regional analysis. Therefore, the second approach is used. However, before the computer can prescribe and implement cutting it must be told what to do. The rest of this paper explains how the user tells the computer how to prescribe and implement cutting on the stands it *will be* encountering.

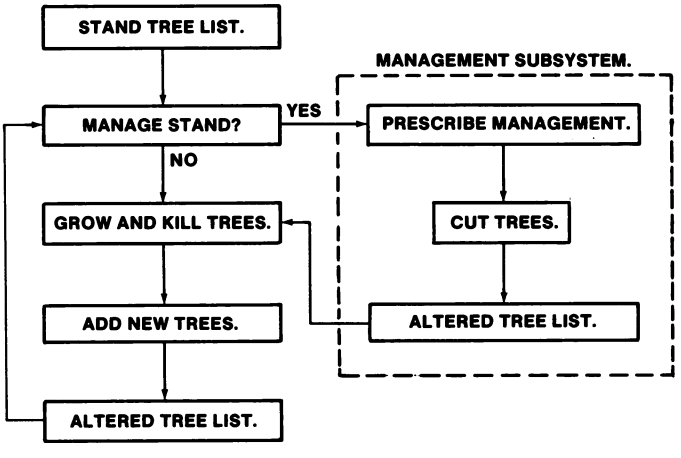

Figure 1.—*Altering the STEMS tree list.*

[1]A major portion of this work was conducted under a cooperative agreement between the North Central Forest Experiment Station and the College of Forestry, University of Minnesota, St. Paul, Minnesota.

[2]*Belcher, David M., Margaret Holdaway, and Gary Brand. (In preparation.) A description of STEMS.*

[3]*STEMS was designed to be part of an overall Forest Resource Evaluation Program (FREP). Currently only the tree growth model STEMS exists. A prior accronym for STEMS was FREP78.*

The timber management guides for the following cover types form the basis for the rules on deciding how cutting should be done:

Cover type	Source
Jack pine	Benzie 1977a
Red pine	Benzie 1977b
White pine	USDA For. Serv. 1958
Spruce-fir	USDA For. Serv. 1967
Black spruce	Johnston 1977a
Mixed swamp conifers	Johnston 1977b
Northern white-cedar	Johnston 1977b
Tamarack	Johnston[4]
Oak-hickory	Sander1977
Aspen	Perala1977
Paper birch	Tubbs 1977, Godman[4], Perala[4]
Lowland hardwoods	Godman[4]
Northern hardwoods	Tubbs 1977, Godman[4]
Understocked	Benzie[4]

TIMBER MANAGEMENT SIMPLIFIED

Timber management guides recommend prescriptions for a stand on the basis of research results, experience, and silvical knowledge. However, the prescriptions are only guidelines. In practice the forest manager in the woods integrates the complex set of factors which affect the growth of a stand. These factors are such things as: potential for disease, insect, or physical damage; species composition; spacing of the trees; amount of inhibiting vegetation; and type of soil. The manager may modify the prescription from the management guide to better reflect these local conditions.

To simulate the skill and subjective judgement that the manager uses to integrate these many factors would be complicated. It would also require a lot of information. Therefore simplifying assumptions were made in developing the management subsystem. Two basic assumptions are: trees are uniformly spaced; and shrubs and herbaceous plants are unimportant. In addition each guide may have its own particular assumptions (see Appendix A).

The management subsystem has two tasks: (1) to *prescribe* or determine a management prescription; and (2) to *implement* the prescription by designating which, if any, trees to cut. These two tasks are described in the following sections.

[4]*Personal communications.*

DETERMINING THE MANAGEMENT PRESCRIPTION

The first step in constructing a computerized subsystem is to convert each management guide to a decision diagram. The diagram is much like a road with signs at each intersection indicating where the road goes. For example, a guide for jack pine might prescribe a clearcut at age 50 for stands with a site index greater than or equal to 60 (SI $\geq$ 60) and a clearcut at age 65 if the site index is less than 60 (SI $<$ 60). Figure 2 converts this verbal statement to a decision diagram. At the first intersection go up if the site index is less than 60, and go down if it is not. Regardless of which branch is taken, age is considered next to determine if the prescription is "do nothing" or "clearcut". If the stand age is less than the prescribed clearcut rotation age, nothing is done. If the stand age is greater than or equal to the specified rotation age, a clearcut is prescribed. Usually management guides are more complex than this but the principle is the same.

Decision diagrams (Appendix A) were developed for the types listed in the previous tabulation. The lowland hardwood guide (fig. 3) is discussed below to show how it is used and how it can be changed to produce different prescriptions for the same stand condition.

In figure 3 tree cutting prescriptions are based on three stand characteristics: site index in feet (SI), stand age in years (Age), and basal area in square feet per acre (BA). These stand characteristics are used to decide which action to prescribe. At each decision point the stand's characteristics are compared to the decision values given by the management guides. These management guide values are called critical values. For this lowland hardwood guide the critical value for site index is 55. Stands

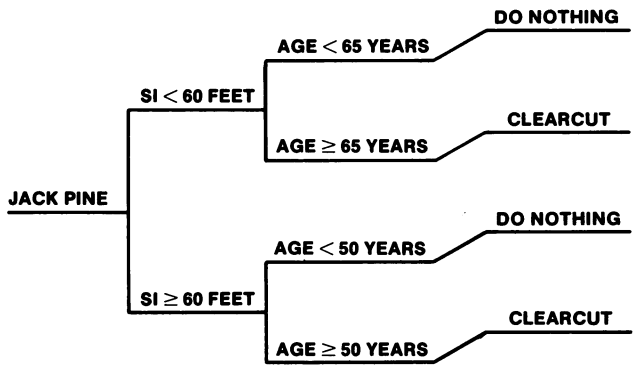

Figure 2.—*Diagram of a simple jack pine management guide.*

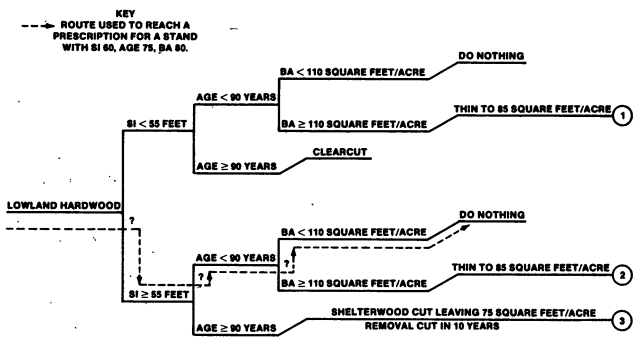

Figure 3.—*Example of how a lowland hardwood diagram is used.*

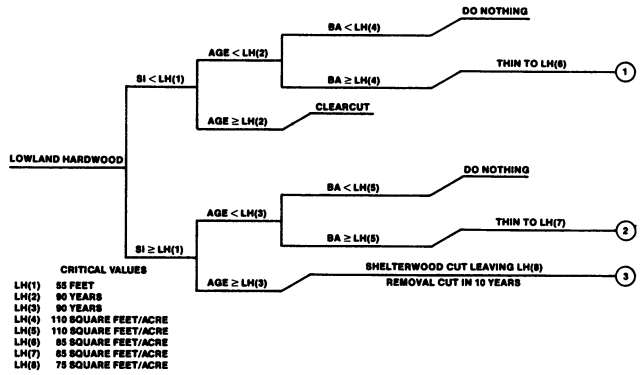

Figure 4.—*Generalized lowland hardwood diagram.*

with site indexes less than 55 follow a different prescription path than stands with a site index of 55 or higher. Similarly, the critical value for age is 90 and for basal area is 110. These critical values happen to be the same for each branch, but they may be different for some diagrams.

Now let's see how such a diagram is used to determine a cutting prescription. Suppose a lowland hardwood stand has these characteristics:

Site index - 60 feet at 50 years
Age - 75 years
Basal area - 80 square feet per acre.

To find the current prescription for this stand, the stand site index of 60 is compared with 55, the value at the first intersection. Since the site index is greater than 55 the lower path is taken. Next, the stand age of 75 years is compared with the value at the next intersection, 90 years, and top route is selected because the stand age is less than 90. Finally, the stand basal area of 80 square feet per acre is less than 110 so the prescription is "do nothing" (fig. 3).

Although this management guide may be very reasonable, local conditions might make another guide more useful, or a manager might like to explore the effect of several different management guides. A simple change in the diagram makes this kind of manipulation easy.

To make the diagram more general the critical values in figure 3 are replaced with symbols or variables which indicate that they may change (fig. 4). Ordinarily the variables will take on values that have been determined from published management guides. In figure 4 the critical value for the variable at the first intersection, LH(1), is 55. This is the same value that appeared in figure 3. If the listed critical values are used, the generalized diagram (fig. 4) and the specific diagram (fig. 3) produce the same prescription for any given stand.

The advantage of the generalized diagram is that it can be easily changed by the program user to simulate other management guides. Could a manager use this diagram for a guide that prescribes shelterwood cutting of all lowland hardwood stands, regardless of site, at age 70? Yes, by making two changes in the critical values. Change the critical values LH(1) to zero and LH(3) to 70 (fig. 5). Since all site indexes will be greater than zero, the upper path will never be used, and all stands will be routed to the lower path.

In the previous example, our stand has an age of 75, so according to this new guide it should be shelterwood cut. The new diagram prescribes this. Comparing the stand site index 60 with the critical value at the first intersection (LH(1) is now zero), shows we must take the lower path. Next, the age is greater than 70 (the critical value of LH (3)) so again the lower path is selected and the prescription is "shelterwood cut".

Many other lowland hardwood guides could be produced with this diagram. The limitation is that the structure of the diagram cannot be changed. This means that intersections are not added and other stand characteristics are unimportant. If a lowland hardwood guide recommends different prescriptions for three ranges of site index this diagram cannot be used. Neither can it be used for a guide that makes a prescription based on average diameter. In these cases a new diagram must be constructed and programmed.

Generalized diagrams for the other forest types are in Appendix A. They make prescriptions for various stand conditions, but this is only part of the task. To carry out the prescription the manager must mark the trees to be cut.

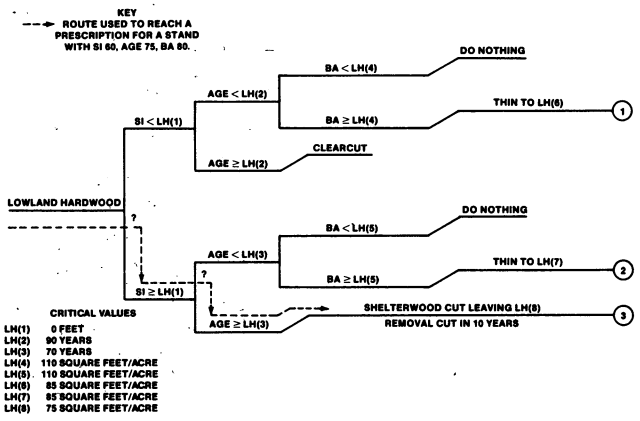

Figure 5.—*Modified lowland hardwood diagram.*

IMPLEMENTING THE PRESCRIPTION—DESIGNATING TREES TO BE CUT

For prescriptions like "clearcut" and "do nothing" all trees are either cut or left. A more interesting problem is what to do when only some of the trees are cut. Prescriptions in the latter category are indicated by a circled number in the diagrams.

