Development of a Model for Simulation of Forest Regulation Techniques

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Introduction

"The organization and control of the growing stock for a sustained yield of forest products from a specific forest area has traditionally been called forest regulation." (Meyer, Recknagel, Stevenson, and Bartoo, 1962).

The primary regulation tool available to the manager is the timing and size of timber cuts. Management of many forest properties has been under the constraint of sustained yield. Sustained yield management is defined by the Society of American Foresters (1958) as:

"Management of a forest property for continuous production with the aim of achieving, at the earliest practicable time, an approximate balance between net growth and harvest, either by annual or somewhat longer periods."

Sustained yield, thus, is concerned both with a continuity of growth and of yield or harvest. In a much wider sense, it means continuity of all goods and services from the forests.

There are a number of arguments for acceptance of the sustained principle. Many reasons are essentially external to the forest itself, and are based on economic, social, and administrative factors:

- —Yearly cut of approximate equal volume, size, quality, and value of timber implies a **stable business planning base** and workload continuity.
- —Current growth (harvested) and income not larger than necessary; maximum return on invested capital.
- —Balance between yearly expenditures and receipts (liquidity).
- —Maximum degree of safety from fire, insects, and diseases.

Several critical questions complicate the determination of sustained yield:

- —Sustained yield can be maintained at different levels depending on rotation length, current and expected utilization standards, current and expected technologies, and investment levels in timber management programs.
- —How should the conversion to sustained yield from currently unregulated conditions be accomplished? Should economic consideration enter the decision on length of conversion period and the size of the cut? Should larger cuts be allowed during the conversion period or should even-flow constraints be imposed?

The concept of sustained yield was developed in the early 19th century in Germany during a time when, generally, the forests of the country were in poor condition, and guidelines for their management were missing. During this period, the model of a normal forest was developed. The normal forest was an idealized model of a fully regulated forest and was advocated as the condition towards which all forest properties should be managed.

Normal Forest Model

The essential requirement of the normal forest model is that age and size classes be represented in such proportion and be growing consistently at such rates that an approximately equal annual or periodic yield of products of desired size and quality may be obtained.

The forest should be normal in terms of:

- —Growth.
- —Rotation.
- —Age-class distribution (equal areas).
- —Growing stock.
- —Cut (to provide sustained yield).

Other assumptions are:

- —Equal site quality.
- —Equal stocking with only one species.
- —No intermediate yields.

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Figures 1a and 1b illustrate a normal forest.

From this model the following relationships can be developed:

G_i = growing stock of age-class i, i = 1,2,...R

where

R = rotation or age of oldest age-class

Y_i = growth of age-class i

$\sum_{i=1}^{R} G_i$ = total growing stock of forest

$$= \frac{R}{2} G_R$$

$\sum_{i=1}^{R} Y_i$ = total annual growth

$$= G_R$$

Annual cut;

$$G_R = \sum_{i=1}^{R} Y_i$$

$$= \frac{2\sum^{R} G_i}{R} \text{ and}$$

$R(G_R) = 2\sum_{i=1}^{R} G_i$, i.e., cut during one rotation is twice the normal growing stock.

These relationships should be well understood before continuing. The cut regulation techniques to be discussed will be related back to this ideal situation.

Determination of the Cut

The determination of the cut is probably the most important decision a forest manager makes. The cut has far-reaching consequences for the total forest enterprise, both its biological and economic components. However, the existence of multiple objectives implies that there is no exact solution.

The accuracy needed in the determination of the cut varies with the timber supply and demand situation. The allowable cut is typically calculated for a specific period, utilizing the most current inventory information, and is revised periodically. Allowable cut is composed of both final and intermediate cuts.

Major considerations concerning the cut are:

- —Total volume that should be cut.
- —Cutting sequence of stands.
- —Species, size, and quality.
- —Spatial arrangement of cuts.

The answer to these questions will depend on:

- —Objectives of management.

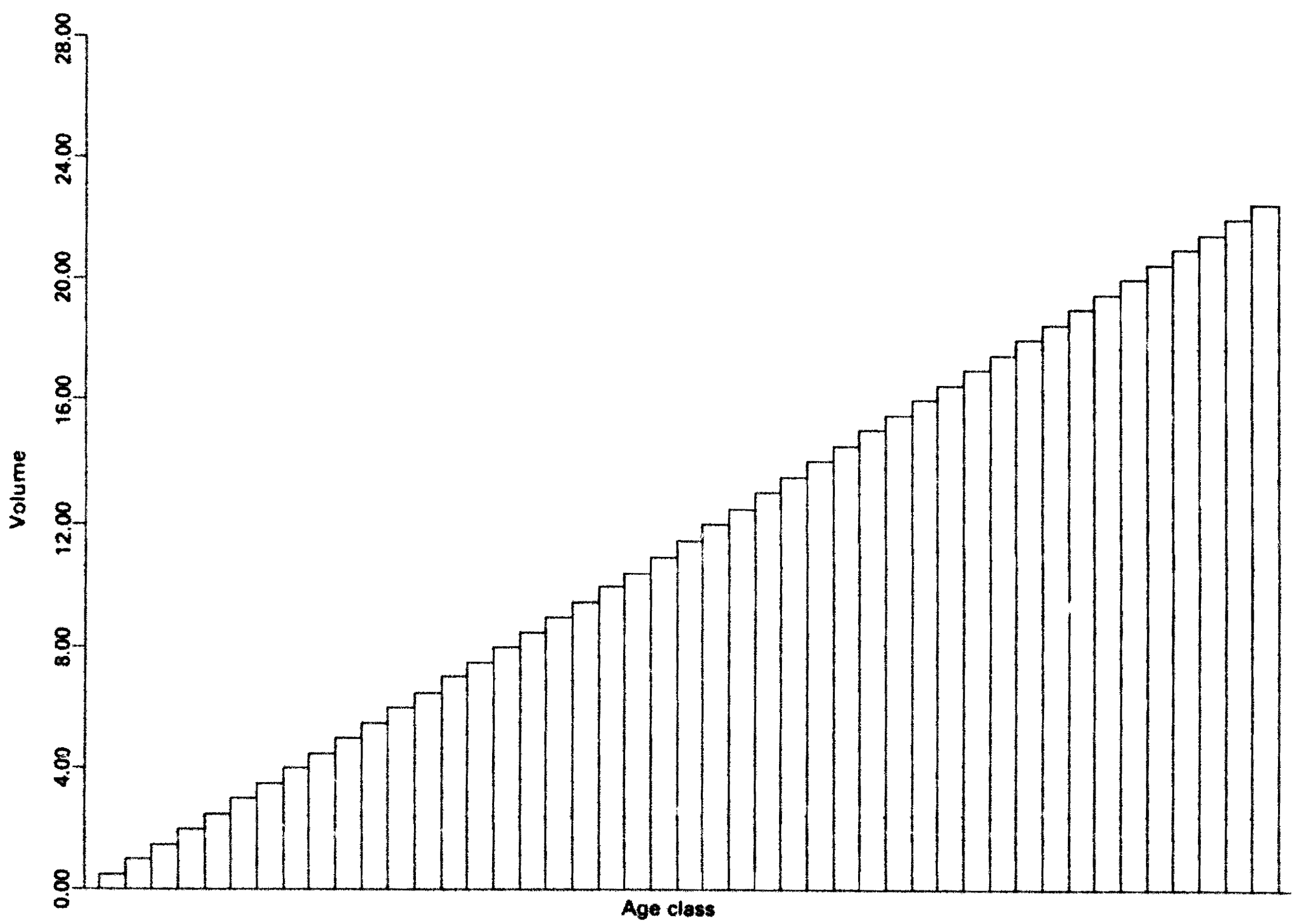


Figure 1a. Normal growing stock distribution.

—Markets.
—Silvicultural needs.
—Logging problems.
—Degree of harvest continuity desired.

The one feature of forests that we should not forget is that the crop seldom requires immediate removal and that storage is possible. Managers can take advantage of this.

There are many different approaches to the determination of the cut. All are based on the common regulatory principle that, if the actual volume of the forest is equal to the desired volume and distribution, then the actual yield on a sustained yield basis may be equivalent to the actual growth (Recknagel, Stevenson, and Bartoo, 1962). If the actual volume is below the desired level, the cut is kept below growth to provide for the accumulation of additional growing stock. Obviously, the reverse is true when the reserve is larger than desired.

Several general approaches to cut determination exist:

1. Area control.
2. Volume control.
3. Combined area and volume control.
4. Modern operations research techniques.

It should be emphasized that timber regulation problems are solved more and more by using operations research techniques such as linear programming and simulation. An example of the first is Timber RAM (Resources Allocation Model) developed by the U.S. Forest Service (Navon, 1971). An example of the second is ECHO (Economic Harvest Optimization), a model developed by Walker (1971). These models often are more difficult to use because they require knowledge of operations research methods by forest managers and access to a computer. Such techniques also typically require more inventory information than the first three approaches.

It is important, therefore, to be familiar with some of the simpler cut determination models which can provide useful solutions if properly applied and interpreted. If not properly applied, these models can lead to less than desirable conditions of growing stock and growth. It is the intent of this paper to introduce these models (1 to 3 above) and to provide illustrative examples. These examples will serve to highlight advantages and disadvantages of various methods, and point to some of the major factors that should be considered in their selection. A com-

