FOREST GEOMETRY & THE LIVING BLUEPRINT

Translating growth metrics into practical field and inventory methods.



From growth curves to non-destructive measurement

BIG IDEA

Good forest measurement connects growth theory with reliable field observations.

The Core Metrics of Forest Growth

Three measures describe how much a forest grows and how quickly it grows.



Current Annual Increment (CAI)

Formula:

$$V_t - V_{t-1}$$

Timeframe: 1 year (the latest).

Biological Meaning: The immediate pulse of stand productivity.



Periodic Annual Increment (PAI)

Formula:

$$\frac{V_{t2} - V_{t1}}{t_2 - t_1}$$

Timeframe: 5–10 year average.

Biological Meaning: Smoothes out short-term climate anomalies.



Mean Annual Increment (MAI)

Formula:

$$\frac{Y(t)}{t}$$

Timeframe: Cumulative (Stand age).

Biological Meaning: The lifetime average productivity up to a specified age.

The differences

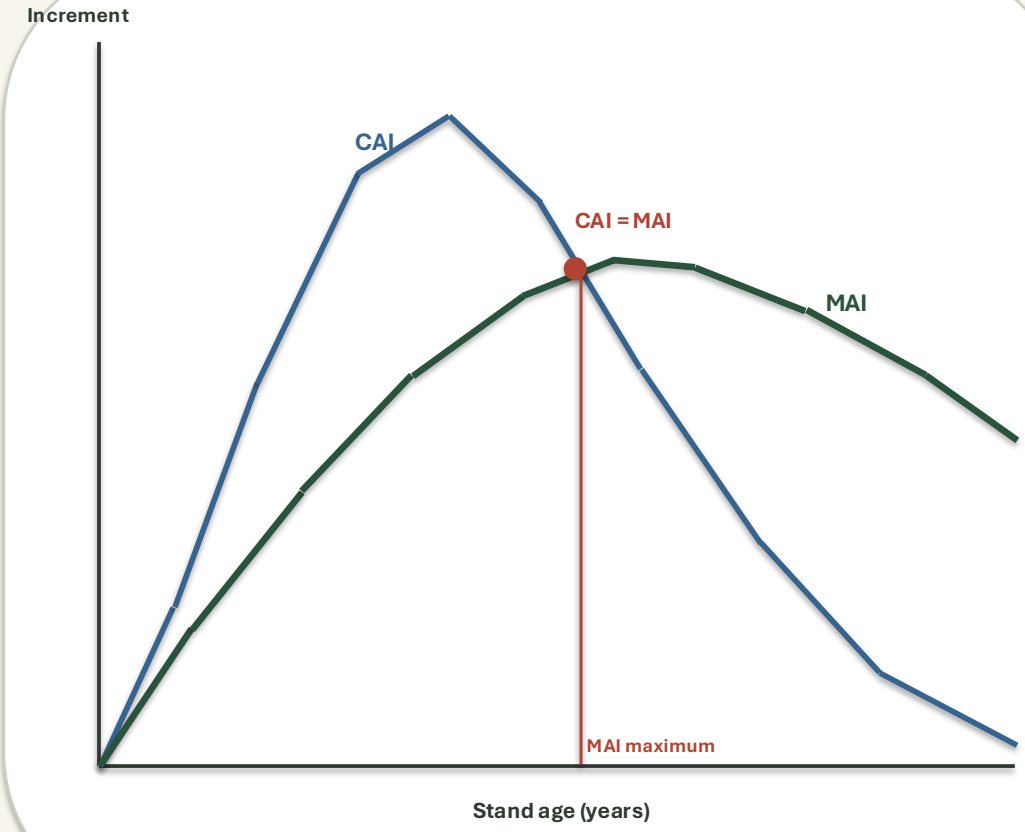
- CAI: growth in the most recent year.
- PAI: average annual growth across a selected period.
- MAI: average annual growth since the stand began.

FIELD MEANING

Each metric answers a different question about stand productivity.

Finding the CMAI: When MAI Reaches Its Peak

The key relationship for maximum average growth is CAI = MAI.



HOW TO READ THE GRAPH

Before the intersection

CAI is above MAI, so MAI increases.

At the intersection

CAI equals MAI; MAI is at its maximum.

After the intersection

CAI is below MAI, so MAI declines.

Schematic illustration — not measured data.

Where Does PAI Fit In?