The lowland hardwood guide has three prescriptions with circled numbers, two are "thin" and one is "shelterwood cut". For each of these prescriptions the manager must develop a marking rule that ranks the trees for cutting. A marking rule when thinning a lowland hardwood stand might be:

(1) first mark low quality trees;
(2) next mark elms from above (with the largest diameters cut first) to minimize the loss to Dutch elm disease;
(3) then mark from below the undesirable species; (cut the smallest diameter trees first);
(4) finally, mark from below the desirable species (black ash, red maple, yellow birch).

A method was developed to simulate marking rules like these.

The method involves selecting different combinations of removal procedures. The order of the removal procedures determines which is done first, second, and so forth. The procedures rank trees using the tree characteristics: species, diameter, crown ratio, and quality. In each of the nine procedures (table 1), different tree characteristics are used in ranking trees for cutting.

To simulate the marking rule just described for lowlands hardwoods, four removal procedures would be used. They are procedure codes 1, 5, 2, and 4. The first marks low quality trees. Number five thins from above (marks the largest diameter trees first) the specified species (which is elm for lowland hardwoods). The next procedure, number two, thins from below (marks the smallest diameter trees first) the undesirable species. This procedure requires the desirable species to be listed. For this example they are black ash, red maple, and yellow birch. The last procedure (4) thins the desirable species from below. Appendix B contains marking rules for all prescriptions in the management diagrams (Appendix A) which end in a circled number.

Each removal procedure must have certain information supplied (table 1). A code is used by the program to determine the procedure and needed information. the code is a 13 digit number with the first digit indicating the procedure and the rest of the digits coded according to table 1. The codes that produce the previous marking rule are:

digit position	1	2	3	4	5	6	7	8	9	10	11	12	13	
	1	0	0	9	9	0	0	0	0	0	0	0	0	size of trees to cut 0 to 99.
	5	0	0	9	9	1	5	0	0	0	0	0	0	species code for elm-15.
codes	2	0	0	9	9	1	1	1	4	1	6	0	0	code for black ash-11,
	4	0	0	9	9	1	1	1	4	1	6	0	0	red maple - 14, yellow birch - 16.

If a manager did not mark trees smaller than 5 inches the third digit in each code would be replaced by a 5. Up to five removal procedures can be combined to simulate a marking rule. Even though tree spacing or other tree characteristics cannot be used, these removal procedures can be combined to produce many marking rules.

USING THE MANAGEMENT SUBSYSTEM

This management subsystem exists as subroutines within STEMS (Hahn and Brand 1979)[2]. So far they have been used in estimating the treatment opportunities existing on a national forest and on areas in Wisconsin and Minnesota. Inventory plots taken for statewide surveys were used as initial conditions. The results were helpful in identifying which forest types needed treatment. In conjunction with the projection system, treatment needs were followed through time.

Table 1.— *Removal Procedures*

Procedure CODE	Procedure	Information needed for coding	Code	
			Digit position	Value
1	Remove rough and rotten trees in designated size class unitl required BA is achieved. (Tree quality codes are needed for this procedure.)	Size class to remove.	1 2-3 4-5 6-13	1 Lower diameter limit Upper diameter limit All zeros
2	Remove smallest trees of unspecified species until required BA is achieved.	Size class to remove, 4 species groups to leave.	1 2-3 4-5 6-7, 8-9 10-11, 12-13	2 Lower diameter limit Upper diameter limit 4 species group codes to leave
3	Remove largest trees of unspecified species until required BA is achieved.	Size class to remove, 4 species groups to leave.	1 2-13	3 Same as 2
4	Remove smallest trees of specified species until required BA is achieved.	Size class to remove, 4 species groups to remove.	1 2-3 4-5 6-7, 8-9 10-11, 12-13	4 Lower diameter limit Upper diameter limit 4 species group codes to remove
5	Remove largest trees of specified species until required BA is achieved.	Size class to remove, 4 species groups to remove.	1 2-13	5 Same as 4
6	Shelterwood cut leaving required BA (leave largest d.b.h, highest crown ratio trees).	Size class to remove, 4 species groups to favor.	1 2-3 4-5 6-7, 8-9 10-11, 12-13	6 Lower diameter limit Upper diameter limit 4 species group codes to favor
7	Reduce number of trees.	Number of trees to leave.	1 2-5 6-13	7 Number of trees/ac to leave All zeros
8	Remove all overtopping.	Lower d.b.h of trees to remove.	1 2-3 4-13	8 Lower d.b.h of trees to remove All zeros
9	Remove all trees of a certain size and species.	Size class to remove, 4 species groups to remove.	1 2-13	9 Same as 4

Major variations in the diagrams can be created by setting the critical values to extremely large or small quantities. However, if a decision is desired about a variable not in the diagram a new diagram must be programmed. This is a relatively simple task for someone with moderate programming skills, provided the decision diagram is known. A second concern is that there is no provision for constraints on management within a property. All stands are treated according to the prescription. A definite need is to incorporate area or volume control within the system.

In summary, a computerized procedure for prescribing tree cutting for Lake States' timber types has been developed based upon published management guides. This management system is flexible and provides a means to analyze and assess the effect that various treatments will have on the timber resource in a particular area. Although the computer subroutines were written to be included in STEMS, they could be readily incorporated into other systems as well. To make management prescriptions the stand characteristics mentioned in Appendix A and species basal areas must be known. If the presciptions are to be implemented then a tree list must be available or another method of carrying out the prescription must be developed.

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APPENDIX A

Management Diagrams

Plot or stand description	Diagram number
Jack pine	1
Red pine	2
White pine	3
Spruce-fir	4
Black spruce	5
Mixed swamp conifers[5]	6
Northern white-cedar[5]	7
Tamarack	5
Oak-hickory	8
Aspen	9
Paper birch	10
Northern hardwood	11
Lowland hardwood	12
Understocked	13

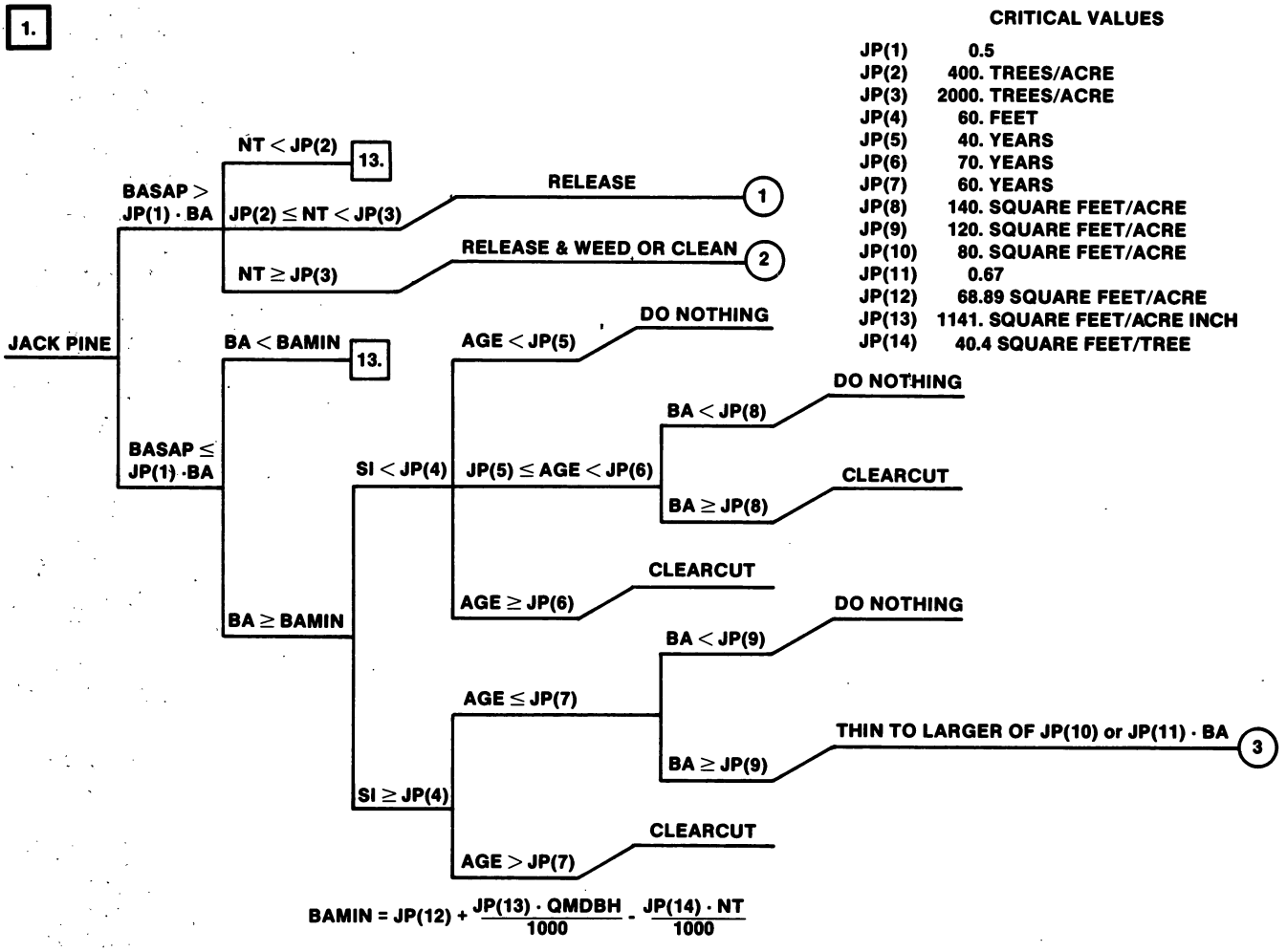
Diagram numbers appear within squares. If a diagram ends with a number within a square, continue to that diagram to determine the management prescription. Numbers which appear within circles indicate that particular trees must be marked. These marking rules are described in Appendix B.

