10.0 Growth & Yield (Increment & its Accumulation)

The body of information and techniques concerned with estimating future forest conditions is known collectively as growth and yield.

How forest stands change over time is affected greatly by the age structure of the trees within the stand.

Even-aged stands are comprised of trees close in age (within 10 – 20 yr).

- Such stands generally are comprised of shade intolerant species occupying a site after a disturbance (e.g., fire, blow-down, clear cutting)
- Many of the commercially important coniferous species in North America are managed as even-aged stands; certain silviculture techniques produce single-cohort stands

Uneven-aged stands are comprised of trees that have a wide range of ages.

- Trees generally are shade tolerant, able to reproduce in their own shade
- Many uneven-aged stands (e.g., northern hardwood stands in the Northeast) are comprised of a wide variety of species

Predicting (forecasting) future forest growth is essential to credible forest planning

Growth and yield information is required to make all major forest management decisions.

Uses of growth and yield information

- Determining sustainable harvest levels
- Updating inventories
  - Expensive, yet needed for planning
  - G & Y predictions can "re-measure" plots
- Choosing silvicultural treatments
- Returns on investment
- Choosing "rotation age"
- Comparison of production
  - Same species on a different site
  - Different species on the same site

10.1 Growth of Trees

Tree growth consists of elongation and thickening of roots, stems, and branches

Growth causes trees to change in weight and volume (size) and shape (form)

Linear growth results from primary meristem activity; girth (diameter) growth results from secondary meristem (or cambium) activity, producing new wood and bark

Factors Affecting Tree Growth

Species - different species have different inherent genetic capabilities

Environmental Influences

Stable factors (do not change appreciably over the lifespan of a tree):

- Climatic factors - long term air temperature, average precipitation, insolation
- Soil factors - physical and chemical properties, moisture holding capacity, microorganisms
- Topography - slope, aspect, elevation

Transient factors (prone to changing cyclically or erratically over life time of tree):

- Weather - current (short term) air temperature, current precipitation, wind, cloud cover
- Competition - interference with other trees, lower statured vegetation, animals, diseases

Site quality - Sum of all environmental influences as they impact a *particular* species. Natural extremes exist for all species providing absolute limits, e.g., tree lines on mountains, polar / desert regions, etc.

Silviculture - fertilization, irrigation, drainage, juvenile (pre-commercial) spacing, thinning, tree improvement – in some respects, proper silviculture lessens the importance of competition

Considerations for Expressing Tree or Stand Growth

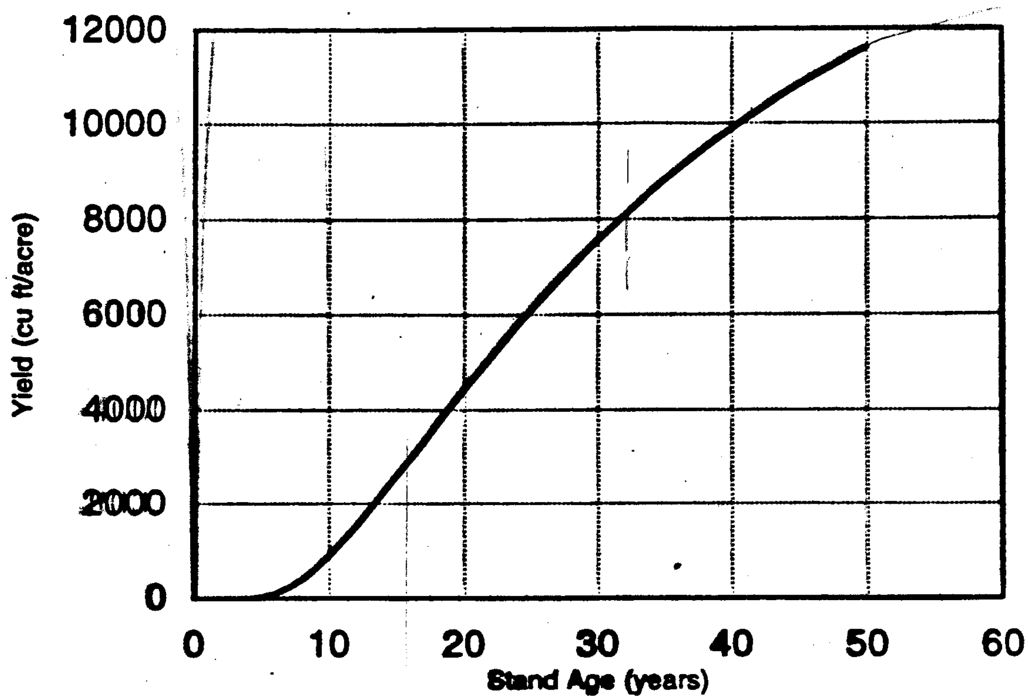
The increase in a tree (or stand) dimension should be qualified by the period of time during which the increment occurred