PAI and CAI are related, but they are not interchangeable.

PAI • PERIODIC AVERAGE

$$PAI = (V_2 - V_1) / (t_2 - t_1)$$

Average annual volume growth over a selected time interval.



Use PAI to compare growth across a defined period.

CMAI • MAXIMUM AVERAGE GROWTH

1 **Focus on MAI**

MAI is average annual growth since establishment.

2 **Use CAI–MAI**

The MAI peak occurs where CAI = MAI.

3 **Keep terms clear**

PAI depends on the selected interval; it does not automatically identify CMAI.

Takeaways & Reflection

Connect growth measures to forest management decisions.

01 CAI, PAI AND MAI USE DIFFERENT TIME FRAMES

CAI = latest year • PAI = selected period • MAI = average since establishment.

02 CMAI IS THE PEAK OF MAI

In the standard growth-curve relationship, MAI reaches its maximum where CAI = MAI.

03 CMAI IS ONE MANAGEMENT REFERENCE

Rotation planning must also consider ecological, economic and operational objectives.

REFLECTION

1. Why does CAI = MAI indicate maximum average growth?
2. Would you always harvest at the CMAI age? Why or why not?

The Measurement Paradox

We need reliable growth data without damaging the trees being measured.

The mathematics of rotation age demand precise CAI data. However, accurately measuring current annual volume growth traditionally requires felling trees to analyse stems. Thus, we need a method to calculate the volume increment of standing trees.



The Goal: Sustainable Standing Measurement



The Traditional Method: Destructive Stem Analysis

The challenge

- Destructive methods can provide detailed information.
- But cutting or sampling trees damages the resource.
- Sustainable inventories need non-destructive alternatives.

TARGET

Measure growth accurately while keeping the forest standing.

The Bottleneck: Estimating Height Increment (Δh)

Accurately measuring height growth in a standing forest is difficult.

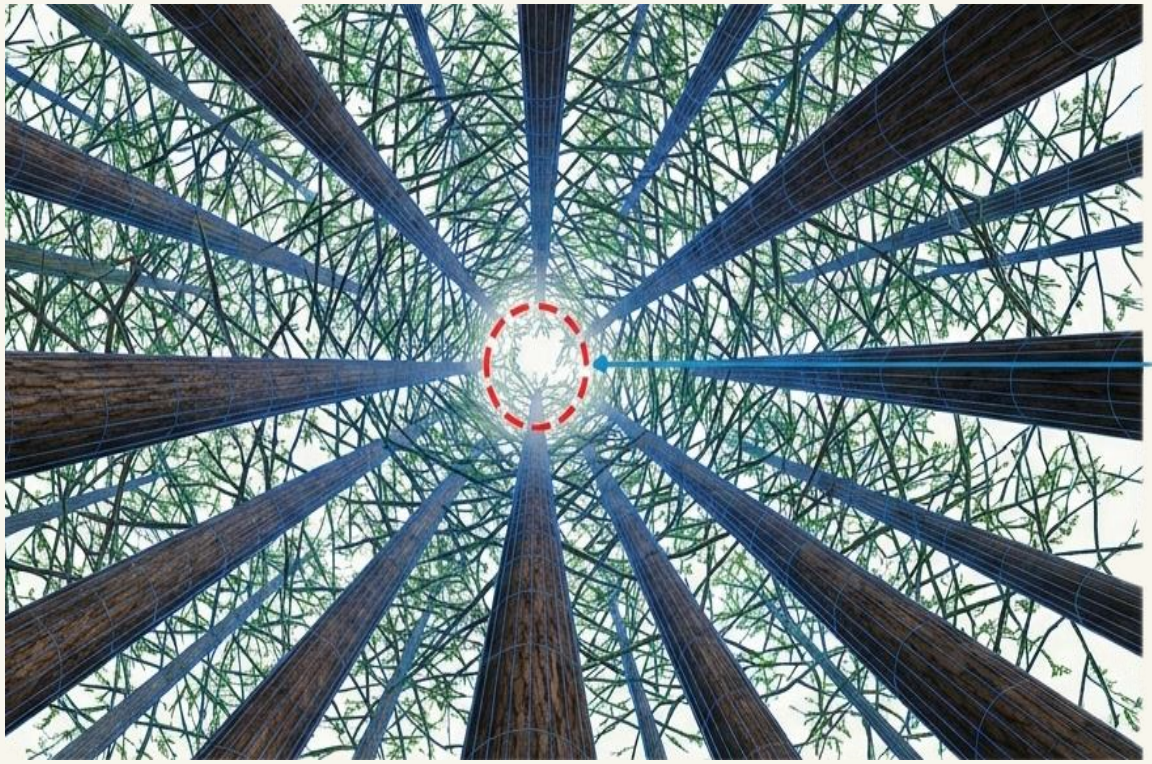
While radial growth is accessible, Δh is nearly impossible to measure on standing mature trees. Without Δh, Schneider's K becomes a guess, and the entire CAI calculation falters. We must estimate Δh mathematically.