Description of Symbols in Management Diagrams

Symbol	Units	Description
Age	years	Stand age.
BA	square feet/acre	Basal area of all live trees on the plot.
BAPOLE	square feet/acre	Basal area of all live trees with d.b.h. greater than or equal to 5 inches and less than 10 inches.
BASAP	square feet/acre	Basal area of all live trees with d.b.h. less than 5 inches
BASAW	square feet/acre	Basal area of all live trees with d.b.h. greater than or equal to 10 inches.
$\overline{DBH}$	inches	Arithmetic mean d.b.h. of live trees on the plot.
ICOMP	—	Species composition code.
NT	trees/acre	Number of live trees on plot.
QMDBH[6]	inches	D.b.h. of tree of average basal area.
SI	feet	Plot site index.
$<$		as in a<b— a is less than b
$\leqslant$		as in a$\leqslant$b— a is less than or equal to b
$>$		as in a>b— a is greater than b
$\geqslant$		as in a$\geqslant$b— a is greater than or equal to b

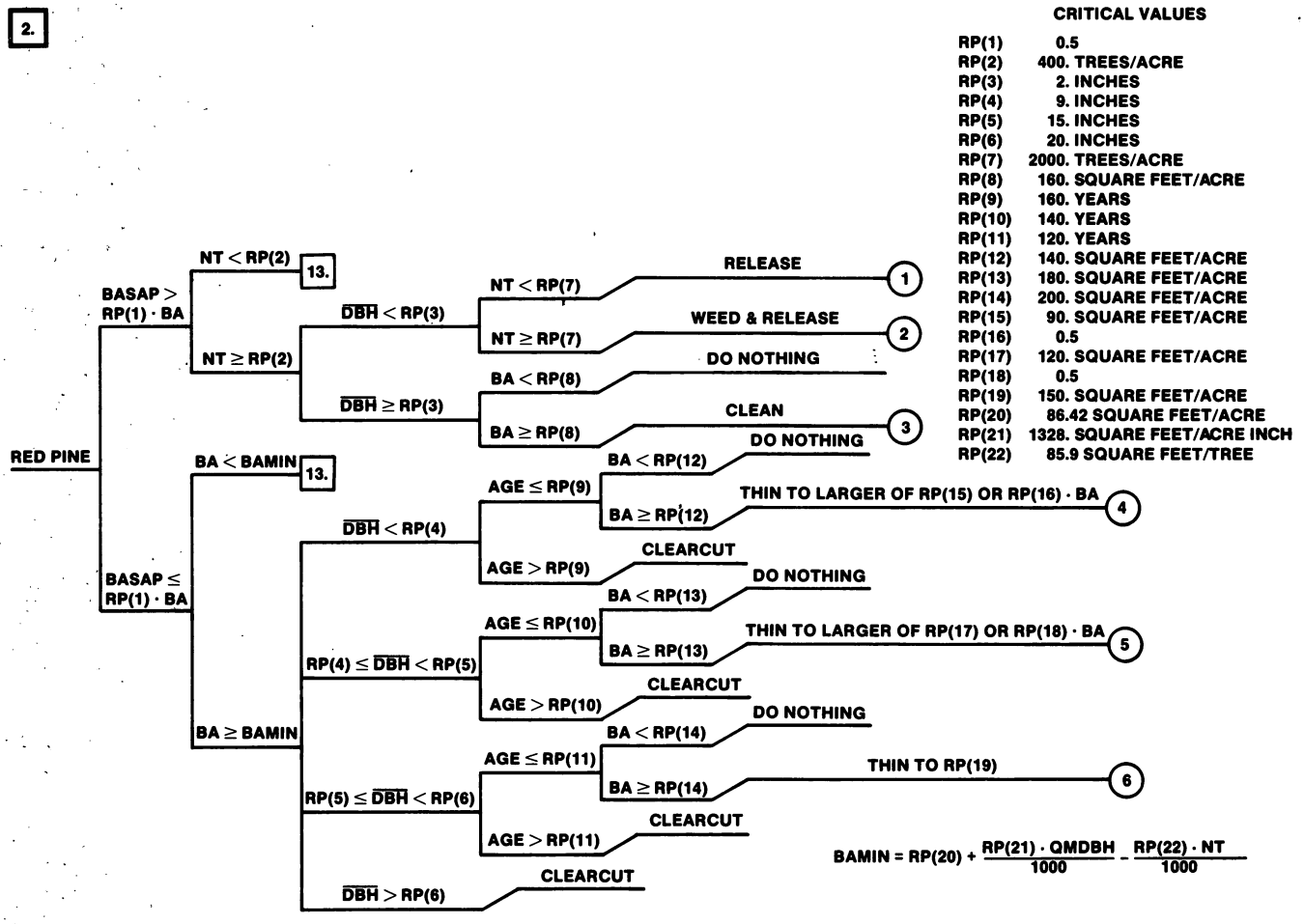
[5]*The final harvest is a three strip system. The first two strips are clearcut and on better sites the last strip is shelterwood cut. In STEMS, three plots of the same site class and at rotation age are needed to simulate the three strip system. The first plot is clearcut, the second is clearcut after a 10-year wait, and the third is clearcut or shelterwood cut after a 20-year wait.*

[6]$QMDBH = \sqrt{\frac{BA}{.005454 \times NT}}$



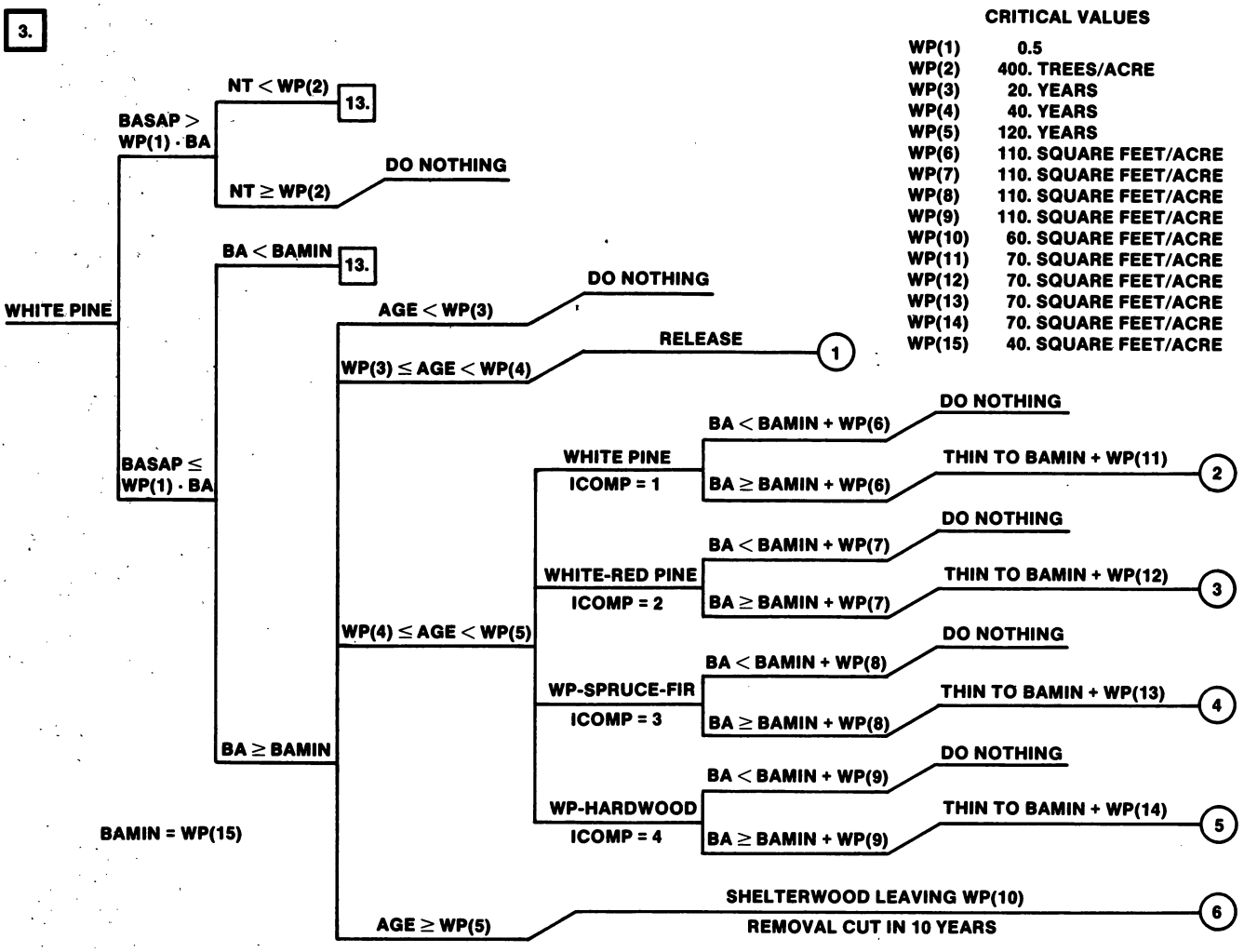
Jack Pine Objectives and Assumptions

1. Maintain jack pine.
2. Manage for timber, particularly large products if possible.
3. Trees are uniformly distributed in the even-aged stand.
4. There is a low risk of loss from damaging agents.
5. Conditions are appropriate for using the clearcut silvicultural system.