current annual increment (c.a.i.) – when the time period is a year, this is the difference between dimensions measured at the beginning of the period and at the end

periodic annual increment (p.a.i.) – because it is difficult to measure the change in some attributes for a single year, this is the average yearly growth for a fixed period of years, found by obtaining the difference between the dimensions of interest measured at beginning and end of the period, say five or ten years, divided by the number of years in the period

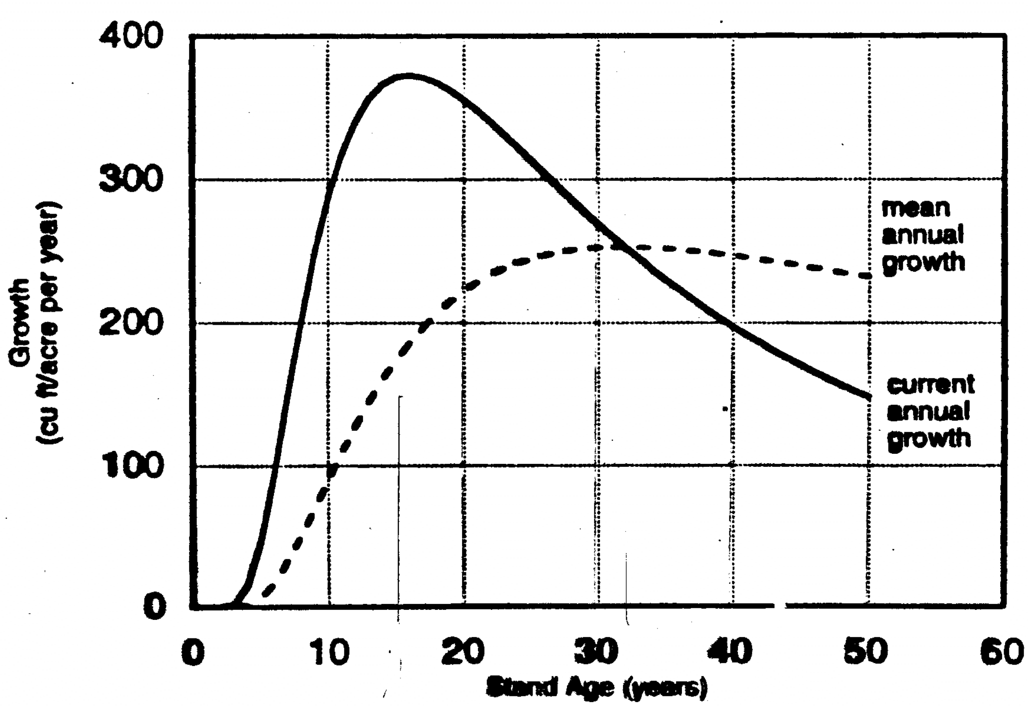
periodic increment – when the difference between beginning and ending dimensions is not divided by the length of the period *mean annual increment* (m.a.i.) – average annual increase to any age, is found by dividing current dimension by age

Yield Curves



Note that yield curves are "S-shaped" (sigmoidal), and represent accumulated (or attained) size for some tree (or stand) dimension

Growth Curves



Note that growth curves are peaked

CAI: Initial period of rapidly increasing growth, followed by a slower decline

Peaks at inflection point of yield curve

PAI: Expressed mathematically:

$$PAI_t = \frac{Y_t - Y_{t-p}}{p},$$ where t = time now; p = period of specified length