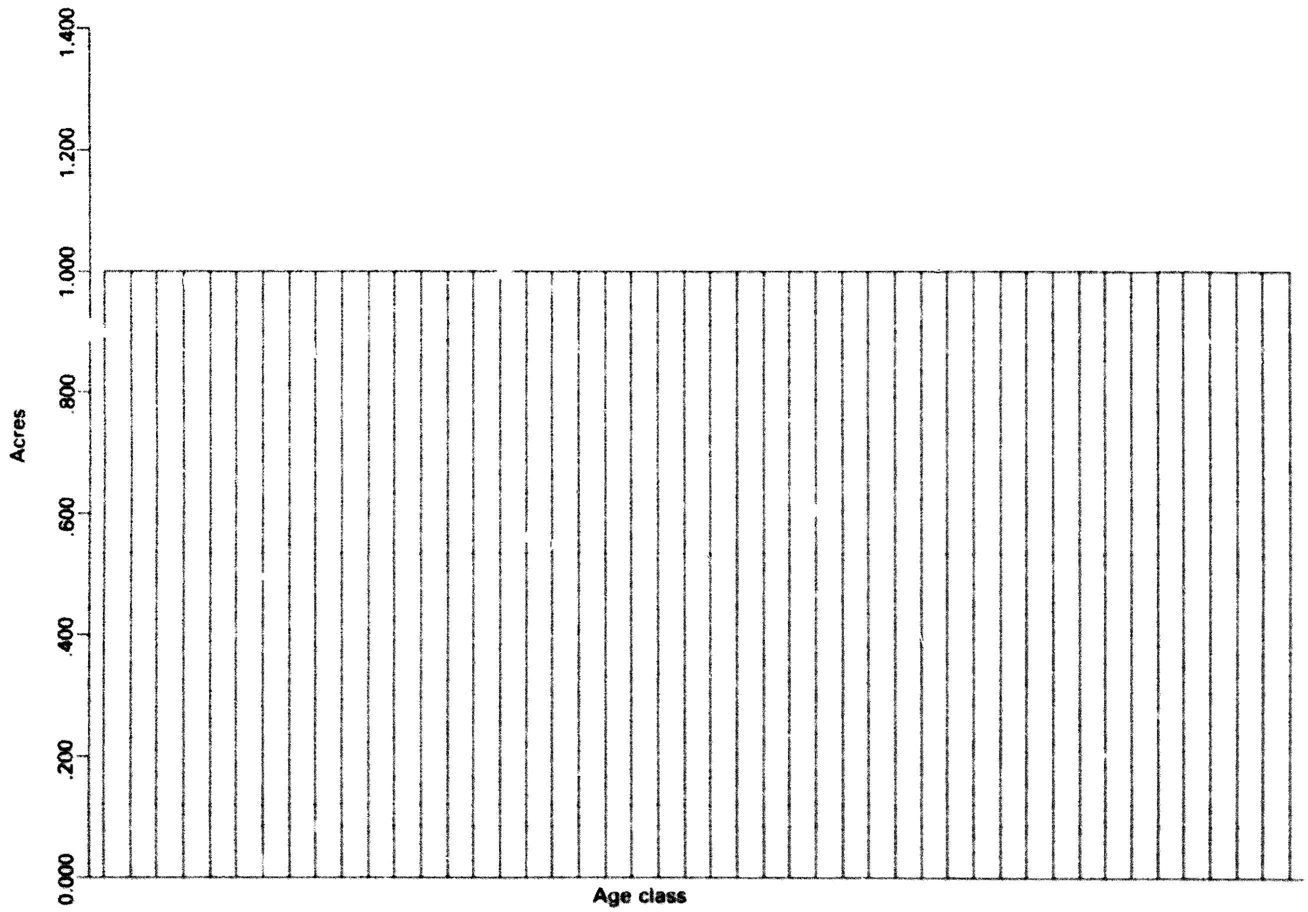


Figure 1b. Normal forest acreage distribution.

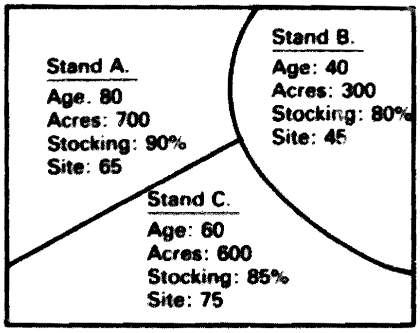
puter model will be introduced to facilitate speedy calculations and examination of various strategies and initial conditions.

Area Control

The principle of area control is very simple. This method determines the allowable cut in terms of volume on the basis of acres assigned for cutting. Specifically the area cut per year equals the total acres divided by rotation. Since volume must occupy area and area available directly determines volume, cutting in this manner is quite logical.

As an example consider the following situation. A 1,600 acre tract of forest has been inventoried. It was found that the entire area is well stocked with red pine. Three distinct, even-aged compartments (stands) are present. The manager decides that the area would be best utilized if it were regulated at the earliest possible time. Projected market conditions are such that any cutting schedule used during rotation one will not alter the supply-demand relationship. Area control techniques seem to be appropriate in this situation. A rotation age of 80 years will be assumed. Experience shows that a stocking level (in relation to normal yield table values) of 90 percent can be maintained once the forest is regulated.

The information obtained from the inventory is shown in the following diagram. The necessary step-by-step calculations follow using the yield table (Table 1).



I. Acres per age class under regulation assuming equal site productivity = acres/rotation age = 1,600/80 = 20 acres.

The procedure must be modified when different sites and stocking levels are present to adjust for differences in productivity. The aim is to get areas of equal productivity rather than equal surface area. The question that must be answered is: how much acreage should be cut annually to insure uniform volume production after rotation one?

II.

Stand	Yield per acre at 80 years
A.	6,280 ft^3
B.	3,199 ft^3
C.	8,165 ft^3

III. Average productivity weighted by acres:
= [6,280 (700) + 3,199 (300) + 8,165 (600)]/1,600
= 6,409 ft^3.

IV. Areas of equal productivity (acres cut per year):
A. (6,409/6,280) × 20 = 20.4 acres.
B. (6,409/3,199) × 20 = 40.1 acres.
C. (6,409/8,165) × 20 = 15.7 acres.

V. Cutting time per stand:
A. 700/20.4 = 34.3 years
B. 300/40.1 = 7.5 years
C. 600/15.7 = 38.2 years
80.0 years

The order in which the stands will be cut must now be known. For simplicity we will assume that stands will be cut from oldest to youngest, i.e. A, C, B.

VI. Average age at harvest:
A. 80 + 34.3/2 = 97 years.
C. 60 + 34.3 + 38.2/2 = 113 years.
B. 40 + 34.3 + 38.2 + 7.5/2 = 116 years.

VII. Volume harvested (per year) in rotation one:[1]
A. 7,187 × 20.4 × 0.90 = 131.95 M ft^3.
C. 10,222 × 15.7 × 0.85 = 136.4[illegible] M ft^3.
B. 4,062 × 4[illegible].1 × 0.80 = 130.31 M ft^3.

VIII. Volume harvested (per year) in future rotations:
A. 6,280 × 20.4 × 0.90 = 115.30 M ft^3.
C. 8,165 × 15.7 × 0.90 = 115.37 M ft^3.
B. 3,199 × 40.1 × 0.90 = 115.45 M ft^3.

There are a number of advantages and disadvantages the forest manager should be aware of when considering area control. Davis (1966) lists the following:

—The volume cut is the average volume per unit of area multiplied by the area cut.

[1]Yield per acre at average harvest age times IV (area of equal productivity) times stocking percent.

Table 1. Yield per acre (ft^3) by age and site index of fully-stocked, even-aged red pine stands in Minnesota.[1]

Stand age	Site index 45	55	65	75
30	888	1,283	1,743	2,266
40	1,483	2,142	2,910	3,784
50	2,017	2,914	3,959	5,147
60	2,476	3,577	4,860	6,319
70	2,866	4,142	5,627	7,316
80	3,199	4,623	6,280	8,165
90	3,485	5,035	6,841	8,894
100	3,731	5,392	7,325	9,523
110	3,946	5,702	7,746	10,071
120	4,134	5,974	8,116	10,552
130	4,301	6,214	8,442	10,976
140	4,449	6,428	8,732	11,353
150	4,581	6,619	8,992	11,691

[1]Values found from the equation: Yield = 6.4088 S[illegible] e[illegible]
where: S = site index
A = age

Base data are from Table 10, Eyre, F. H. and P. Zehngraff. 1948. "Red Pine Management in Minnesota." USDA Cir. No. 778, 70 pp. Yield is total cubic feet per acre excluding bark of trees 5 inches dbh and larger, to a top diameter of 4 inches inside bark.

—Area control applied to an irregular forest and strictly followed yields irregular cuts in volume, size, and quality of timber.

—After one rotation, the forest will be completely regulated.

—An approximately uniform annual cut in rotation one cannot be obtained from an irregular forest by strict area control.

—The procedure is simple and direct.

—Areas to be cut are identified with areas on the ground (good for silvicultural considerations).

—It is particularly suited to forests composed of even-aged stands.

—If the forest is largely mature, the method may cause great losses from holding stands too long.

—Volumes (unit of production) are not explicitly considered.

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Volume Control

In volume control the cut is determined by the conditions of the existing growing stock and often the growth of the growing stock. It should be noted that:

—Most volume control methods provide an approximate estimate which is applied for a short period of time and then re-evaluated.

—Many of the methods are equally applicable to uneven-aged and even-aged stands (in fact all those not dependent on yield tables).

—In all cases a cut figure in terms of volume is determined and as many acres as necessary are cut.

A brief synopsis of the various formulas follows. For more detailed information, see Chapter 6 of Davis (1966) or Chapter 4 of Meyer, et *al.* (1961).

VON MANTEL'S AND HUNDESHAGEN'S

—Both are very simple to apply.

—Neither consider whether present growing stock is desireable.

—They **should** only be applied in well-regulated stands.

—Von Mantel's assumes linear increase in growing stock with age.

1. Von Mantel Formula

a) Von Mantel formula is applicable if age class distribution is approximately normal.

b) Irregularity can exist in density of stocking.

c) This formula will give satisfactory results if the above conditions exist.

d) Best results are obtained if cubic measure is used.

Y_a = actual yield or allowable cut =

$$\frac{\text{actual growing stock volume}}{R/2}$$

R = rotation age

G_a = actual volume of growing stock

$$Y_a = \frac{G_a}{R/2} \text{ or } \frac{2G_a}{R\text{-}a}$$

where a = adjustment period

2. Hundeshagen Formula

a) Needs same condition as Von Mantel formula—normal age class distribution.

b) In adddition requires yield table for its application.

c) The formula is essentially a scheme for estimating growth from a yield table.

d) Hundeshagen's formula assumes that **growth** or **yield** in an actual forest, approximately regular in distribution, bears the same relation to its total growing stock as growth in a fully stocked regulated forest, as represented by normal yield tables, bears to its growing stock.

Expressed as a proportion:

$$\frac{Y_a}{G_a} = \frac{Y_R}{G_R}$$

Y_a = actual yield.
G_a = actual growing stock.
Y_R = growth or yield in a fully stocked forest.
G_R = growing stock in a fully stocked forest.

Consideration of the growth of the growing stock is incorporated in a number of volume regulation models. Generally, these models are superior to the ones which ignore growth. It should be understood, however, that the determination of the growth is one of the most difficult measurements in forestry practice. A discussion of the measurement of growth can be found in Chapter 4 of Davis (1966) and Chapter 16 of Husch, Miller and Beers (1972).

Examples of allowable cut formulas which modify increment with growing stock information are.

3. Austrian

$$AC = I + \frac{G_a - G_R}{a}$$

I = current annual increment
a = number of years in adjustment period.

—Reduce or increase the cut to build up or reduce average growing stock level.

—Better than Von Mantel and Hundeshagen in irregular conditions (age).

—Best when growing stock consists of even-aged second growth stands.

—Assume balanced stocking.

4. Chapman's

$$AC = I_e + \frac{G_a - G_R}{R}$$

I_e = MAI at rotation age and average density of stocking. G_a, G_R, and R as before.

5. The "Modified" Barnes Method and Tabular Check

Barnes (1951) described a new method of volume regulation that was based on the calculation of allowable cut in such a manner that the total inventory would be cut once over one rotation. Since annual allowable cut is closely related to average age at harvest, it follows that if an estimate can be made of average cutting age during rotation one, the actual yield obtainable at that age should furnish a good estimate of allowable cut (Barnes, 1951).

To calculate allowable cut, the following steps are required:

1) Compute average weighted (by acres) age of growing stock over all stands (AG).
2) Determine average cutting age.
   - If a forest has a "normal" distribution of age classes then average age of growing stock is R/2.
   - As an approximation to actual average cutting age we use: RA = AG + R/2.
3) Compute average weighted (by acres) stocking over all stands.
4) AC = (normal volume/acre at RA for average SI) $\times$ stocking $\times \frac{A}{R}$.