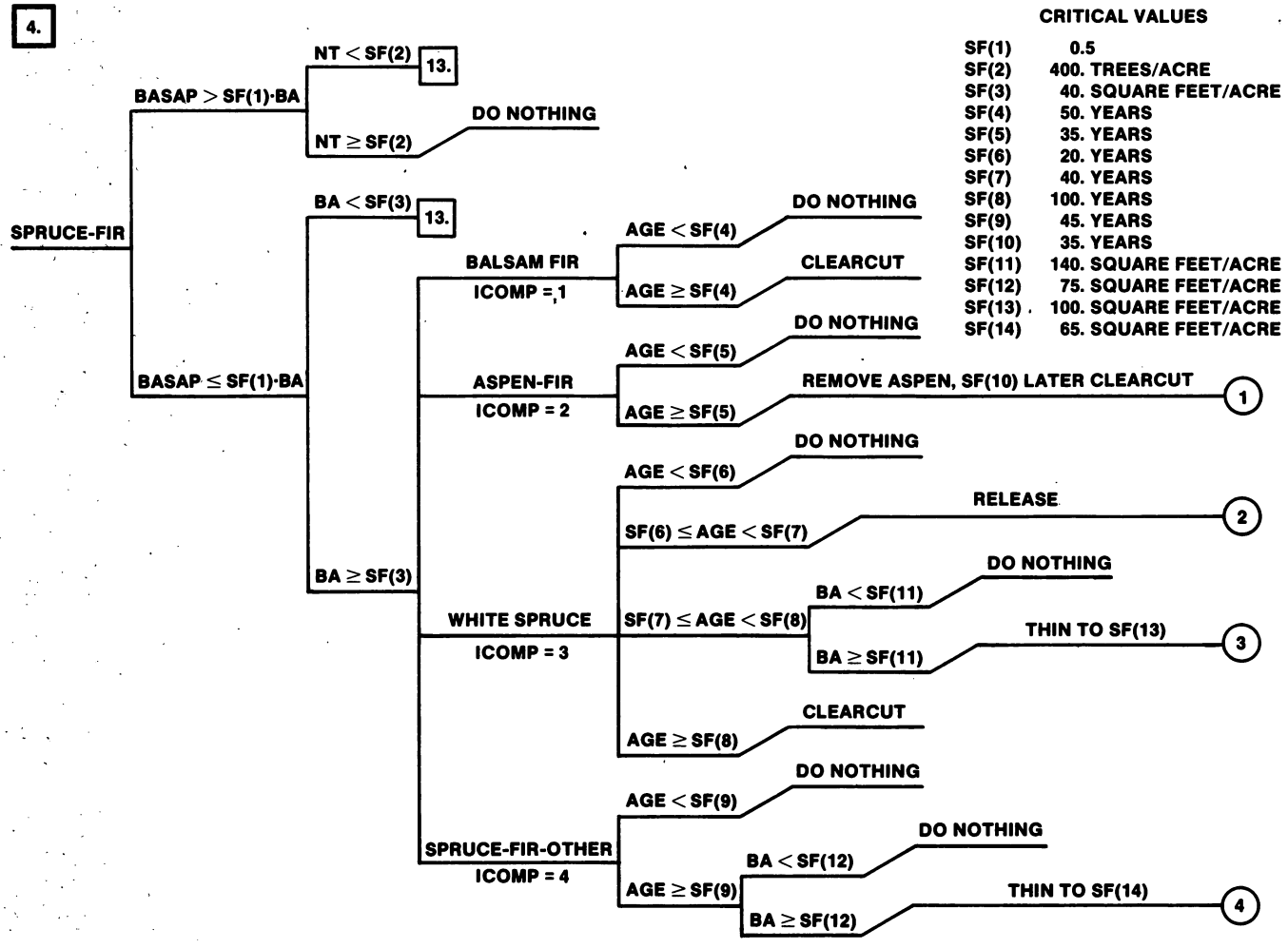
Red Pine Objectives and Assumptions

1. Maintain red pine.
2. Manage for timber, particularly large products if possible.
3. Trees are uniformly distributed in the even-aged stands.
4. There is a low risk of loss from damaging agents.
5. Conditions are appropriate for using the clearcut silvicultural system.



White Pine Objectives and Assumptions

1. Maintain white pine.
2. Manage for timber, particularly large products if possible.
3. Conditions are appropriate for using the shelterwood silvicultural system.
4. The stand is considered pure white pine if 80 percent of the basal area is in white pine. ICOMP = 1.
5. The stand is considered white-red pine if 70 percent of the basal area is in white and red pine. ICOMP = 2.
6. The stand is considered white pine-hardwood if 70 percent of the basal area is in white pine, basswood, sugar maple, white ash, and oak. ICOMP = 4.
7. The stand is considered white pine-spruce-fir if white spruce and balsam fir basal area is greater than hardwood or red pine basal area. ICOMP = 3.



Spruce-Fir Objectives and Assumptions

1. In stands which are predominantly balsam fir, manage for maximum fiber production and natural regeneration.
2. Manage white spruce for large products.
3. There is adequate advance regeneration of white spruce and balsam fir at the end of the rotation.
4. The stand is considered balsam fir if 80 percent of the basal area is in balsam fir. ICOMP = 1.
5. The stand is condsidered white spruce if 50 percent of the basal area is in white spruce. ICOMP = 3.
6. The stand is considered aspen-fir if 70 percent of the basal area is in aspen and balsam fir. ICOMP = 2.
7. Stands not meeting these criteria (4, 5, 6) are considered spruce-fir-other. ICOMP = 4.

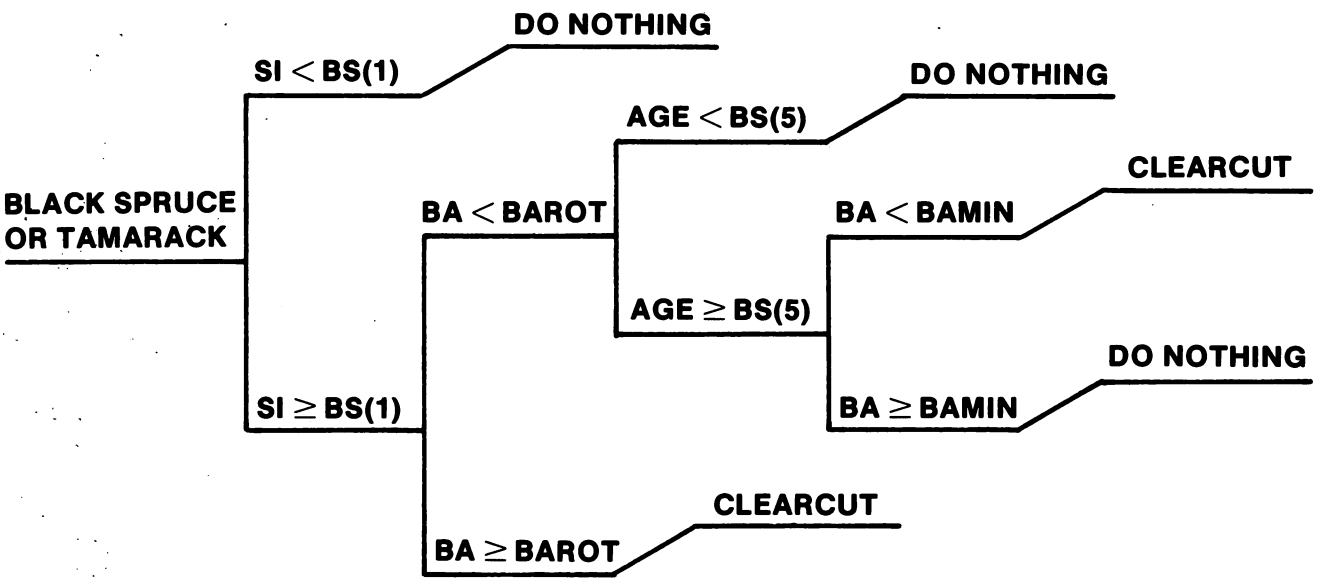
5.

$$BAROT = BS(2) - \frac{BS(3) \cdot AGE}{1000} + \frac{BS(4) \cdot AGE^2}{1000}$$

$$BAMIN = BS(6) + BS(7) \cdot AGE$$

CRITICAL VALUES

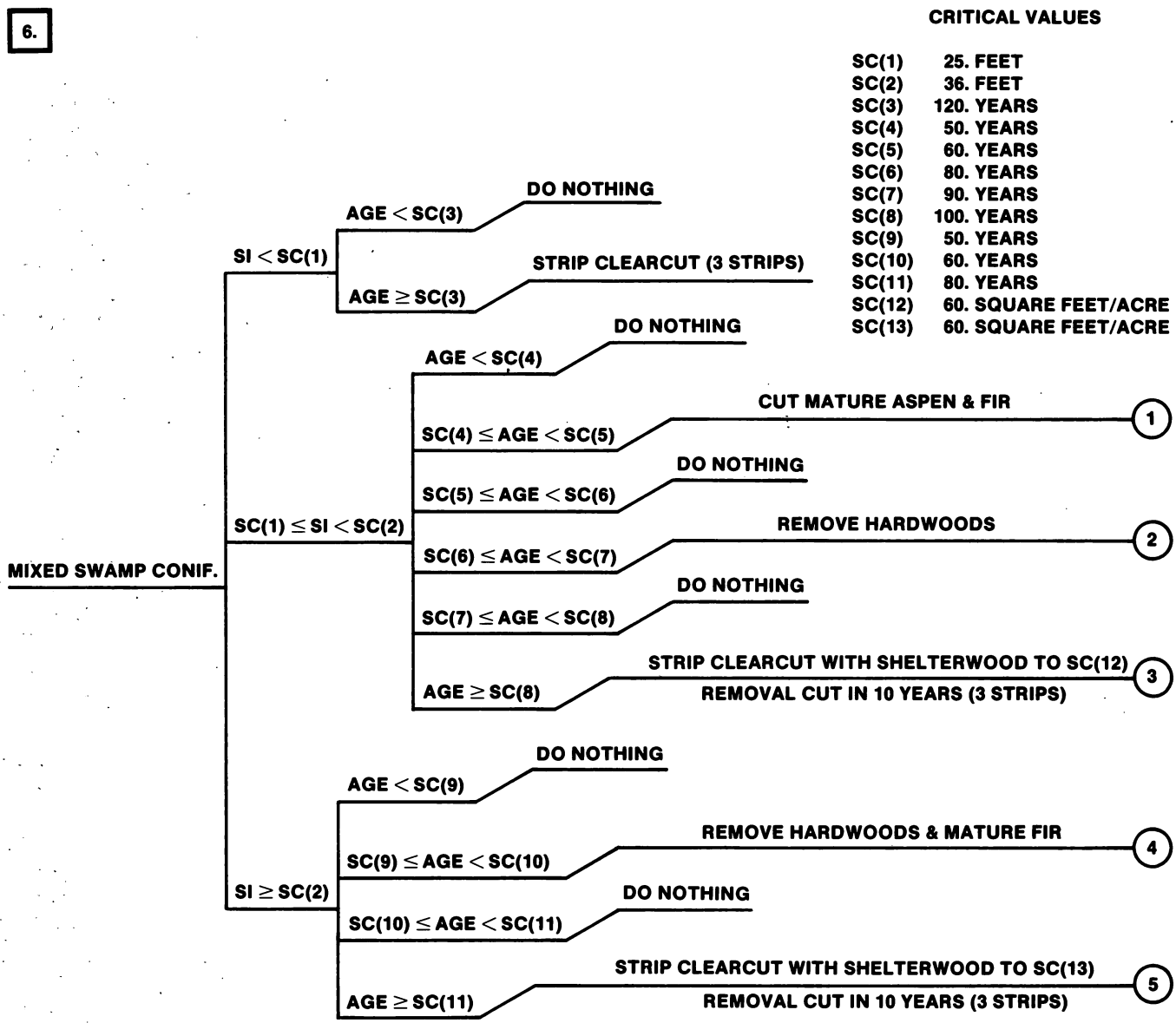
BS(1)	25. FEET
BS(2)	209. SQUARE FEET/ACRE
BS(3)	1837. SQUARE FEET/ACRE YEAR
BS(4)	10.6 SQUARE FEET/ACRE YEAR^2
BS(5)	80. YEARS
BS(6)	-175.4 SQUARE FEET/ACRE
BS(7)	2.583 SQUARE FEET/ACRE YEAR



Black Spruce (Tamarack) Objectives and Assumptions

1. Maintain black spruce.
2. Manage for pulpwood.
3. Stands occur on organic soil.
4. There is a low risk of loss from damaging agents.
5. Conditions are appropriate for using the clearcut silvicultural system.
6. Since very little is known about how to manage the tamarack type, black spruce management was selected as probably being the most reasonable regime to follow.