Why is it difficult?

- The tree crown may block the true top.
- The observer may not see the full stem clearly.
- Small height errors can affect increment calculations.

FIELD MESSAGE

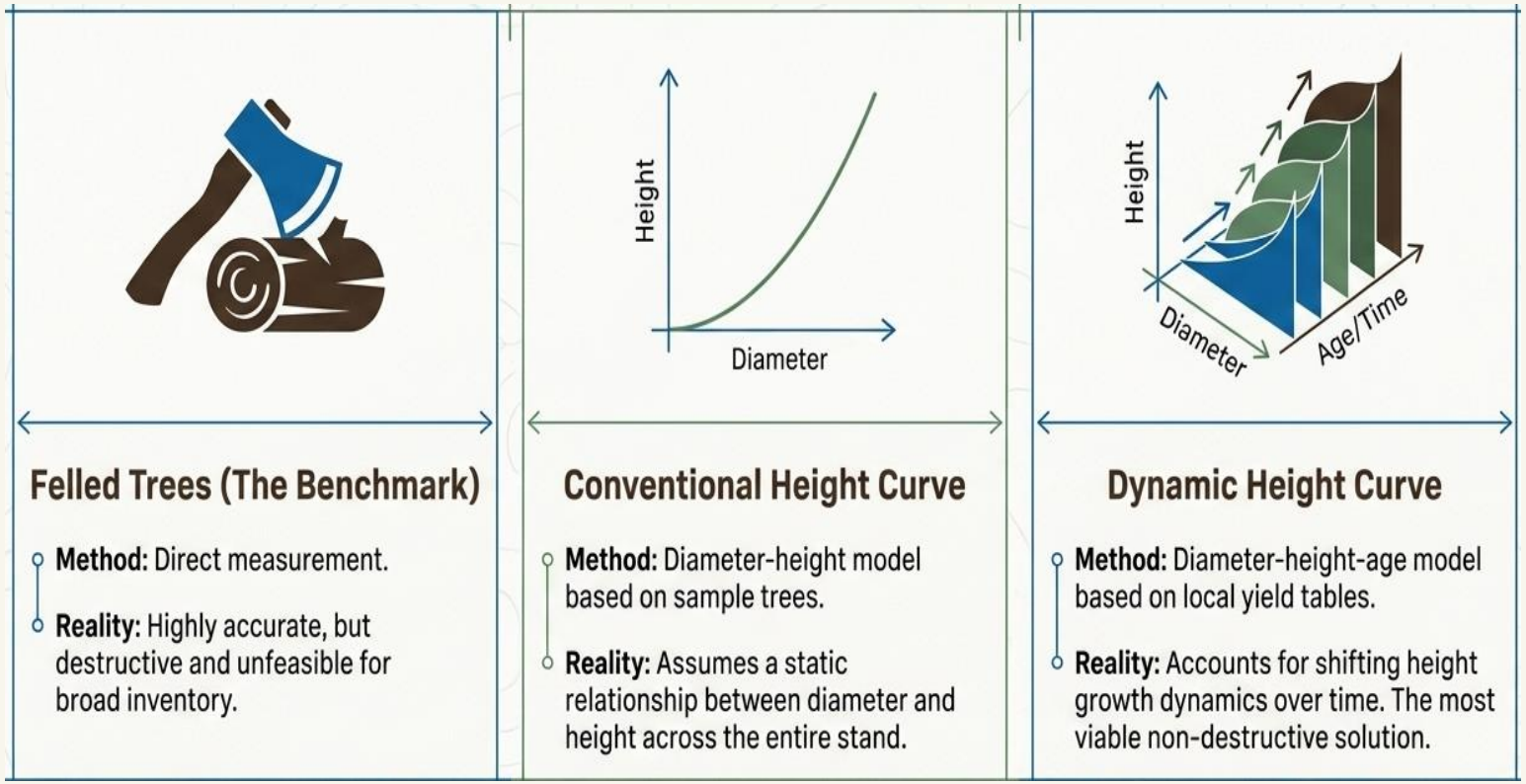
Accurate height measurement is often the hardest part of the calculation.