We will call this allowable cut the "modified" Barnes estimate. (Barnes describes a slightly more cumbersome estimate.) In the procedure recommended by Barnes, this allowable cut "guess" becomes the starting point of an iterative process designed to refine the "guess" and derive a better estimate of allowable cut. With this estimate the sum of the individual cutting times of all stands in the inventory equals rotation age. This iterative process to be described next is known as the Tabular Check or Barnes Method.

It involves:

a) The estimation of a "true" cutting time for each stand given an initial trial harvest level.
b) The summation of the individual cutting times of each stand for the given harvest level.
c) An adjustment if the trial harvest level yields a sum of cutting times unequal to rotation.

We will outline these steps in the following:

Estimation of "true" cutting time for a stand:

1) Set trial-cut level (from modified Barnes).
2) Calculate initial estimate of cutting time for stand.

$$= \frac{\text{yield at current stand age}}{\text{trial cut}} = NY_1$$

3) Calculate average age at harvest

$$= \text{current age} + \frac{NY_i}{2}$$

$$= AC_i$$

where: i = 1, 2, 3,...indicates the step reached in the iteration.

4) Calculate yield at average harvest age AG_i.
5) Recalculate years to cut from stand

$$= \frac{\text{yield at age } AG_i}{\text{trial cut}} = NY_{i+1}.$$

6) If (AG_i − AG_{i+1} ≤0.01) start at step 1 for next stand where 0.01 is an arbitrary stopping level which defines accuracy of the cutting time. Use a starting age for next stand: stand age + NY_{i+1}.
7) Otherwise go back to step 3.

A graphical illustration of this procedure is shown in Figure 2. We, therefore, approach a "true" cutting time by using increasingly accurate estimates of volume at average harvest age. With a large number of stands iteration gets out of hand, suggesting a computer solution.

Excurs: Interpolation in the yield table, e.g.,

	SI 90
Age	**Volume/acre**
60	14,180 bd ft
65	14,885 bd ft

To determine volume at age 62.98 for site index 65, use straight-line interpolation or substitute age into yield function:

$$V_{62.98} = V_{60} + \frac{(\text{actual age} - 60)}{(70\text{-}60)} (V_{70} - V_{60})$$

$$= 4{,}860 + \frac{62.98 - 60}{10} (5{,}627 - 4{,}860)$$

$$= 5{,}088 \text{ ft}^3$$

or

$$V_{62.98} = 6.4088\, S^{1.8342} e^{-61.534\, A}$$

$$= 5{,}101 \text{ ft}^3 \text{ using } S = 65, \quad A = 62.98$$

Once this procedure has been carried out for each stand using the initial trial level for allowable cut, an estimate is obtained of the sum of cutting times over all stands. If the sum of cutting times is not equal to the rotation, a new level for the allowable cut is set and a new cutting time iteration, stand by stand, is started with the new cutting level. Obviously, if the sum of cutting times is greater than rotation age, our next guess should be larger than the initial and correspondingly smaller if the sum of cutting times is less than rotation age.

This iteration is continued until the difference between the sum of cutting times over all stands and rotation age is negligible. To find a cutting level which will ultimately make this difference equal or close to zero, an efficient iteration technique such as **Newton-Raphson** or **interval halfing** should be used (Figures 3,4).

Volume Control (Illustration)

- Same data as area control example.
- Need to calculate:
  a) Actual growing stock volume G_a.

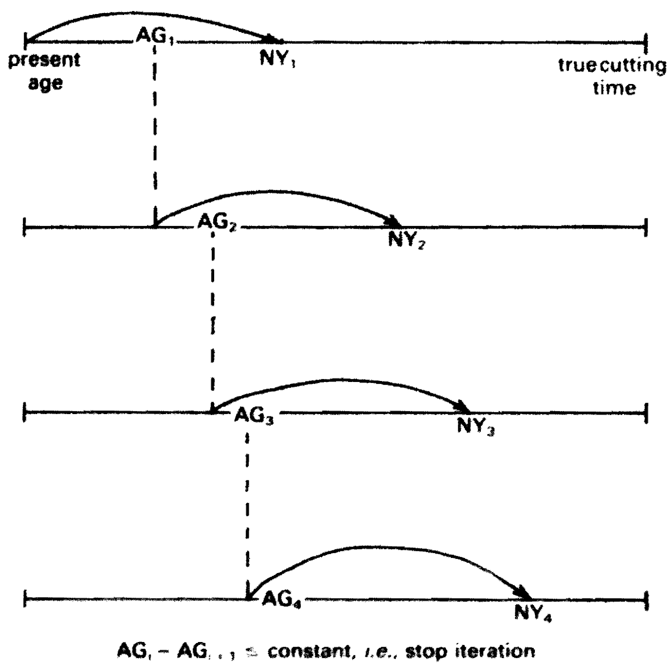

Figure 2. Cutting time iteration.

b) Regulated growing stock volume G_R.

c) Yield for regulated growing stock condition Y_R.

d) Current annual increment (CAI).

e) Mean annual increment at rotation age (MAI_R).

f) Average age of current growing stock weighted by acres A_W.

g) Average stocking level at present weighted by acres S_W.

h) Average weighted site index SI_W (weighted by acres).

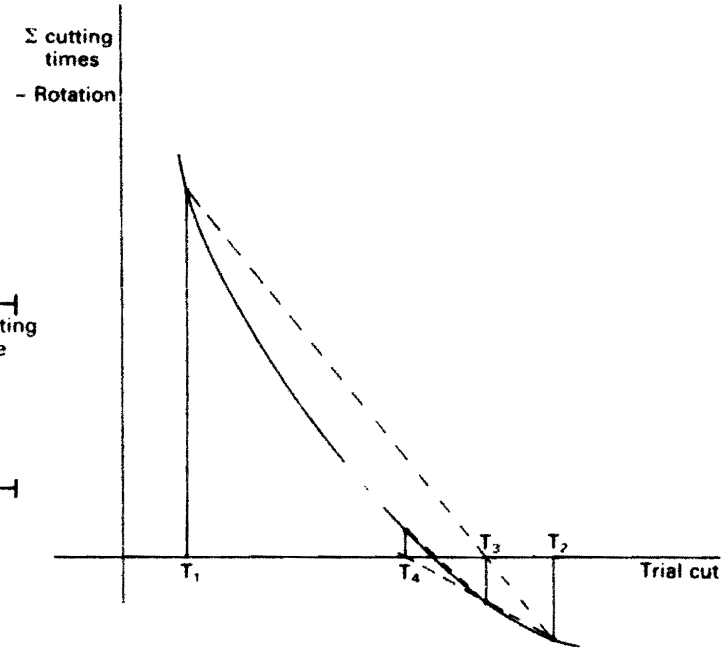

Figure 3. Newton-Raphson iteration of determining allowable cut with the Tabular Check.

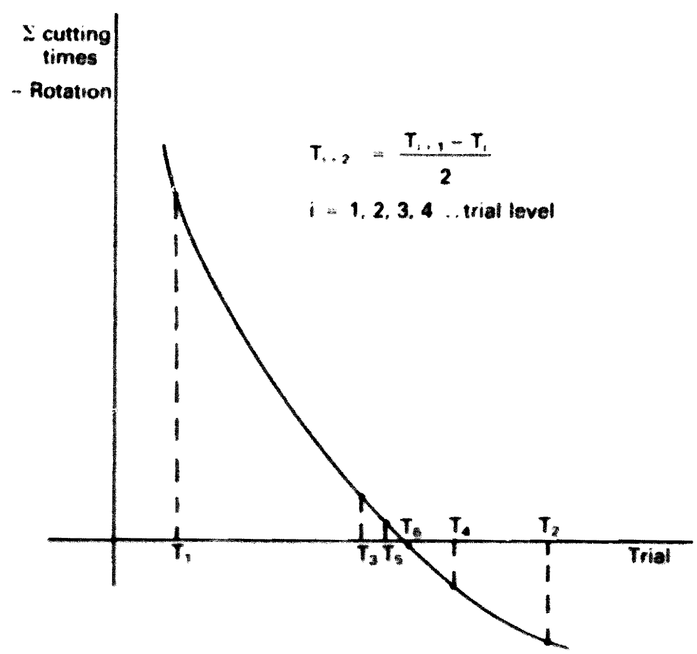

Figure 4. Interval halfing method of determining allowable cut with the Tabular Check.

(1) Actual growing stock volume G_a:

$G_a = 6.280 \times 0.90 \times 700 + 1.483 \times 300 \times 0.80 + 6.319 \times 0.85 \times 600 = 7.535.010$ ft^3.

(2) Regulated growing stock volume G_R (yield table summation)

— Need to calculate average weighted site index SI_W

$SI_W = (65 \times 700 + 75 \times 600 + 45 \times 300)/1.600 = 65$

$$G_R = G_{80} = 10\,(1.743 + 2.910 + 3.959 + 4.860 + 5.627 + \frac{6.280}{2}) =$$

222.390 ft^3 on 80 acres

or

$$222.390\ \frac{1.600}{80} = 4.447.800 \text{ ft}^3 \text{ on } 1.600 \text{ acres.}$$

Often managers have evidence that their stands are not growing at the level indicated in the yield table requiring an adjustment of G_R obtained from a yield table. Assume that the growth of the inventory is at 90 percent of the yield table. then desired growing stock volume after regulation would be:

$G_R = 4.447.800 \times 0.9 = 4.003.020$

(3) Yield for regulated growing stock

$$Y_R = Y_{80} = 6.280 \times \frac{1.600}{80} \times 0.90 = 113.040 \text{ ft}^3.$$

(4) Current annual increment.

—Calculate derivative of yield function for each stand in its current condition and sum over all stands.

Red pine yield.

$$Y = \frac{6.4088SI^{1.8342}}{e^{-61.534\ age}}$$

$$CAI = \frac{dy}{d\ Age} = \frac{394.359\ SI^{1.8342}e^{61.534\ Age}}{Age^2}$$

Giving CAI for fully stocked stands on a per acre basis

Stand	Age	CAI	CAI × acres × stocking
A	80	60.382	60.382 × 700 × 0.90
B.	40	57.016	57.016 × 300 × 0.80
C.	60	108.001	108.001 × 600 × 0.85
Total			106.805 ft^3

Alternative method: Calculate CAI for average age-site-stocking combination.

a) Average weighted age: A_W

$A_W = (80 \times 700 + 60 \times 600 + 40 \times 300)/1.600 - 65$ years.

b) Average weighted stocking:

$S_W = (0.90 \times 700 + 0.80 \times 300 + 0.85 \times 600)/1600 = 0.86$

c) Average weighted site index SI_W

CAI for A_W, S_W, and SI_W would be misleading because of severe nonlinearity of growth curve. but surely is less work.

CAI $(A_W, S_W, SI_W) = [394.359 \times 65^{1.8342} \times e^{-61.534/65})/65^2] \times 0.86 = 76.59 \times 0.86 = 66.06$ ft^3/acre or a total of 105.696 ft^3.

Note that the first method is preferred especially when widely differing stands are being considered.