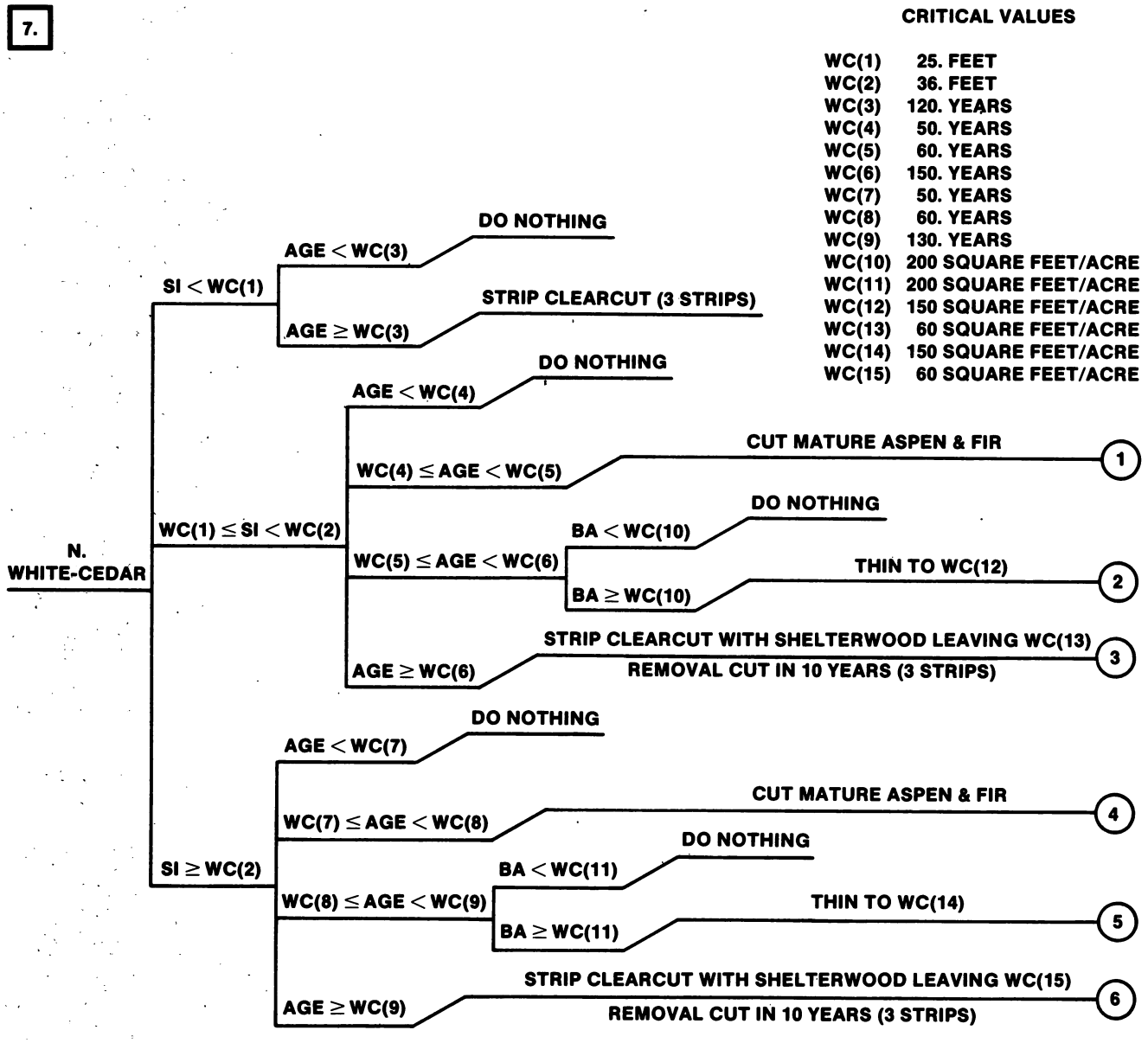
6.



Mixed Swamp Conifer Objective and Assumptions

1. Maintain swamp conifers.
2. Manage for maximum fiber yield.
3. There is low risk of loss from damaging agents.
4. Conditions are appropriate for using the strip clearcut-shelterwood silvicultural system.

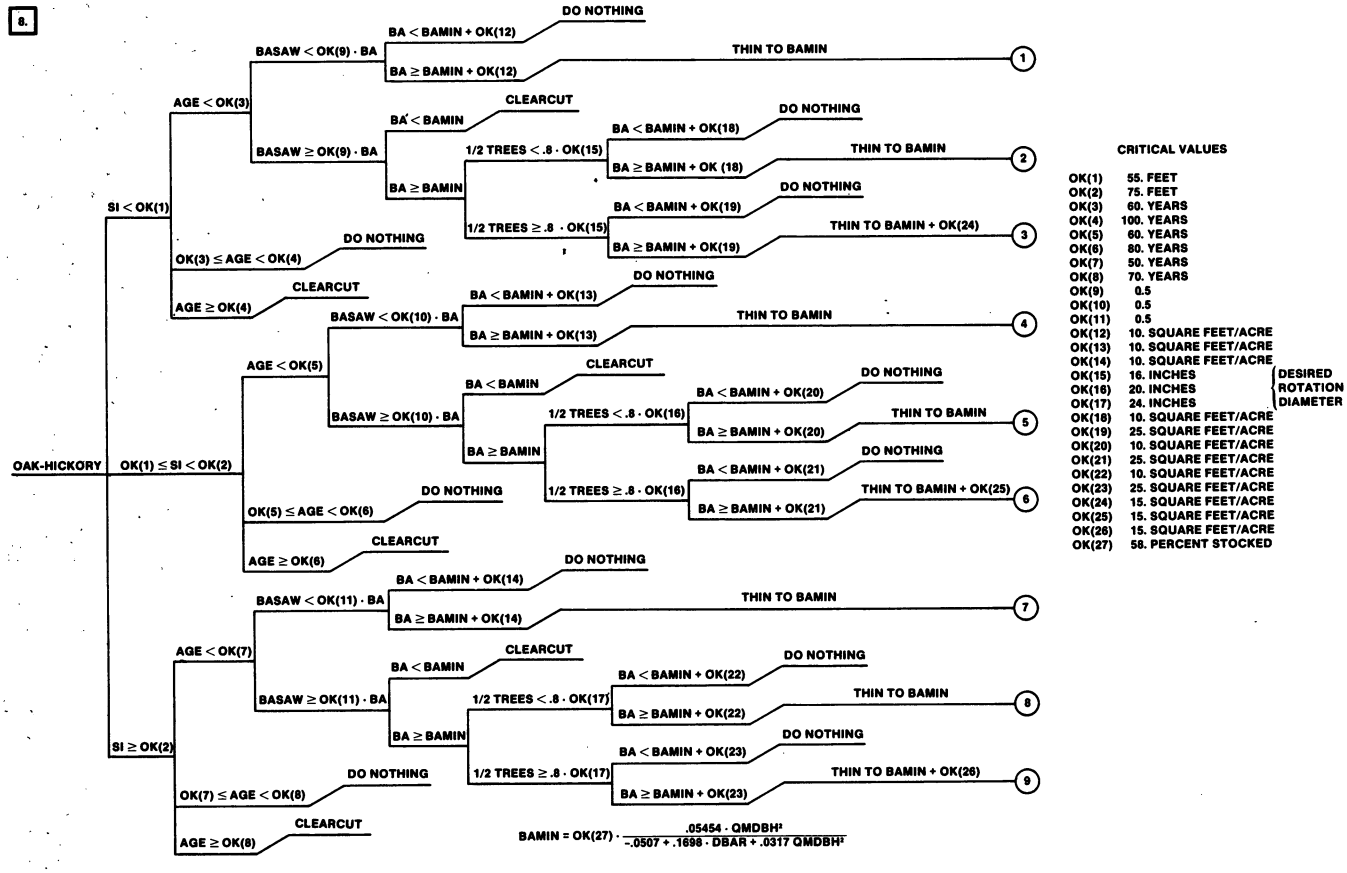
7.



Northern White-cedar Objectives and Assumptions

1. Maintain northern white-cedar.
2. Timber management and deeryard management are of equal importance.
3. Manage for large products since older stands also provide better shelter for deer.
4. Stand does not provide the only deer shelter in the area.
5. There is a low risk of loss from damaging agents.
6. Conditions are appropriate for using the strip clearcut-shelterwood silvicultural system.

8.