MAI: Can also be computed as the slope of a line drawn from the origin to a point of tangency to the yield curve

The age at point of tangency is called "culmination age"

Sometimes it is also called "biological rotation" age or point of maximum average production

10.2 Dimensional Increment

Height and DBH growth

Height - Shows a juvenile period of about a decade or less, a long maturing trend that is nearly linearly increasing, and a leveling off in old age

DBH - Trend is much the same as for height, except that the maturing trend is more curvilinear, and much of the juvenile period is unobservable, because trees have to be at least 4.5 feet tall to have a measureable diameter at breast height

Areal and Volume growth

Areal growth (growth in area) comprised of basal area growth and surface area growth, and volume (weight) growth may also be of interest

Cumulative growth (yield) curves for these are also S-shaped

Basal area may be measured from periodic measurements of DBH

Bole surface area growth may be estimated by calculating surface area from periodic measurements taken on a set of upper stem diameters chosen at fixed, predetermined heights (see Table A-3 in appendix of Husch, et al. 2003)

Volume growth may be estimated by taking period measurements of DBH; DBH and height; or DBH, height, and form, then applying an appropriate local, standard, or form-class volume table, respectively

One method has been devised for rapid field determination of current annual increment:

$$\Delta V = \frac{D \cdot H \cdot W}{100} = \frac{D \cdot H}{100 \cdot RI},$$

where, ΔV denotes c.a.i (cu.ft), *D* denotes dbhib (in.), *H* denotes total height (ft), *W* denotes width of last annual ring at breast height (in.), and *RI* denotes rings per inch based on latest period of growth

Stem analysis is the most accurate way to measure areal and volume growth directly

10.3 Stem Analysis

Knowing how a tree grew in the past sheds light on how it responded to environmental conditions over its lifespan

A record of how a tree grew in height and diameter and changed in form is available from stem analysis

In conducting a stem analysis, one counts and measures the growth rings on stem cross-sections at different heights above the ground

Measurements can be taken on a standing tree using an increment borer, or on a felled tree that has been bucked into cut, cross-sections

Diameter and section measurements are conveniently recorded as in the following table:

Measurements for Stem Analysis of a 34-Year Old Red Oak

Species Red Oak **DBH** 10.2″ **Total Height** 54′

Years to attain stump height 2 **Total Age** 34

Date March 2, 1968 **Measured by** CIM

Section No.	Length (feet)	Top Dib (inches)	No. of Rings at Top	Distance Along Average Radius from Heart to Each 10th Ring-Inches (inches)*									
				1	2	3	4	5	6	7	8	9	10
1 stump	1	10.3	32	0.65	2.50	3.80	5.15						
2	16	8.7	24	1.30	3.00	4.35							
3	16	6.0	17	1.65	3.00								
4	14	2.7	9	1.35									
5	7	0	0										

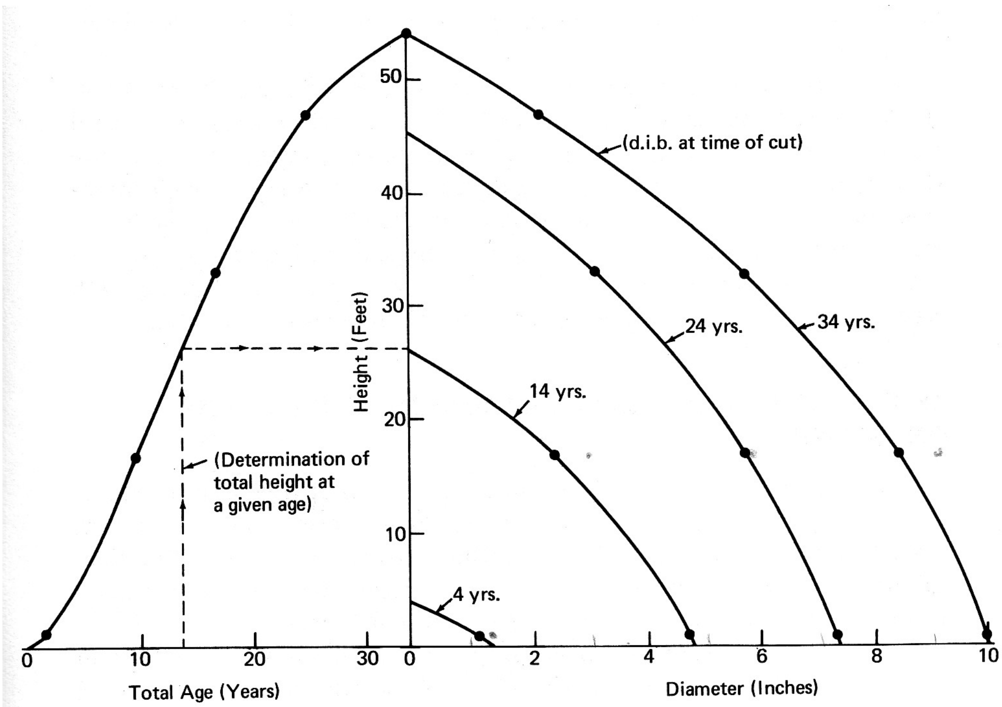
*Double these values to give average diameters when plotting taper curves.