(5) Mean annual increment at rotation age (and average SI):

$$MAI_R = \frac{\text{yield at age 80 for } SI_W = 65}{80}$$

$$= \frac{6.280}{80} = 78.5 \text{ ft}^3/\text{acre.}$$

To find appropriate a value for the current forest multiply by acres and S_W:

$MAI_R = 78.5 \times 1.600 \times 0.86 = 108.330$ ft^3

which estimates the sum of all increments for all stands as if they were harvested at rotation age.

Summary of information:

G_a	= 7,535,010 ft^3	SI_W	= 65
G_R	= 4,003,020 ft^3	S_W	= 0.86
Y_R	= 113,040 ft^3	A_W	= 65
CAI	= 106,805 ft^3		
MAI_R	= 108,330 ft^3		

Von Mantel

$$AC = \frac{2}{R} G_a = \frac{2}{80}(7.535.010)$$

= 188,375 ft^3.

or

$$AC = \frac{2}{R-a} G_a = \frac{2}{80-30}(7.535.010)$$

= 301.400 ft^3.

Hundeshagen

$$AC = \frac{Y_R}{G_R} G_a = \frac{113.040}{4.003.020} 7.535.010$$

= 212,779 ft^3

Austrian Formula

$$AC = CAI + \frac{G_a - G_R}{a} = 106.805 + \frac{7.535.010 - 4.003.020}{30}$$

= 224.538 ft^3 assuming 30-year adjustment period.

Chapman's Formula

$$AC = MAI_R + \frac{G_a - G_R}{R}$$

$$AC = 108.330 + \frac{7.535.010 - 4.003.020}{80}$$

= 152,480 ft^3.

Modified Barnes Formula

AC = yield at average cutting age times average weighted density.

Average cutting age RA = $A_W + R/2 = 65 + 80/2 = 105$

yield at age 105 (and average SI_W = 65) = 7542.4

$$AC = 7.542.4 \times 0.86 \times \frac{1.600}{80} =$$

130.106 ft^3.

TABULAR CHECK

The following three tables illustrate all the calculations necessary in the Tabular Check or Barnes Method (Tables 2-4). Note that the initial trial cut for the harvest time iteration is based on the calculation of allowable cut according to the Modified Barnes Method, *i.e.*, 130 M ft^3. The sum of the cutting times being greater than the rotation, a new trial harvest level is calculated (138 M ft^3), yielding a sum of cutting times smaller than the rotation. The next and final trial cut of 134 M ft^3, obtained using a Newton-Raphson iteration, stops the procedure because the sum of cutting times closely approximates the rotation.

At this point we have generated six solutions to the volume control problem (Table 5). It is apparent that the results of the various approaches differ substantially, from 130,106 ft^3 for the Modified Barnes method to 224,538 ft^3 for the Austrian method.

A number of questions arise at this point: Which of the regulation formulas should be used? What is the long-term effect on inventory growth and growing stock of following each of the calculated cutting levels? To answer these and other questions a simulation program will be introduced that will facilitate the calculations of allowable cuts and their implementation while keeping track of the changing conditions of inventories due to cutting and growth accumulation. The program, furthermore, will be used to compare the regulation formulas described here over a 200-year projection period using an actual forest inventory.

Table 2. Tabular check, first iteration.

Stand	Site Index	Stocking Percent	Present Age	Present Volume (Total)	Average Age at Harvest	Average Volume at Harvest	Cutting Time: Per Stand	Cutting Time: Cumulative
	Acres							
A	65	.90	80	6.280 x 0.90	$80 + \left(\frac{3956}{130}\right)/2$ = 95.2	7.101 x .90 x 700 = 4474	4474/130 = 34.4	35
	700			x 700	80 + 34.4/2 = 97.2	7.196 x .90 x 700 = 4533	4533/130 = 34.9	
				3956	80 + 24.9/2 = 97.4	7.207 x .90 x700 = 4540	4540/130 = 35.0	
C	75	.85	60 + 35 = 95	9.220 x 0.85	$95 + \left(\frac{4702}{130}\right)/2$ = 113.1	10.226 x .85x600 = 5215	5215/130 = 40.1	35 + 40.5 = 75.4
	600			x600	95 + 40.1/2 = 115.1	10.332 x .85 x600 = 5264	5264/130 = 40.5	
				4702	95 + 40.5/2 = 115.2	10.331 x .85 x600 = 5269	5269/130 = 40.5	
B	45	.80	40 + 75.4 = 115.4	4.061 x 0.80	$115.4 + \left(\frac{972}{130}\right)/2$ = 119.1	4.119 x .80 x300 = 988	988/130 = 7.6	75.4 + 7.6 = 83
	300			x300	115.4 + 7.6/2 = 119.2	4.120 x.80 x 300 = 989	989/130 = 7.6	
				972				

Table 3. Tabular check, second iteration.

Stand	Site Index	Stocking Percent	Present Age	Present Volume (Total)	Average Age at Harvest	Average Volume at Harvest	Cutting Time	
	Acres						Per Stand	Cumulative
A	65	0.90	80	6.280 X 0.90 x 700 3956	$80+\left(\frac{3956}{138}\right)/2 = 94.3$ $80 + \frac{32.2}{2} = 96.1$ $80 + \frac{32.6}{2} = 96.3$	7.058 x .90 x 700 = 4447 7.145 x .90 x 700 = 4501 7.154 x .90 x 700 = 4506	4447 /138 = 32.2 4501 / 138 = 32.6 4506 / 138 = 32.7	32.7
	700							
C	75	0.85	60 + 32.7 = 92.7	9.069 x 0.85 x 600 4626	$92.7 + \left(\frac{4626}{138}\right)/2 = 109.5$ 92.7 + 37.1/2 = 111.3 92.7 + 37.5/2 = 111.4	10.043 x .85 x 600 = 5122 10.134 x .85 x 600 = 5169 10.143 x .85 x 600 = 5173	5122/138 = 37.1 5169/138 = 37.5 5173/138 = 37.5	32.7 + 37.5 = 70.2
	600							
B	45	0.80	40 + 70.2 = 110.2	3.949 x 0.80 x 300 947.9	$110.2 + \left(\frac{947.9}{138}\right)/2 = 113.6$ 110.2 + 7/2 = 113.7	4.017 x .80 x 300 = 964 4.018 x .80 x 300 = 964	964 / 138 = 7.0 964 / 138 = 7.0	70.2 + 7.0 = 77.2
	300							

Table 4. Tabular check, final iteration.

Stand	Site Index	Stocking Percent	Present Age	Present Volume (Total)	Average Age at Harvest	Average Volume at Harvest	Cutting Time	
	Acres						Per Stand	Cumulative
A	65	0.90	80	6.280 x 0.90 x 700 3956	$80 + \left(\frac{3956}{134}\right)/2 = 94.8$ 80 + 33.3/2 = 96.6 80 + 33.7/2 = 96.9	7.079 x .90 x 700 = 4460 7.169 x .90 x 700 = 4517 7.180 x .90 x 700 = 4523	4460/134 = 33.3 4517 / 134 = 33.7 4523 / 134 = 33.8	33.8
	700							
C	75	0.85	60 + 33.8 = 93.8	9.141 x 0.85 x 600 4662	$93.8 + \left(\frac{4662}{134}\right)/2 = 111.2$ 93.8 + 38.6/2 = 113.1 93.8 + 38.9/2 = 113.3	10.132 x .85 x 600 = 5167 10.226 x .85 x 600 = 5215 10.234 x .85 x 600 = 5220	5167 /134 = 38.6 5215 /134 = 38.9 5220 / 134 = 39.0	33.8 + 39.0 = 72.8
	600							
B	45	0.80	40 + 72.8 = 112.8	4.000 x 0.80 x 300 960	$112.8 + \left(\frac{960}{134}\right)/2 = 116.4$ 112.8 + 7.3/2 = 116.4	4.069 x .80 x 300 = 976 4.070 x .80 x 300 = 977	976/134 = 7.3 977 / 134 = 7.3	72.8 + 7.3 = 80.1
	300							

Table 5. Summary: volume control results.

Stand	Acres	Age	Site	Stocking %
A.	700	80	65	90
B.	300	40	45	80
C.	600	60	75	85

SI_W	= 65; S_W = 0.86; A_W = 65	Von Mantel	AC = 188,375 or 301,400 with a = 30
G_a	= 7,535,010	Hundeshagen	AC = 212,779
G_R	= 4,003,020	Austrian	AC = 224,538
Y_R	= 113,040	Chapman	AC = 152,480
CAI	= 106,805	Modified Barnes	AC = 130,106
MAI_R	= 108,330	Tabular Check	AC = 134,000
		All volume units in ft^3	

Table 6. Yield per acre (ft^3) by age and site index of fully stocked, even-aged, pure aspen stands in the Lake States.[1]

Stand			Site index		
age	40	50	60	70	80
20	396	575	777	1,001	1,248
30	855	1,235	1,668	2,151	2,681
40	1,253	1,810	2,445	3,153	3,929
50	1,575	2,276	3,075	3,965	4,942
60	1,836	2,653	3,583	4,621	5,759
70	2,048	2,459	3,997	5,154	6,424
80	2,223	3,211	4,338	5,594	6,972
90	2,369	3,423	4,623	5,962	7,431

[1]Values found from the equation.

$$\text{Yield} = 8.9836\, S^{1.6494}\, e^{45.876\, A}$$

where: S = site index
A = age

Base data are from Table 154, Brown, R. M. and S. R. Gervorkiantz. 1934. "Volume, Yield, and Stand Tables for Tree Species in the Lake States." University of Minnesota Agricultural Experiment Station Technical Bulletin 39. 208 pp.
Yield is total cubic feet per acre excluding bark for all trees 10 inches dbh and larger

Table 7. Yield per acre (ft^3) by age and site index of fully stocked, even-aged, second-growth upland oak stands.[1]

Stand			Site index		
age	40	50	60	70	80
25	500	661	830	1,006	1,180
35	890	1,176	1,477	1,790	2,114
45	1,226	1,620	2,034	2,465	2,912
55	1,503	1,986	2,493	3,022	3,570
65	1,731	2,287	2,871	3,480	4,111
75	1,919	2,536	3,183	3,859	4,558
85	2,077	2,744	3,445	4,176	4,933
95	2,211	2,921	3,667	4,445	5,251
105	2,326	3,072	3,857	4,676	5,523

[1]Value found from the equation:

$$\text{Yield} = 37.658\, S^{1.2479}\, e^{50.412\, A}$$

where: S = site index
A = age

Base data are from Table 12, Schnur, G.L. 1937. "Yield, Stand, and Volume Tables for Even-aged Upland Oak Forests." USDA Technical Bulletin 560. 88 pp.
Yield is total cubic feet per acre excluding bark for all trees 0.6 inches dbh and larger

Simulation of Area and Volume Control Techniques

A simulation package was written to illustrate how different regulation techniques will result in different allowable cuts and how applications of these cuts will lead to different growing stock and growth over time. The simulation model is, furthermore, useful for testing how different initial inventory conditions influence allowable cut levels under the various formula approaches.

The user currently has the choice of three species: aspen, red pine, and upland oak (Tables 1, 6, 7).

The user should have little difficulty in running the simulation, especially if the input data are entered via the terminal keyboard.