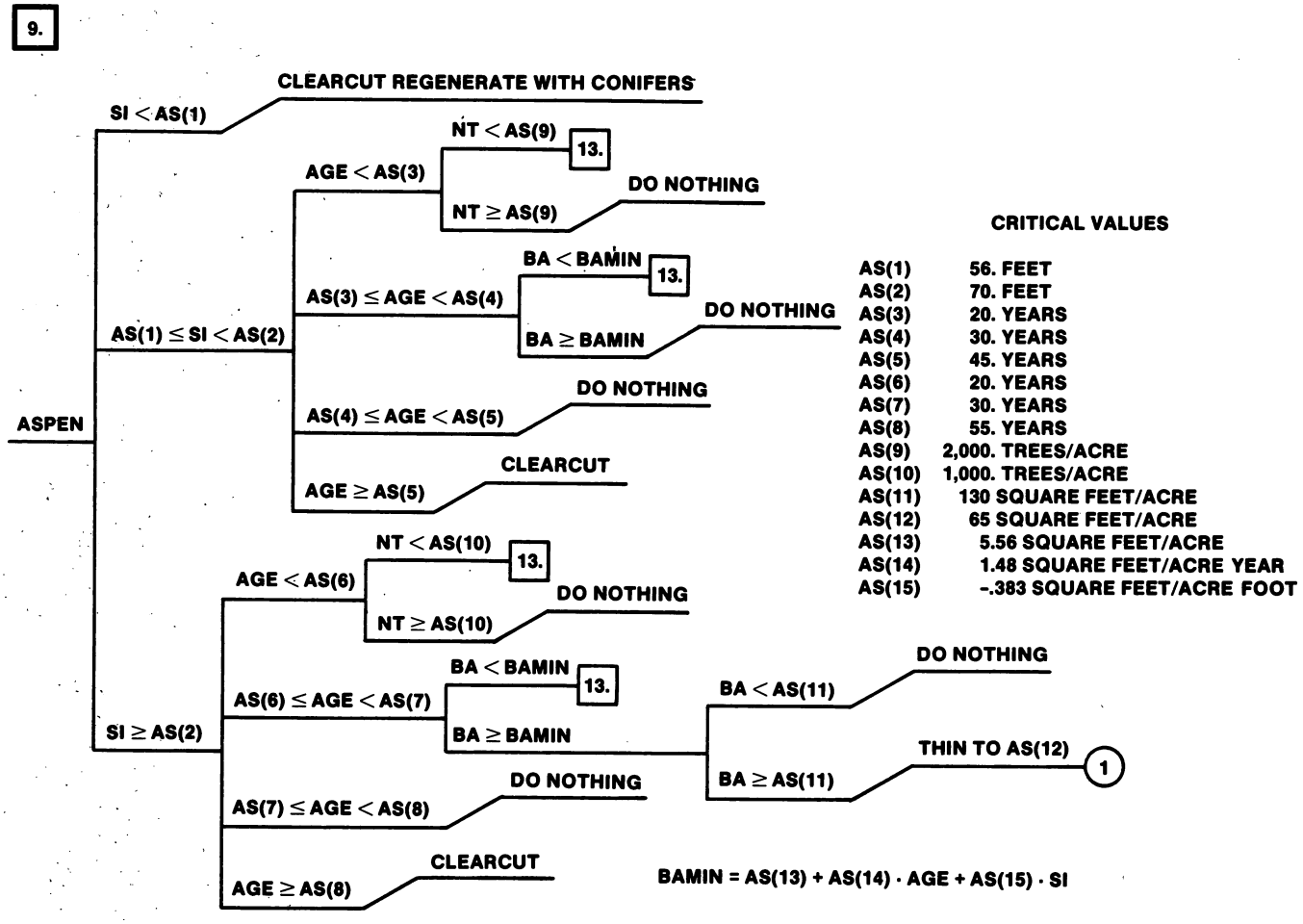


CRITICAL VALUES

OK(1)	55. FEET	
OK(2)	75. FEET	
OK(3)	60. YEARS	
OK(4)	100. YEARS	
OK(5)	60. YEARS	
OK(6)	80. YEARS	
OK(7)	50. YEARS	
OK(8)	70. YEARS	
OK(9)	0.5	
OK(10)	0.5	
OK(11)	0.5	
OK(12)	10. SQUARE FEET/ACRE	
OK(13)	10. SQUARE FEET/ACRE	
OK(14)	10. SQUARE FEET/ACRE	
OK(15)	16. INCHES	DESIRED ROTATION DIAMETER
OK(16)	20. INCHES	
OK(17)	24. INCHES	
OK(18)	10. SQUARE FEET/ACRE	
OK(19)	25. SQUARE FEET/ACRE	
OK(20)	10. SQUARE FEET/ACRE	
OK(21)	25. SQUARE FEET/ACRE	
OK(22)	10. SQUARE FEET/ACRE	
OK(23)	25. SQUARE FEET/ACRE	
OK(24)	15. SQUARE FEET/ACRE	
OK(25)	15. SQUARE FEET/ACRE	
OK(26)	15. SQUARE FEET/ACRE	
OK(27)	58. PERCENT STOCKED	

Oak-Hickory Objectives and Assumptions

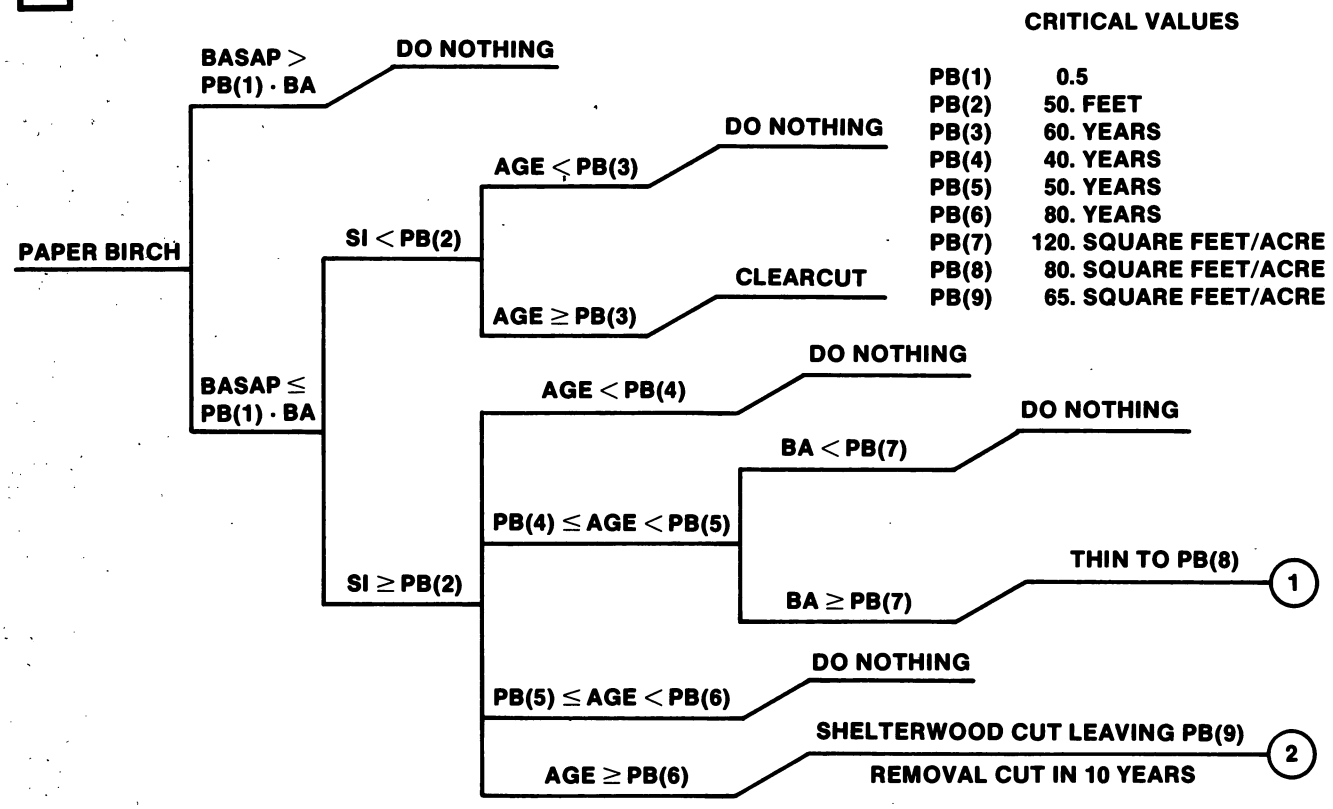
1. Favor pines where the oak site index is low. Favor northern hardwoods where the oak site index is high. Otherwise, maintain oaks.
2. Manage for timber, particularly large products if possible.
3. The minimum acceptable stand basal area is dependent on the size of the trees present. That is, it is a measure of stocking. The percent of full stocking considered acceptable can be changed by altering the value of OK(27).
4. Advanced regeneration must be present before clearcutting.



Aspen Objectives and Assumptions

1. Maintain aspen on better sites.
2. Manage for timber, particularly large products if possible.
3. Understocked stands are not capable of producing 1,000 cubic feet per acre at age 40.

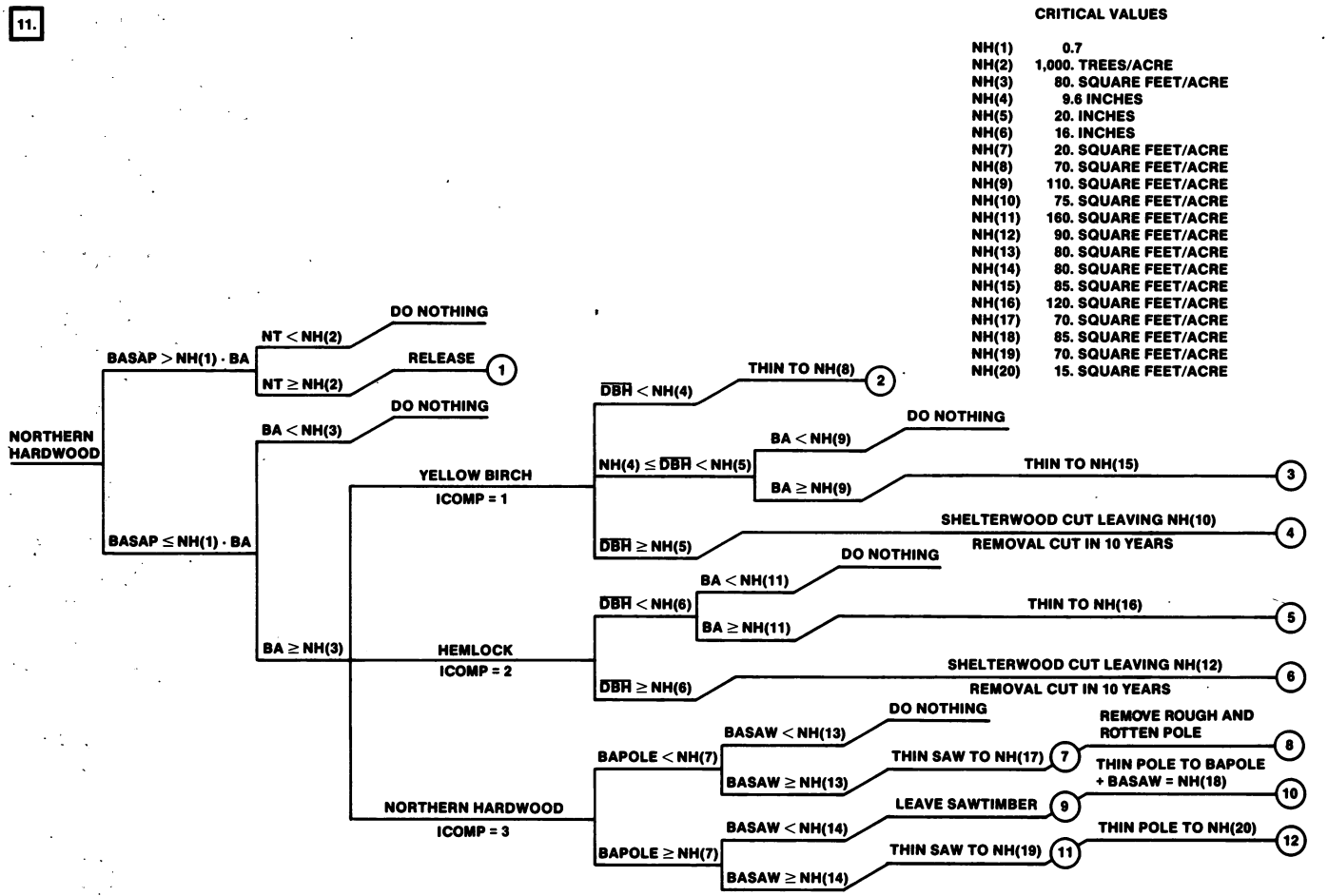
10.



Paper Birch Objectives and Assumptions

1. Maintain paper birch on better sites, convert to conifers on other sites.
2. Manage for timber, particularly large products if possible.
3. Conditions are appropriate for using the shelterwood silvicultural system on better sites. The assumption is made that the removal cut will also include scarification.