Visual obstruction: Impossible to accurately measure annual apical growth from the ground.

Three Approaches to Estimating Δh

Choose the method based on accuracy needs and field effort.



Felled Trees (The Benchmark)

- **Method:** Direct measurement.
- **Reality:** Highly accurate, but destructive and unfeasible for broad inventory.

Conventional Height Curve

- **Method:** Diameter-height model based on sample trees.
- **Reality:** Assumes a static relationship between diameter and height across the entire stand.

Dynamic Height Curve

- **Method:** Diameter-height-age model based on local yield tables.
- **Reality:** Accounts for shifting height growth dynamics over time. The most viable non-destructive solution.

Method options

- Felled trees: direct measurement, but destructive.
- Conventional height curve: easier, but may underestimate.
- Dynamic height curve: uses modelled height–diameter relationships.

BALANCE

The best method balances accuracy, cost and field practicality.

Why Conventional Curves Can Flatten Out

A single curve may not represent height growth across all diameter classes.

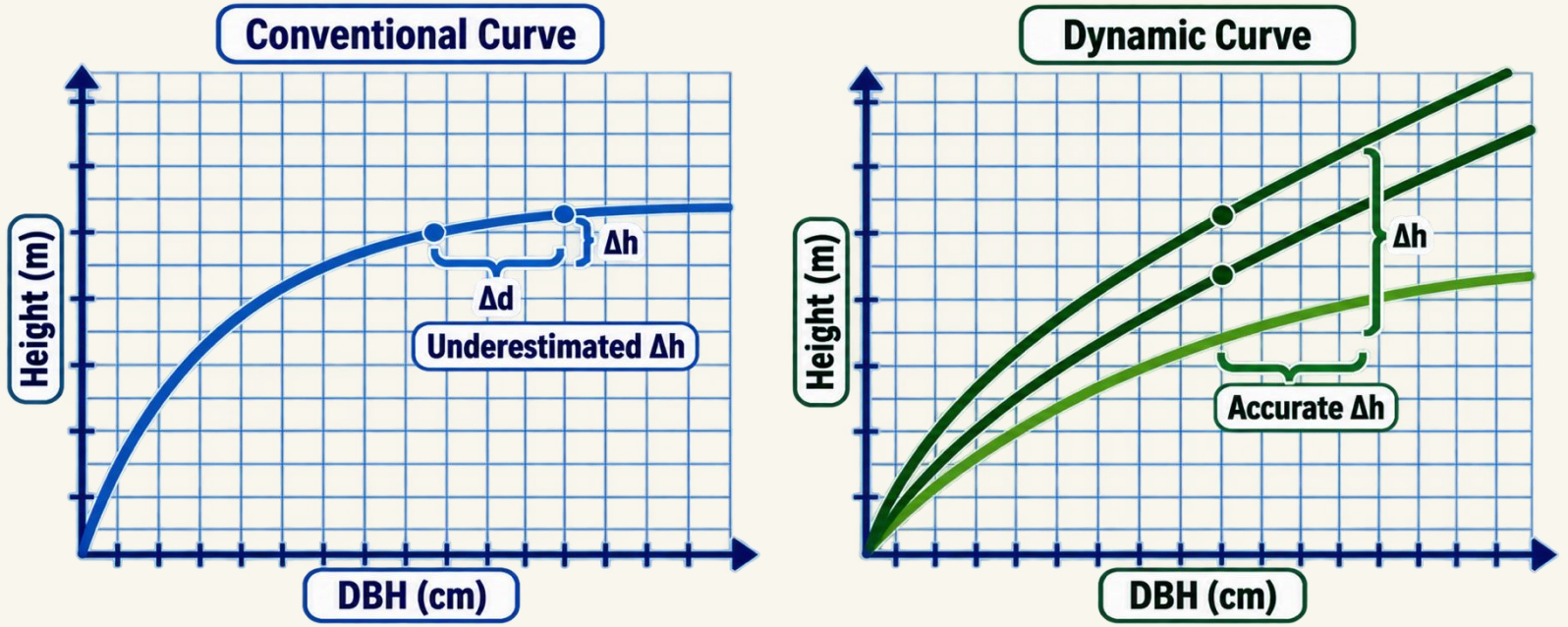
In mature, even-aged stands, tree height varies little as diameter increases. Estimating Δ*h* through a conventional static curve often yields falsely low values. Dynamic curves integrate age class & create steeper/accurate representation of actual growth.