For repeated simulation of different regulation methods using the same inventory base it is convenient, however, to have the stand data reside on a disk file. To create a file "ASPSTAT" with stand input data for an aspen inventory the following commands should be used:

```
X, CCR. INPUT, ASPSTAT
?   1264   75   .238   65
?   2766   65   .361   65
?  14045   55   .333   65
?   4002   55   .254   55
?   1422   55   .597   45
?  19003   45   .391   65
?   4433   45   .353   55
?  13849   35   .592   65
?   1555   35   .594   55
?   2971   25   .553   65
?   5993   15   .578   65
?   2849   15   .763   55
?   9925    5   .500   65
?   6673    5   .500   55
?   1383    5   .500   45
?
READY.
REPLACE.ASPSTAT
```

A listing of the file is produced using the following commands:
GET, ASPSTAT

```
       X, CCR, ASPSTAT
 1264   75   .238   65
 2766   65   .361   65
14045   55   .333   65
 4002   55   .254   55
 1422   55   .597   45
19003   45   .391   65
 4433   45   .353   55
13849   35   .592   65
 1555   35   .594   55
 2971   25   .553   65
 5993   15   .578   65
 2849   15   .763   55
 9925    5   .500   65
 6673    5   .500   55
 1383    5   .500   45
```

To run the program with this data file, study the following example:

```
GET,TAPE12=ASPSTAT
/MANAGEB
 V O L U M E   C O N T R O L
 DO YOU NEED INSTRUCTIONS ? YES
THIS PROGRAM SIMULATES THE MANAGEMENT OF PURE, EVENAGED
FORESTS FOR TIMBER BENEFITS. ITS PURPOSE IS TO ALLOW
THE USER TO STUDY THE DIFFERENT FLOW STRATEGIES
PRODUCED WHEN VARIOUS STANDARD CUT DETERMINATION METHODS
ARE APPLIED TO HIS FOREST. IT IS ASSUMED THE USER
CAN DIVIDE HIS FOREST INTO A FINITE NUMBER OF UNIFORM
(WITH RESPECT TO AGE, DENSITY, AND SITE INDEX)
MANAGEMENT UNITS LABELLED STANDS. THROUGHOUT A
SIMULATION RUN THESE STANDS ARE 'GROWN' ACCORDING
TO A NORMAL YIELD FUNCTION ADJUSTED BY THE STAND'S
STOCKING PERCENT(INITIAL STANDS DO HOWEVER LOSE THEIR
IDENTITY AFTER THE FIRST CUT). AT PRESENT ONE OF
THREE(RED PINE, ASPEN, UPLAND OAK) YIELD FUNCTIONS
MAY BE CHOSEN.

OTHER USER SPECIFIED INFORMATION INCLUDES:
  (A)AGE AT WHICH HARVESTABLE YIELD FIRST APPEARS(FY)--
     THIS IS SIMPLY THE AGE AT WHICH THE USER FEELS THE
     YIELD FUNCTION FIRST PREDICTS REASONABLE VALUES.
  (B)ROTATION AGE(RA)--AGE AT WHICH HARVEST WOULD
     ALWAYS OCCUR IF THE FOREST WERE REGULATED.
  (C)MINIMUM CUTTING AGE(MINCUT)--A WARNING WILL BE
     GIVEN IF STANDS LESS THAN THIS AGE ARE CUT.
  (D)ANTICIPATED STOCKING UNDER MANAGEMENT(MODSTK)--
     THE STOCKING PERCENT THE USER FEELS IS OBTAINABLE
     WHEN A STAND HAS BEEN CUT OVER.
  (E)INTERVAL(IN YEARS) AT WHICH ALLOWABLE CUT IS
     REEVALUATED(EVAL)--THE PROGRAM WILL CUT THE FOREST
     ACCORDING TO THE SPECIFIED FORMULA RESULT FOR THIS
     NUMBER OF YEARS, AT WHICH TIME A REVISED CALCULATION
     WILL BE MADE.
  (F)NUMBER OF TIMES ALLOWABLE CUT IS TO BE REEVALUATED
     (IMES)--THE NUMBER OF PERIODS OF LENGTH 'EVAL'
     FOR WHICH THE CUT IS TO BE SIMULATED.
  (G)CUT DETERMINATION METHOD(WHMETHOD)--ONE OF THE
     STANDARD ALLOWABLE CUT FORMULAS DISCUSSED IN
     TIMBER MANAGEMENT TEXTS. FOR AN EXACT DESCRIPTION
     OF HOW THIS PROGRAM CALCULATES EACH OF THESE SEE
     THE PAPER REFERENCED BELOW.

ALL INPUTS MAY BE INTEGER EXCEPT STOCKING(SEE BELOW).IF AN
INPUT MUST BE AN INTEGER AND IS ENTERED AS A REAL,AN ERROR
WILL BE PRINTED AND A REQUEST MADE FOR THE USER TO CORRECT
IT.

ACTUAL STAND INFORMATION MAY BE ENTERED ONCE YOU HAVE
BEGUN RUNNING THE PROGRAM OR STORED ON LOCAL FILE 'TAPE12'
PREVIOUS TO PROGRAM EXECUTION(PREFERRED). IN EACH CASE
DATA ARE TO BE TYPED ONE STAND PER LINE, EACH LINE
CONTAINING THE FOLLOWING INFORMATION IN SEQUENCE:
  1.ACRES IN STAND
  2.AGE OF STAND
  3.STOCKING LEVEL OF STAND
       (VOLUME/ACRE OR PERCENT NORMAL STOCKING)
  4.SITE INDEX OF STAND
THE ORDER OF THE STANDS MUST CORRESPOND TO THE CUTTING
PRIORITY DESIRED. THIS INFORMATION MAY BE ENTERED AS
REAL OR INTEGER NUMBERS EXCEPT STOCKING. WHEN STOCKING
IS 'PERCENT OF NORMAL', THE PERCENTS MUST BE EXPRESSED
AS DECIMAL FRACTIONS(I.E. 80 PERCENT EQUALS 0.80).
AS A NOTE, WHEN STOCKING IS GIVEN AS VOLUME/ACRE IT IS
CONVERTED(FOR SIMULATION USE) TO A STOCKING PERCENT USING
THE APPROPRIATE NORMAL YIELD FUNCTION. ALL INFORMATION
IS READ IN FREE-FORMAT MODE.

THE USER MAY ALSO CHOSE BETWEEN TWO TYPES OF OUTPUT.
WHEN THE 'ABBREVIATED' FORM OF OUTPUT IS CHOSEN
CURRENT STAND ACREAGE, SITE INDEX, YIELD/ACRE, TOTAL
YIELD, AND GROWTH ARE OUTPUT ALONG WITH THE ALLOWABLE CUT
LEVEL FOR THE PERIOD AND THE ACRES CUT IN THE PERIOD.
WITH THIS OPTION THE USER MUST SPECIFY THE AGE CLASS WIDTH
USED TO OUTPUT RESULTS. OTHERWISE AREA, YIELD, HARVEST
```

AGE, AND VALUE INFORMATION ARE PRINTED OUT AT EACH STAND'S AVERAGE HARVEST AGE DETERMINED ACCORDING TO PRESENT FOREST CONDITIONS AND THE CHOSEN CUT DETERMINATION METHODOLOGY. TOTALS AND AVERAGES AT AVERAGE HARVEST AGE ARE ALSO GIVEN. FINALLY, A PROJECTED CUTTING SCHEDULE IS OUTPUT. THIS SCHEDULE IS VALID WHEN THE CUTTING LEVEL BEING USED HAS FULLY REGULATED THE FOREST. FOR BOTH TYPES OF OUTPUT ALLOWABLE CUT ESTIMATES ARE GIVEN FOR ALL METHODOLOGIES.

USERS ARE ALSO ALLOWED TO REEVALUATE ALLOWABLE CUT FOR YEARS IN ADDITION TO WHAT WAS FIRST REQUESTED AND TO(IF DATA ARE STORED ON TAPE12) COMPLETELY RERUN A PROBLEM(WITH THE SAME STANDS) WITH DIFFERENT INITIAL SPECIFICATIONS.

THE PROGRAM WAS WRITTEN SO THAT ANYONE WITH A MINIMAL AMOUNT OF PROGRAMMING EXPERIENCE COULD EASILY MAKE A NUMBER OF USEFUL CHANGES. THESE WOULD INCLUDE (1) THE SPECIES GROUPS AND ASSOCIATED YIELD FUNCTIONS, (2) THE COEFFICIENTS AND/OR FORM OF THE TIMBER VALUE EQUATION, (3) THE INTEREST RATE AT WHICH VALUES ARE DISCOUNTED, (4) THE UNITS ON YIELD, AND (5) THE SIZE AND PRECISION REQUIREMENTS FOR ANY PARTICULAR PROBLEM. INTERESTED USERS SHOULD CONSULT:

UNIVERSITY OF MINNESOTA, COLLEGE OF FORESTRY
STAFF PAPER NO. 8, A FOREST REGULATION SIMULATOR,
BY T.E. BURK AND D.W. ROSE(1979).

END OF INFORMATION

```
ARE YOUR DATA ON TAPE12 ? YES
DO YOU WANT THE ABBREVIATED OUTPUT ? YES
AGE CLASS WIDTH TO BE USED(MULTIPLE OF 5) ? 10
WHICH SPECIES ARE YOU CONSIDERING
  1.RED PINE
  2.ASPEN
  3.UPLAND OAK
? 2
NUMBER OF STANDS ? 15
AGE AT WHICH HARVESTABLE YIELD FIRST APPEARS ? 15
ROTATION AGE ? 50
MINIMUM CUTTING AGE ? 40
ANTICIPATED STOCKING(DECIMAL) UNDER MANAGEMENT ? 0.75
AUSTRIAN FORMULA ADJUSTMENT PERIOD ? 30
INTERVAL TO REEVALUATE ALLOWABLE CUT(A.C.) ? 10
NUMBER OF TIMES A.C. IS TO BE REEVALUATED ? 2
WHICH CUT DETERMINATION OPTION(NUMBER)
  1.TABULAR CHECK
  2.MODIFIED BARNES
  3.AUSTRIAN
  4.CHAPMAN
  5.HUNDESHAGEN
  6.VON MANTEL
? 1
IS 'STOCKING'(1)PERCENT OF NORMAL OR (2)ACTUAL VOLUME ? 1
```

****

IN THE OUTPUT THAT FOLLOWS UNIT IS CORD WOOD VOLUME

****

DISTRIBUTION OF GROWING STOCK AT YEAR 0

AGE (YEARS)	SITE (FT)	AREA (ACRES)	YIELD/ACRE (UNITS)	TOTAL YIELD (M.UNITS)	ANNUAL GROWTH (UNITS)
80	65.	1264.	14.381	18.176	149.25
70	65.	2766.	19.817	54.815	595.19
60	61.	19469.	14.671	285.63	4331.8
50	63.	23436.	14.748	345.62	7830.0
40	64.	15404.	17.326	266.88	9994.7
30	65.	2971.	9.8182	29.170	2141.1
20	62.	8842.	3.0212	26.713	5446.6
10	60.	17981.	0	0	199.64
TOTAL		92133.		1027.0	30687.
DESIRABLE				1180.7	49075.