11.



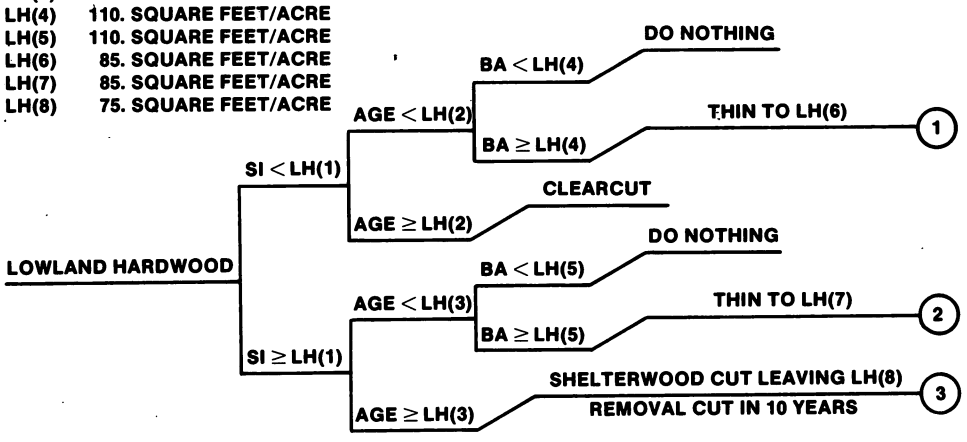
Northern Hardwood Objectives and Assumptions

1. Maintain or develop all-aged northern hardwood stands.
2. Manage for timber, particularly large products if possible.
3. Maintain stands that are primarily yellow birch or hemlock through the use of the shelterwood silvicultural system.
4. If yellow birch basal area is more than 25 percent of the northern hardwood basal area the stand is considered primarily yellow birch. ICOMP = 1.
5. If hemlock basal area is more than 50 percent of the northern hardwood basal area the stand is considered primarily hemlock. ICOMP = 2.
6. If conditions 4 or 5 are not met the stand is considered northern hardwoods. ICOMP = 3.

12.

CRITICAL VALUES

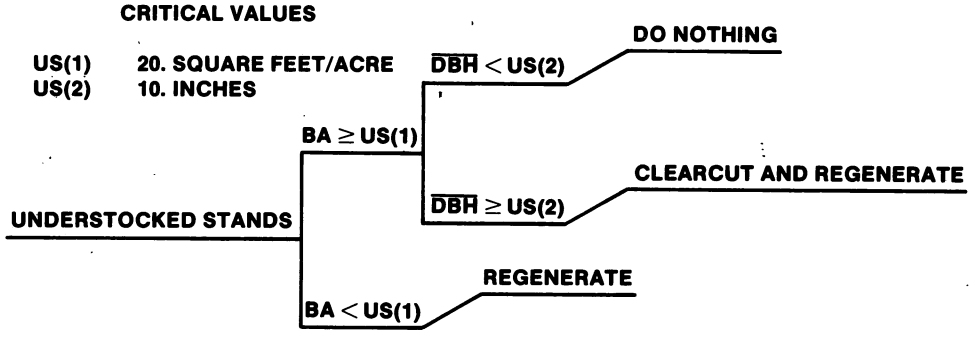
LH(1)	55. FEET
LH(2)	90. YEARS
LH(3)	90. YEARS
LH(4)	110. SQUARE FEET/ACRE
LH(5)	110. SQUARE FEET/ACRE
LH(6)	85. SQUARE FEET/ACRE
LH(7)	85. SQUARE FEET/ACRE
LH(8)	75. SQUARE FEET/ACRE



Lowland Hardwood Objectives and Assumptions

1. Manage for timber.
2. Advanced regeneration must be present before the overstory is removed. Very little is known about how to manage lowland hardwoods.

13.



Understocked Stand Objectives and Assumptions

1. Stands with a basal area less than 20 square feet are open enough so that they can be regenerated without removing the overstory.
2. Stands with a basal area greater than 20 square feet will be operable if the average diameter is greater than 10 inches.

APPENDIX B

Marking rules in this section are preceded by a number that designates the final position in the management diagrams. These numbers appear within circles in the management diagrams. Removal procedures follow a verbal description of the marking rule.

Jack Pine

1. Remove overtopping trees.
   Procedure: 1. Remove trees over 10 inches d.b.h.
2. Remove overtopping trees and leave 1,000 trees/acre.
   Procedure: 1. Remove trees over 10 inches d.b.h.
   2. Remove trees until there are only 1,000 trees/acre.
3. Remove rough and rotten trees and thin from below favoring pines and white spruce until BA is less than the larger of JP(10) or JP(11) × BA.
   Procedure: 1. Remove rough and rotten trees.
   2. Remove small d.b.h., non-jack pine, red pine, white pine, white spruce.
   3. Remove small d.b.h., jack pine, red pine, white pine, white spruce.

Red Pine

1. Remove undesirable species (red pine, jack pine, white pine, and white spruce are desirable) and overtopping trees.
   Procedure: 1. Remove non-red pine, jack pine, white pine, white spruce.
   2. Remove trees over 12 inches d.b.h.
2. Remove undesirable species and overtopping trees and reduce the number of trees to 1,000 trees/acre.
   Procedure: 1. Remove non-red pine, jack pine, white pine, white spruce.
   2. Remove trees over 12 inches d.b.h.
   3. Remove trees until there are only 1,000 trees/acre.
3. Reduce the number of trees to 1,000 trees/acre.
   Procedure: 1. Remove trees until there are only 1,000 trees/acre.
4. Remove rough and rotten trees and thin from below favoring red pine until BA is less than the larger of RP(15) or RP(16) × BA.
   Procedure: 1. Remove rough and rotten trees.
   2. Remove small d.b.h., non-red pine.
   3. Remove small d.b.h., red pine.
5. Remove rough and rotten trees and thin from below favoring red pine until BA is less than the larger of RP(17) or RP(18) × BA.
   Procedure: 1. Remove rough and rotten trees.
   2. Remove small d.b.h., non-red pine.
   3. Remove small d.b.h., red pine.
6. Remove rough and rotten trees and thin from below favoring red pine until BA is less than RP(19).
   Procedure: 1. Remove rough and rotten trees.
   2. Remove small d.b.h., non-red pine.
   3. Remove small d.b.h., red pine.

White Pine

1. Remove overtopping trees and undesirable species (white pine, red pine, and white spruce are desirable).
   Procedure: 1. Remove non-white pine, red pine, white spruce.
   2. Remove trees over 12 inches d.b.h.
2. Remove mature aspen and jack pine, rough and rotten trees, and thin from below favoring white and red pine and white spruce until BA is less than BAMIN + WP(11).
   Procedure: 1. Remove jack pine and aspen over 6 inches d.b.h.
   2. Remove rough and rotten trees.
   3. Remove small d.b.h., non-white pine, red pine, white spruce.
   4. Remove small d.b.h., white pine, red pine, white spruce.
3. Remove mature aspen and jack pine, rough and rotten trees, and thin from below favoring white and red pine and white spruce until BA is less than BAMIN + WP(12).
   Procedure: 1. Remove jack pine and aspen over 6 inches d.b.h.

2. Remove rough and rotten trees.
3. Remove small d.b.h., non-white pine, red pine, white spruce.
4. Remove small d.b.h., white pine, red pine, white spruce.

4. Remove mature balsam fir, rough and rotten trees, and thin from below favoring white and red pine and white spruce until BA is less than BAMIN + WP(13).
   Procedure: 1. Remove balsam fir over 5 inches d.b.h.
   2. Remove rough and rotten trees.
   3. Remove small d.b.h., non-white pine, red pine, white spruce.
   4. Remove small d.b.h., white pine, red pine, white spruce.
5. Remove mature aspen and jack pine, rough and rotten trees, and thin from below favoring white and red pine and white spruce until BA is less than BAMIN + WP(14).
   Procedure: 1. Remove jack pine and aspen over 6 inches d.b.h.
   2. Remove rough and rotten trees.
   3. Remove small d.b.h., non-white pine, red pine, white spruce.
   4. Remove small d.b.h., white pine, red pine, white spruce.
6. Make a shelterwood cut leaving WP(10) square feet/acre in seed cutting (favor white pine) with a removal cut 10 years later.
   Procedure: 1. Remove rough and rotten trees.
   2. Leave largest d.b.h., highest crown ratio white pine.

Spruce-fir

1. Remove aspen and leave the balsam fir to grow for another SF(10) years, then clearcut.
   Procedure: 1. Remove aspen.
   2. SF(10) years later clearcut (should contain another stand of aspen).
2. Remove overtopping trees and non-white spruce.
   Procedure: 1. Remove non-white spruce.
   2. Remove trees over 12 inches d.b.h.
3. Remove rough and rotten trees and thin favoring white spruce until BA is less than SF(13). Thin from above in non-white spruce and from below in white spruce.
   Procedure: 1. Remove rough and rotten trees.
   2. Remove large d.b.h., non-white spruce.
   3. Remove small d.b.h., white spruce.
4. Remove rough and rotten trees and thin favoring white spruce until BA is less than SF(14). Thin from above in non-white spruce and from below in white spruce.
   Procedure: 1. Remove rough and rotten trees.
   2. Remove large d.b.h., non-white spruce.
   3. Remove small d.b.h., white spruce.

Mixed Swamp Conifer

1. Remove mature aspen and balsam fir.
   Procedure: 1. Remove aspen over 6 inches d.b.h.
   2. Remove balsam fir over 5 inches d.b.h.
2. Remove hardwoods.
   Procedure: 1. Remove elm, aspen, paper birch.
   2. Remove black ash, red maple, yellow birch.
3. Make a shelterwood cut leaving SC(12) square feet/acre in seed cutting (favor northern white-cedar, black spruce, white spruce, and tamarack) with a removal cut 10 years later. (Done for the third strip only.)
   Procedure: 1. Remove rough and rotten trees.
   2. Leave largest d.b.h., highest crown ratio northern white-cedar, black spruce, white spruce, tamarack.
4. Remove hardwoods and mature balsam fir.
   Procedure: 1. Remove balsam fir over 5 inches d.b.h.
   2. Remove elm, aspen, paper birch.
   3. Remove black ash, red maple, yellow birch.
5. Make a shelterwood cut leaving SC(13) square feet/acre in seed cutting (favor northern white-cedar, black spruce, white spruce, and tamarack) with a removal cut 10 years later. (Done for the third strip only.)
   Procedure: 1. Remove rough and rotten trees.
   2. Leave largest d.b.h., highest crown ratio northern white-cedar, black spruce, white spruce, tamarack.