The following table shows a useful way to summarize height measurements

Height Summary for Stem Analysis of a 34-Year Old Red Oak

	Section No.				
	1	2	3	4	5
Length (feet)	1	16	16	14	7
Height above ground of top of section (feet)	1	17	33	47	54
Ring count top of section	32	24	17	9	0
Years to grow section	2	8	7	8	9
Years to attain height at top of section	2	10	17	25	34

The following figure shows how data from the two previous tables can be summarized graphically



The process unfolds by first plotting attained total height above ground for the top of each section over years to attain that height

Then diameters from the top of each section for each growth period are plotted at a height above ground equivalent to the top of the section

Diameters representing the same age are then connected to form a series of taper curves for the specified periodic ages

The terminal position of each taper curve is estimated from the curve of height over age

10.4 Growth Percentage

Growth Percentage is also known as Relative Growth. Expresses PAI as a percentage of initial yield. Sometimes simply called "growth rate." Although most typically used for expressing volume or basal area growth, can be used for any tree parameter

Expressed mathematically and analogously with *simple interest* rate:

$$G\% = \frac{PAI_t}{Y_{t-p}}(100) = \frac{Y_t - Y_{t-p}}{p \bullet Y_{t-p}}(100)$$

In terms of *compound interest* rate, growth percent is:

$$G\% = \left(\sqrt[p]{\frac{Y_t}{Y_{t-p}}}\right)100, \qquad \left[\text{or} \quad G\% = \left(\frac{Y_t - Y_{t-p}}{Y_t + Y_{t-p}}\right)\frac{200}{p}\right]$$ (Pressler's formula)

Use of compound interest is based on the premise that the increment of each unit of time is accumulated, that is to say, Y_t increases slowly at first, then at an increasing rate.

By comparison, the longer the period, the more simple and compound growth rates will diverge. For short periods, they will be almost the same.

Growth percentages are ratios between increment and initial size, so percentages change as both the amount of increment changes and as the base upon which it accrued changes

Generally, as trees grow, the base of the percentage steadily increases, thus growth percentage declines even though absolute increment may remain steady or even increase slightly

Growth percentage may be a satisfactory tool for forecasting tree growth over short periods, but is generally unsafe for long periods due to uncertainty in extrapolating growth percent curves

For example, compound growth formula can be equivalently expressed with a little algebraic rearrangement to be a yield forecast:

$$\left(1 + \frac{G\%}{100}\right)^p = \frac{Y_t}{Y_{t-p}} \quad \text{i.e.,} \quad Y_{t-p}\left(1 + \frac{G\%}{100}\right)^p = Y_t$$

Summary Ideas

Growth - change in some characteristic (attribute) of a tree or stand over some fixed time interval. Growth is also known as increment. Growth is a biological production *rate* concept

Yield - the quantity of some attribute of a tree or stand at a given point in time. Yield is sometimes called cumulative growth. Yield is an accumulation or removal (harvest) concept

Many factors influence growth, including species, relatively stable environmental factors, transient environmental factors, site quality, and silviculture

The resultant of all tree growth (increment) on a typical acre is stand growth or stand change (stand dynamics)