ESTIMATES OF ALLOWABLE CUT
HUNDESHAGENS = 49750.8562 UNITS
VONMANTELS = 58686.4003 UNITS
CHAPMANS = 33378.3624 UNITS
AUSTRIAN = 25563.2224 UNITS
MODIFIED BARNES = 42542.2804 UNITS

ALLOWABLE CUT FOR YEARS 0 TO 9. = 40570 UNITS/YEAR

DISTRIBUTION OF GROWING STOCK AT YEAR 10.

AGE (YEARS)	SITE (FT)	AREA (ACRES)	YIELD/ACRE (UNITS)	TOTAL YIELD (M.UNITS)	ANNUAL GROWTH (UNITS)
60	63.	22253.	17.692	393.68	5970.5
50	64.	15404.	23.184	357.12	8090.6
40	65.	2971.	16.586	49.276	1845.4
30	62.	8842.	10.268	90.787	6663.9
20	60.	17981.	2.7433	49.328	10058.
10	65.	11538.	0	0	1864.5
0	60.	13144.	0	0	7.8018
TOTAL		92133.		940.20	34500.
DESIRABLE				1180.7	46792.

ACRES CUT IN PERIOD = 24682

ESTIMATES OF ALLOWABLE CUT
HUNDESHAGENS = 45545.4423 UNITS
VONMANTELS = 53725.6695 UNITS
CHAPMANS = 40087.2052 UNITS
AUSTRIAN = 26482.3674 UNITS
MODIFIED BARNES = 47703.8292 UNITS

ALLOWABLE CUT FOR YEARS 10. TO 19. = 45499 UNITS/YEAR

DISTRIBUTION OF GROWING STOCK AT YEAR 20.

AGE (YEARS)	SITE (FT)	AREA (ACRES)	YIELD/ACRE (UNITS)	TOTAL YIELD (M.UNITS)	ANNUAL GROWTH (UNITS)
60	64.	14231.	27.849	396.32	6010.4
50	65.	2971.	22.194	65.938	1493.8
40	62.	8842.	17.345	153.36	5743.4
30	60.	17981.	9.3234	167.64	12305.
20	65.	11538.	6.0623	69.948	10391.
10	62.	24554.	0	0	8976.7
0	61.	12016.	0	0	7.5492
TOTAL		92133.		853.21	44928.
DESIRABLE				1180.7	51259.

ACRES CUT IN PERIOD = 23426

```
DO YOU WISH TO REEVALUATE A.C. FURTHER ? NO
DO YOU WISH TO RERUN WITH NEW CONDITIONS ? NO
   .821 CP SECONDS EXECUTION TIME
```

Model Application Example

Application of the model to a real inventory situation will be illustrated in the following. The purpose is to show differences in the various control methods and to point out potential shortcomings in the models.

DESCRIPTION OF DATA

Aspen inventory data for the Bear Island State Forest, situated northeast of Ely, Minnesota, in Lake and St. Louis counties, were obtained from the Department of Natural Resources 1978 Phase II inventory. This inventory consists of 320 individual aspen stands. Stands were chosen to illustrate the present condition of aspen on many state-owned lands and the need for regulatory management techniques. Figure 5 shows the very irregular nature of the age class distribution of the present inventory. About 77 percent of the total 10,020 acres are between 40 and 69 years old. Five percent of the acreage is in stands 70 years and older, leaving only 18 percent in ages 1 to 39 years. The ages, acres, volumes, and site indexes of these stands were supplied as input into the regulation simulation model.

PROCEDURE

Six volume regulation methods were applied to the aspen inventory over a 200-year simulation period. Annual allowable cuts were recalculated at ten-year intervals. Three model outputs were of special interest for comparison of the regulation approaches: a) allowable cut levels, b) growing stock levels, and c) age-class distributions. Initial stand conditions and input parameters were identical for each method. The input specifications were as follows:

Number of stands = 320.
Age at which harvestable yield first appears = 15 years.
Rotation age = 50 years.
Minimum cutting age = 40 years.
Length of adjustment period (Austrian formula) = 20 years.
Interval at which allowable cut is reevaluated = 10 years.
Number of times allowable cut is reevaluated = 20.
Stocking for young stands = .55.
Anticipated stocking percent under management = 80 percent.
A stand growth model for aspen based on the attached yield table (Table 6) by Brown and Gevorkiantz (1934).

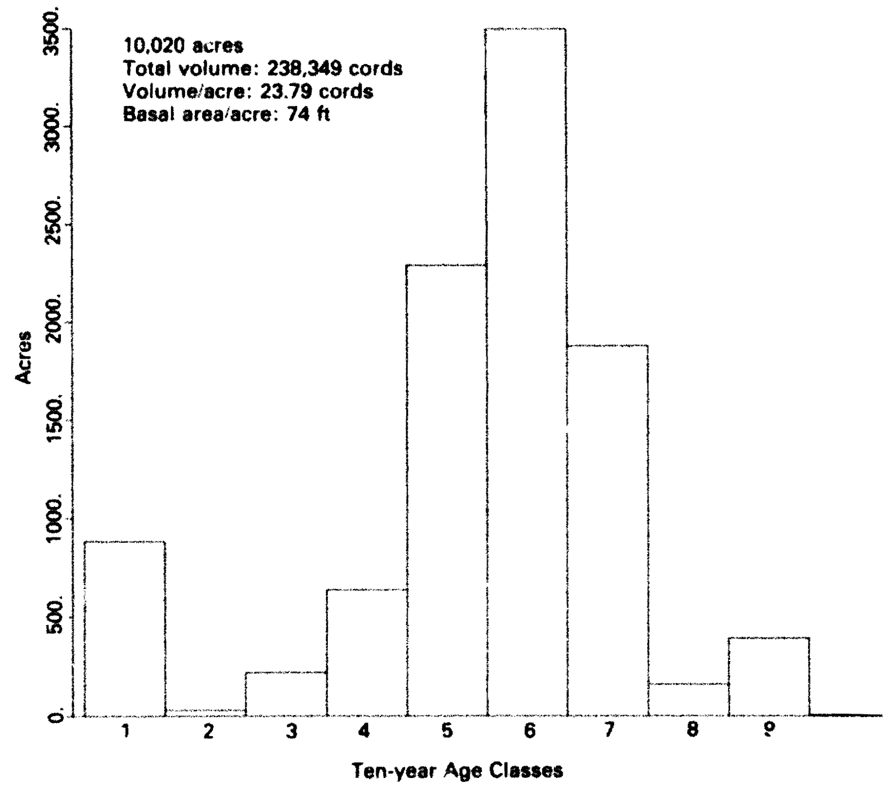

Figure 5. Initial age-class distribution of aspen covertype, Bear Island State Forest, Minnesota.

Discussion and Results

To summarize the more interesting results, a graphing and plotting package developed at the College of Forestry was used to draw graphs of allowable cut and current growing stock and histograms of age class distributions.

Under each of the regulation approaches, nearly regulated conditions were obtained after about 80 years. Allowable cut levels stabilized at about 6,000 cords and show relatively small differences after growing stocks became more fully regulated (Figures 6 and 7). Hundeshagen and Von Mantel are distinctly different in that initial allowable cuts are much higher than for the other procedures, resulting in initial overcutting and a subsequent rapid drop in allowable cut levels for about 20 years. A possible explanation is the lack of any consideration for growth of the inventory in determining allowable cut. The Austrian formula also shows a considerable decline in allowable cut initially despite its incorporation of growth into the formula. Since current periodic growth is relatively small for the largely overmature inventory, it did not greatly influence the allowable cut initially. On the other hand, Chapman's model, which uses mean annual increment at rotation age, shows no drop in allowable cut over time.

Generally, all control procedures appear to do a favorable job in achieving full regulation. On the other hand, the initial fluctuations of the Von Mantel, Hundeshagen, and Austrian formulas make these models possibly unacceptable in this and other situations. One reason of the acceptable long-term behavior of these models is the periodic reevaluation of allowable cuts which the original control methods had not foreseen. With the speed and flexibility of a computer model, frequent updates not only are easily made, but also improve the performance of otherwise inflexible models. A second reason why some of the more inflexible models such as Hundeshagen and Von Mantel appear reasonably acceptable over the long-term in terms of achieving full regulation is the use of normal yield table data for growth projection with only a possibility of adjusting the percent of normal growth that would be achieved by a stand. More precise approaches to growth projection could be incorporated into the model to obtain more realistic results in this respect. However, the method used in this model more closely reflects the procedure which many forestry enterprises use today to project future stand conditions.

Growing stock (Figures 8 and 9) in all cases shows a decline in about the first 20-40 years of the simulation and, then, a general increase to stable, long-term equilibrium conditions. Differences between growing stock levels are substantial. Von Mantel and Hundeshagen result in substantial overcutting initially and a subsequent long and slow build-up to sustainable yield levels. Von Mantel reaches stable growing stock levels far below all other approaches. Since it maintains similar allowable cut levels, this implies that younger age classes must be cut to maintain the cutting level. This result is illustrated in the next set of figures.

Age-class distributions were obtained for each 10-year interval. Figures 10 and 11 show the age-class distributions for year 0 (initial condition), year 10, and every 30 years thereafter for the Tabular Check method.

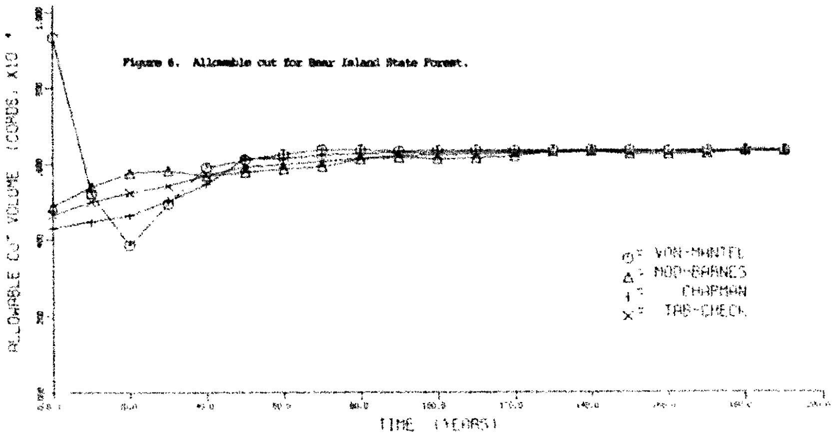

Figure 6. Allowable cut for Bear Island State Forest.