Northern White-cedar

1. Remove mature aspen and balsam fir.
   Procedure: 1. Remove aspen larger than 6 inches d.b.h.

2. Remove balsam fir larger than 5 inches d.b.h.

2. Remove rough and rotten trees and thin from below favoring white spruce, black spruce, and northern white-cedar until BA is less than WC(12).
   Procedure: 1. Remove rough and rotten trees.
   2. Remove small d.b.h., non-white spruce, black spruce, northern white-cedar.
   3. Remove small d.b.h., white spruce, black spruce, northern white-cedar.
3. Make a shelterwood cut leaving WC(13) square feet/acre in seed cutting (favor white spruce, black spruce, and northern white-cedar) with a removal cut 10 years later. (Done for the third strip only.)
   Procedure: 1. Remove rough and rotten trees.
   2. Leave largest d.b.h., highest crown ratio white spruce, black spruce, northern white-cedar.
4. Remove mature aspen and balsam fir.
   Procedure: 1. Remove aspen larger than 6 inches d.b.h.
   2. Remove balsam fir larger than 5 inches d.b.h.
5. Remove rough and rotten trees and thin from below favoring white spruce, black spruce, and northern white-cedar until BA is less than WC(14).
   Procedure: 1. Remove rough and rotten trees.
   2. Remove small d.b.h., non-white spruce, black spruce, northern white-cedar.
   3. Remove small d.b.h., white spruce, black spruce, northern white-cedar.
6. Make a shelterwood cut leaving WC(15) square feet/acre in seed cutting (favor white spruce, black spruce, and northern white-cedar) with a removal cut 10 years later. (Done for the third strip only.)
   Procedure: 1. Remove rough and rotten trees.
   2. Leave largest d.b.h., highest crown ratio white spruce, black spruce, northern white-cedar.

Oak-hickory

1. Remove rough and rotten trees and thin from below favoring pines until BA is less than BAMIN.
   Procedure: 1. Remove rough and rotten trees.
   2. Remove small d.b.h., non-jack pine, red pine, white pine.
   3. Remove small d.b.h., jack pine, red pine, white pine.
2. Remove rough and rotten trees and thin from below favoring pines until BA is less than BAMIN.
   Procedure: 1. Remove rough and rotten trees.
   2. Remove small d.b.h., non-jack pine, red pine, white pine.
   3. Remove small d.b.h., jack pine, red pine, white pine.
3. Remove rough and rotten trees and thin from below favoring pines until BA is less than BAMIN + OK(24).
   Procedure: 1. Remove rough and rotten trees.
   2. Remove small d.b.h., non-jack pine, red pine, white pine.
   3. Remove small d.b.h., jack pine, red pine, white pine.
4. Remove rough and rotten trees and thin from below favoring oaks and hickories until BA is less than BAMIN.
   Procedure: 1. Remove rough and rotten trees.
   2. Remove small d.b.h., non-oaks and hickories.
   3. Remove small d.b.h., oaks and hickories.
5. Remove rough and rotten trees and thin from below favoring oaks and hickories until BA is less than BAMIN.
   Procedure: 1. Remove rough and rotten trees.
   2. Remove small d.b.h., non-oaks and hickories.
   3. Remove small d.b.h., oaks and hickories.
6. Remove rough and rotten trees and thin from below favoring oaks and hickories until BA is less than BAMIN + OK(25).
   Procedure: 1. Remove rough and rotten trees.
   2. Remove small d.b.h., non-oaks and hickories.
   3. Remove small d.b.h., oaks and hickories.
7. Remove rough and rotten trees and thin from below favoring sugar maple, basswood, and white ash until BA is less than BAMIN.
   Procedure: 1. Remove rough and rotten trees.

2. Remove small d.b.h., non-sugar maple, basswood, white ash.
3. Remove small d.b.h., sugar maple, basswood, white ash.

8. Remove rough and rotten trees and thin from below favoring sugar maple, basswood, and white ash until BA is less than BAMIN.
   Procedure: 1. Remove rough and rotten trees.
   2. Remove small d.b.h., non-sugar maple, basswood, white ash.
   3. Remove small d.b.h., sugar maple, basswood, white ash.
9. Remove rough and rotten trees and thin from below favoring sugar maple, basswood, and white ash until BA is less than BAMIN + OK(26).
   Procedure: 1. Remove rough and rotten trees.
   2. Remove small d.b.h., non-sugar maple, basswood, white ash.
   3. Remove small d.b.h., sugar maple, basswood, white ash.

Aspen

1. Remove rough and rotten trees and thin favoring aspen until BA is less than AS(12). Thin from above in non-aspen and from below in aspen.
   Procedure: 1. Remove rough and rotten trees.
   2. Remove large d.b.h., non-aspen.
   3. Remove small d.b.h., aspen.

Paper Birch

1. Remove rough and rotten trees and thin from below favoring paper birch and aspen until BA is less than PB(8).
   Procedure: 1. Remove rough and rotten trees.
   2. Remove small d.b.h., non-paper birch, aspen.
   3. Remove small d.b.h., paper birch, aspen.
2. Make a shelterwood cut leaving PB(9) square feet/acre in seed cutting (favor paper birch) with a removal cut 10 years later.
   Procedure: 1. Remove rough and rotten trees.
   2. Leave largest d.b.h., highest crown ratio paper birch.

Northern Hardwood

1. Remove overtopping trees.
   Procedure: 1. Remove trees over 8 inches d.b.h.
2. Remove rough and rotten trees and thin from below discriminating against elm sawtimber and sugar maple and favoring yellow birch, basswood, white ash, and northern red oak until BA is less than NH(8).
   Procedure: 1. Remove rough and rotten trees.
   2. Remove elms over 10 inches d.b.h.
   3. Remove large d.b.h., sugar maple.
   4. Remove small d.b.h., non-yellow birch, basswood, white ash, northern red oak.
   5. Remove small d.b.h., yellow birch, basswood, white ash, northern red oak.
3. Remove rough and rotten trees and thin from below discriminating against elm sawtimber and sugar maple and favoring yellow birch, basswood, white ash, and northern red oak until BA is less than NH(15).
   Procedure: 1. Remove rough and rotten trees.
   2. Remove elms over 10 inches d.b.h.
   3. Remove large d.b.h., sugar maple.
   4. Remove small d.b.h., non-yellow birch, basswood, white ash, northern red oak.
   5. Remove small d.b.h., yellow birch, basswood, white ash, northern red oak.
4. Make a shelterwood cut leaving NH(10) square feet/acre in seed cutting (favor yellow birch, basswood, white ash, and northern red oak) with a removal cut 10 years later.
   Procedure: 1. Remove rough and rotten trees.
   2. Leave largest d.b.h., highest crown ratio, yellow birch, basswood, white ash, northern red oak.
5. Remove rough and rotten trees and thin from below discriminating against elm sawtimber and favoring hemlock and yellow birch until BA is less than NH(16).
   Procedure: 1. Remove rough and rotten trees.
   2. Remove elms over 10 inches d.b.h.
   3. Remove small d.b.h., non-hemlock, yellow birch.
   4. Remove small d.b.h., hemlock, yellow birch.
6. Make a shelterwood cut leaving NH(12) square feet/acre in seed cutting (favor hemlock and yellow birch) with a removal cut 10 years later.
   Procedure: 1. Remove rough and rotten trees.
   2. Leave largest d.b.h., highest crown ratio, hemlock, yellow birch.

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7. & 8. Remove rough and rotten sawtimber, thin favoring immature yellow birch, sugar maple, and basswood until sawtimber BA is less than NH(17), and remove all rough and rotten poles.

   Procedure:
   1. Remove rough and rotten sawtimber.
   2. Remove non-yellow birch, sugar maple, basswood over 18 inches d.b.h.
   3. Remove yellow birch, sugar maple, basswood over 22 inches d.b.h.
   4. Remove non-yellow birch, sugar maple, basswood sawtimber.
   5. Remove yellow birch, sugar maple, basswood sawtimber.

   1. Remove rough and rotten poletimber.

9. & 10. Leave sawtimber, remove rough and rotten poletimber, and thin poletimber favoring yellow birch, sugar maple, and basswood until poletimber and sawtimber BA is less than NH(18).

   Procedure:
   1. Do nothing to the sawtimber.

   1. Remove rough and rotten poletimber.
   2. Remove non-yellow birch, sugar maple, basswood poletimber.
   3. Remove yellow birch, sugar maple, basswood poletimber.

11. & 12. Remove rough and rotten sawtimber and poletimber, thin sawtimber favoring immature yellow birch, sugar maple, and basswood until sawtimber BA is less than NH(19), and thin poletimber favoring yellow birch, sugar maple, and basswood until poletimber BA is less than NH(20).

    Procedure:
    1. Remove rough and rotten sawtimber.
    2. Remove non-yellow birch, sugar maple, basswood over 18 inches d.b.h.
    3. Remove yellow birch, sugar maple, basswood over 22 inches d.b.h.
    4. Remove non-yellow birch, sugar maple, basswood sawtimber.
    5. Remove yellow birch, sugar maple, basswood sawtimber.

    1. Remove rough and rotten poletimber.
    2. Remove non-yellow birch, sugar maple, basswood poletimber.
    3. Remove yellow birch, sugar maple, basswood poletimber.

Lowland Hardwood

1. Remove rough and rotten trees, remove elms, and thin from below favoring black ash, yellow birch, and red maple until BA is less than LH(6).

   Procedure:
   1. Remove rough and rotten trees.
   2. Remove large d.b.h., elms.
   3. Remove small d.b.h., non-black ash, yellow birch, red maple.
   4. Remove small d.b.h., black ash, yellow birch, red maple.

2. Remove rough and rotten trees, remove elms, and thin from below favoring black ash, yellow birch, and red maple until BA is less than LH(7).

   Procedure:
   1. Remove rough and rotten trees.
   2. Remove large d.b.h., elms.
   3. Remove small d.b.h., non-black ash, yellow birch, red maple.
   4. Remove small d.b.h., black ash, yellow birch, red maple.

3. Make a shelterwood cut leaving LH(8) square feet/acre in seed cutting (favor black ash, yellow birch, and red maple; discriminate against elm) with a removal cut 10 years later.

   Procedure:
   1. Remove rough and rotten trees.
   2. Remove large d.b.h., elms.
   3. Leave largest d.b.h., highest crown ratio, black ash, yellow birch, red maple.

Brand, Gary J.

1981. Simulating timber management in Lake States forests. U.S. Department of Agriculture Forest Service, General Technical Report NC-69, 25 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, MN.

Describes in detail a management subsystem to simulate cutting in Lake States forest types. This subsystem is part of a Stand and Tree Evaluation and Modeling System (STEMS) contained in the Forest Resource Evaluation Program (FREP) for the Lake States. The management subsystem can be used to test the effect of alternate management strategies.

KEY WORDS: silviculture guide, computer model, growth model.