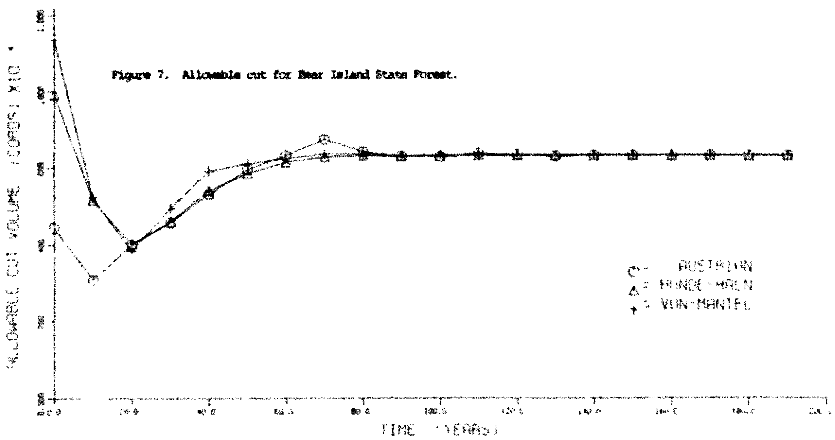

Figure 7. Allowable cut for Bear Island State Forest.

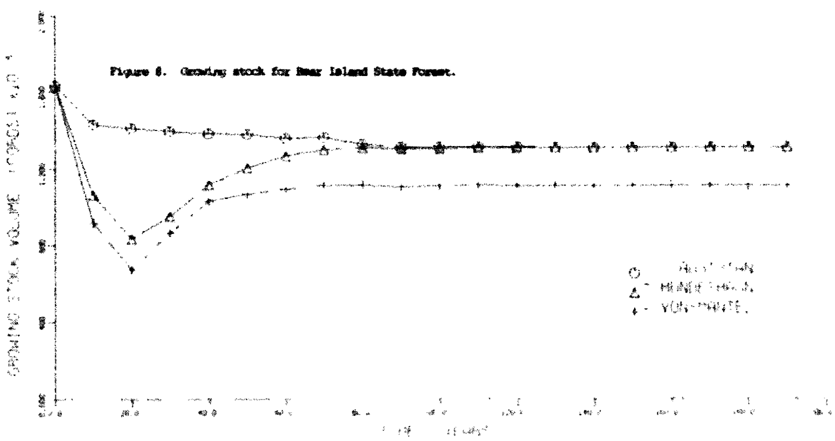
Figure 8. Growing stock for Bear Island State Forest.

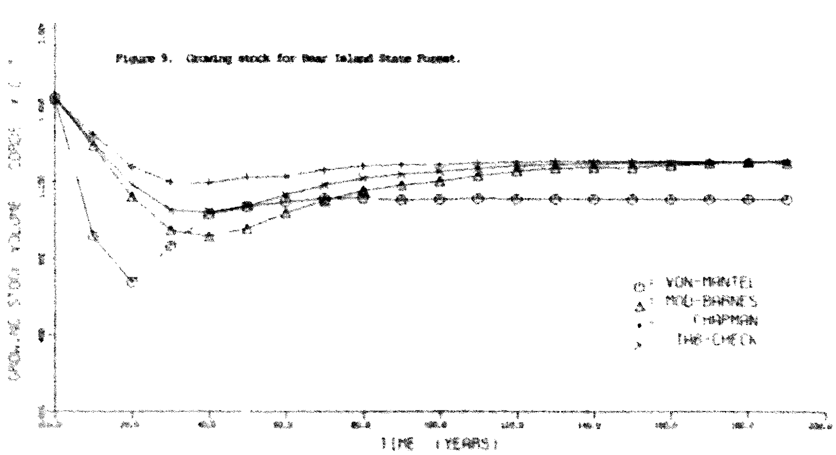

Figure 9. Growing stock for Bear Island State Forest.

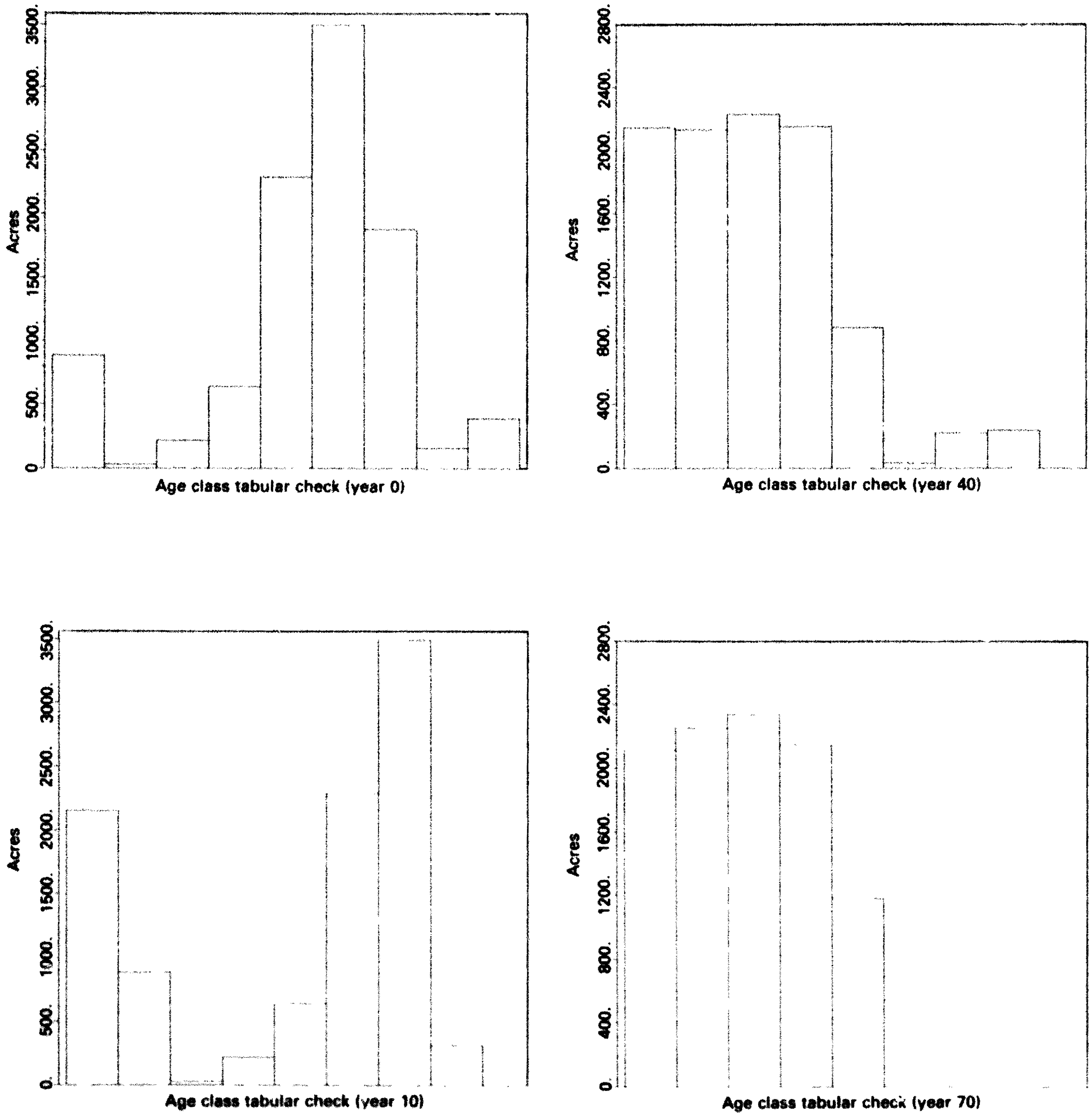

Figure 10. Age-class distribution, Bear Island State Forest.

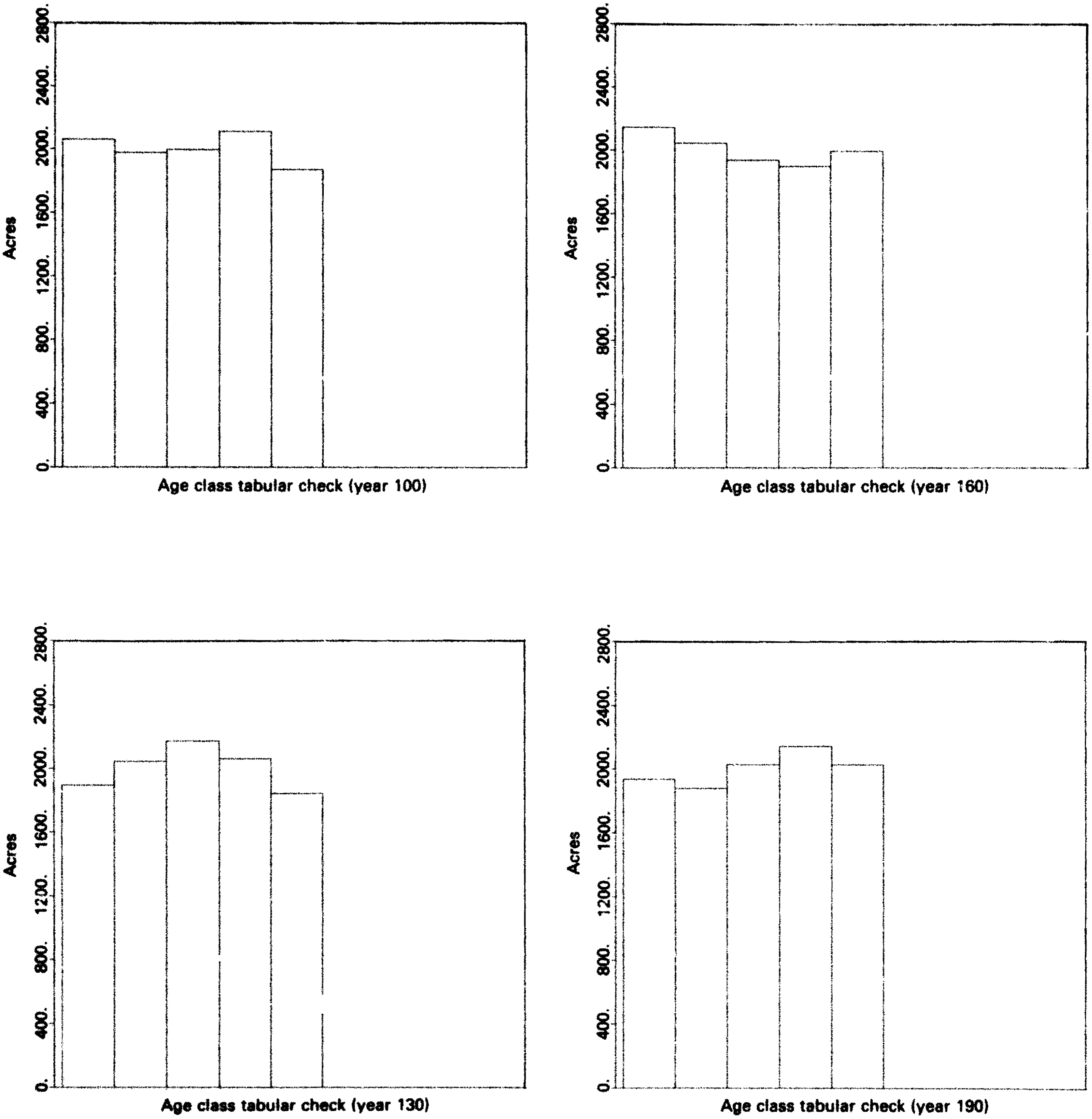

Figure 11. Age-class distribution, Bear Island State Forest.

The effects of the regulation procedure on regulating the severely unbalanced forest within a reasonable short time period is apparent. The distributions are similar for all the other methods except for Von Mantel and Hundeshagen. For the former, cutting into younger age classes occurs to maintain allowable cut levels similar to the other methods from a lower growing stock volume (Figures 12 and 13).[1]

Summary

We have shown that the application of volume control procedures to inventory data over long planning periods is essential to gain insight into the long-term sustainable yield of our forest inventory.

The simple formula approaches to timber regulation, specifically Hundeshagen and Von Mantel, have been widely criticized as being inadequate because of the inherent assumptions of a normal forest. More modern regulation models such as Timber RAM (Navon 1971), a linear programming approach, or ECHO (Walker 1971), an economic harvest optimization model, have been introduced to replace old formula approaches.

There are at least three reasons why the formula approaches still have merit:

1. They provide simple, fast estimates of allowable cut; some of the modern regulation models are very complex and frequently are not understood by the forest on the ground.

2. If current harvest levels are known to be far below allowable cuts, the optimization of cutting levels is far less critical; it is important, however, to gain an understanding of the long-run sustainable yield of an inventory after full regulation has been obtained.

3. Formula approaches can be shown to work satisfactorily in achieving full regulation if allowable cuts according to the various formulas are recalculated at reasonable intervals, e.g., 10 years.

The selection of a specific regulation model depends primarily on the objectives of the forest enterprise. Equally important, however, is the knowledge of how implementation of calculated allowable cuts will change future forest inventories in terms of growing stock, growth, and age-class distributions.

This question can be answered for a specific inventory by simulating allowable cut calculations and implementation over time. It is apparent from our simulations using the Bear Island aspen inventory that the regulation models with the most restrictive or simplifying assumptions, *i.e.*, Von Mantel, Hundeshagen, and Austrian, led to severe fluctuations in the allowable cut which could be unacceptable to the manager for a number of reasons. If we followed Von Mantel, we would have a cut the first decade of 50 percent above sustainable yield levels, followed by a drop two decades later to two-thirds of sustainable yield levels.

All models over the long-run led to stable conditions. It is impossible however, to predict the behavior of the models, especially the more restrictive ones, for different initial inventory conditions. The simplicity of the formula approaches to allowable cut calculations was one of the most important reasons for their use. With the availability of computer programs like the one presented here, it is possible to first examine how various regulation models will affect growth, growing stock, and cutting levels before selecting a specific approach. More importantly, with the availability of this program, there is little reason to not use the superior Tabular Check procedure for calculating the allowable cut.

Our example has shown that current allowable cuts for aspen in the Bear Island State Forest are far below cuts desirable for achievement of regulated forest conditions. If full regulation within a reasonable time period is an objective, increased harvest would be in the interest of the supervising agency and would contribute to the solution of silvicultural problems posed by an overmature aspen inventory. Calculation of reliable, long-run sustainable yields has also become more critical recently because new and substantial future demands for timber are becoming apparent. While current demand for aspen in still below desirable cutting levels, recent developments could bring about substantial increases in the demand for aspen and other hardwoods. Several timber companies have announced plans for or have begun construction of waferboard plants which will increase utilization of the hardwood resource. Demand increases will be substantial and provide a great opportunity for forest managers to speed up the job of regulating unbalanced timber inventories. The availability of this powerful simulation program should facilitate this job greatly.

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[1]The average scaled cutting volume of aspen over the last 5 years has been 1,135 cords.

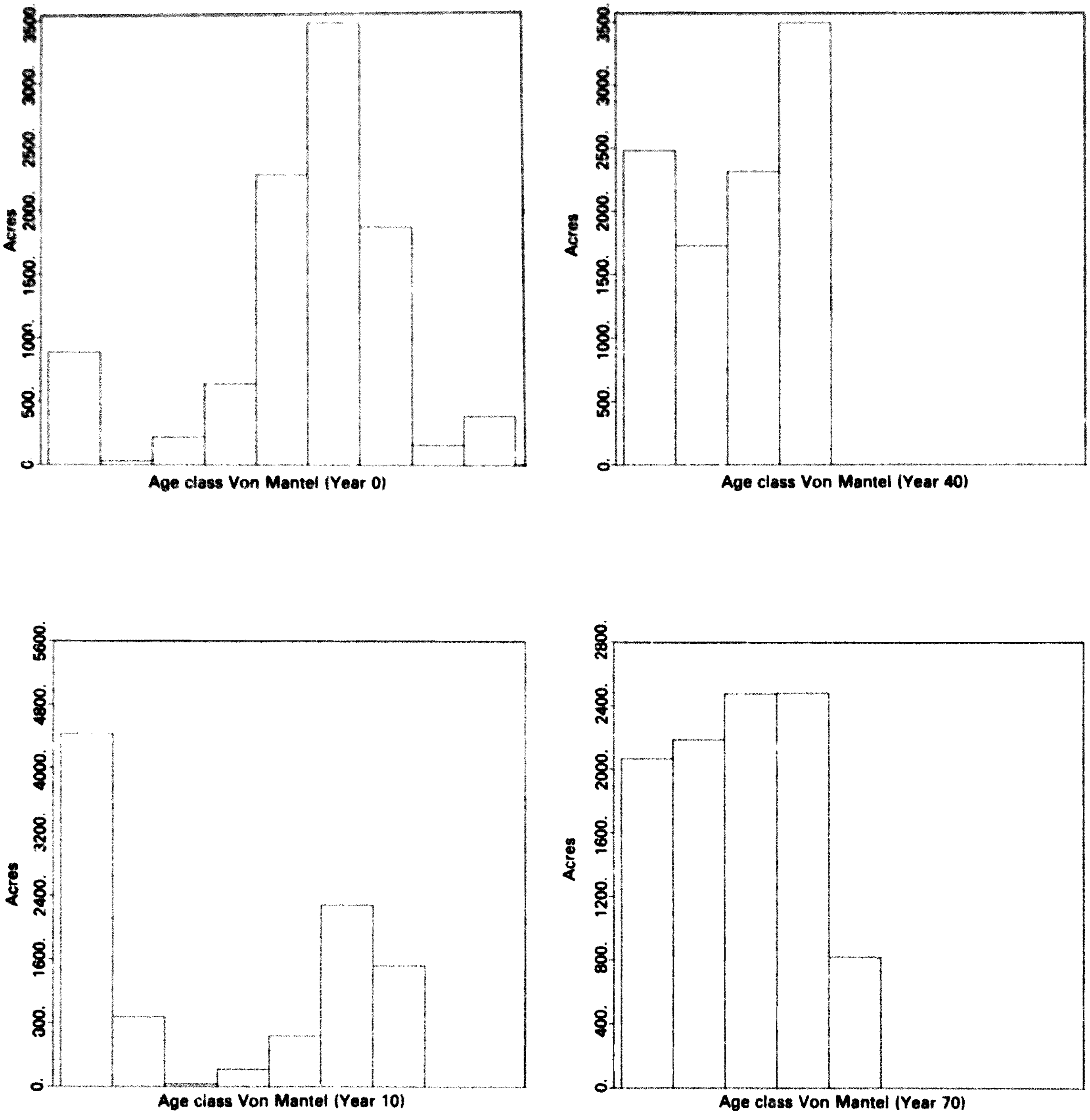

Figure 12. Age-class distribution, Bear Island State Forest.

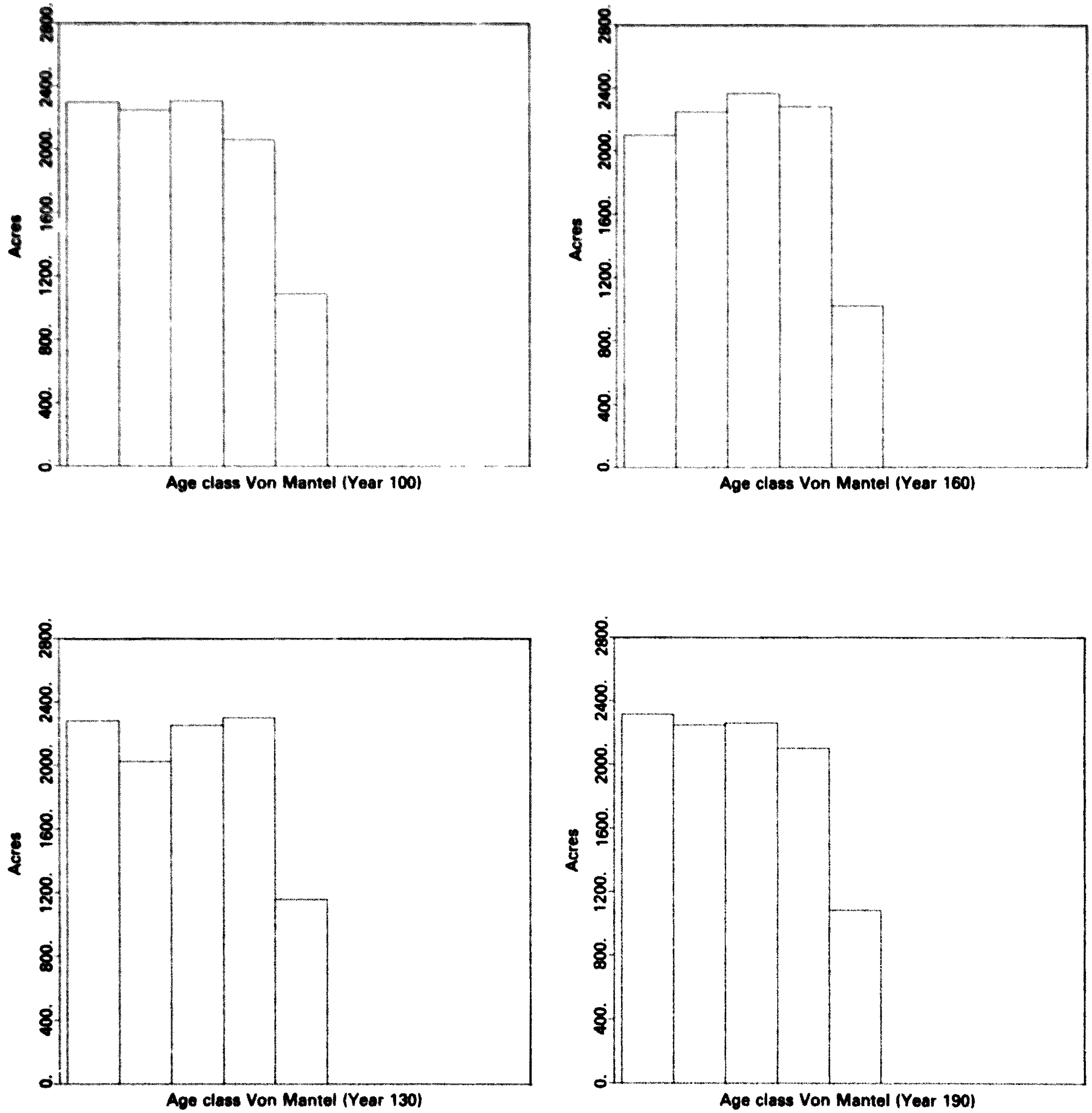

Figure 13. Age-class distribution, Bear Island State Forest.