The problem

- A conventional curve assumes a stable height–diameter pattern.
- Real trees may have different growth histories.
- The same diameter may be linked to different heights.

IMPLICATION

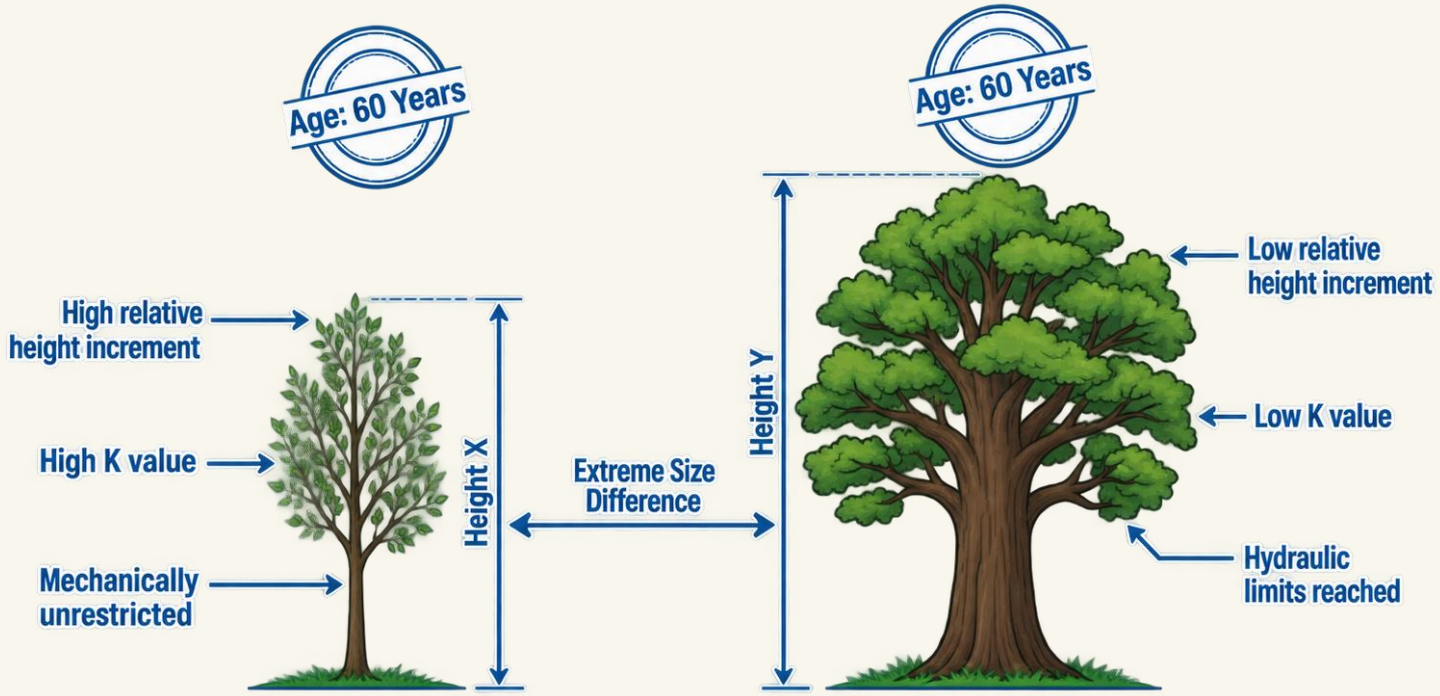
Dynamic curves may better reflect changing stand conditions.



Size vs Age: Redefining Growth Constraints

Tree size is shaped by more than chronological age.

The data reveals a critical biological truth: the reduction of height increment is driven by functional tree-size constraints (hydraulics and mechanics), not strict chronological age. Small, suppressed older trees can still exhibit high relative height increments. K values must be assigned by size, not age.



What can influence growth?

- Hydraulic and mechanical limits.
- Tree size and crown structure.
- Suppressed trees may show different growth patterns.
- Chronological age alone cannot explain every change.

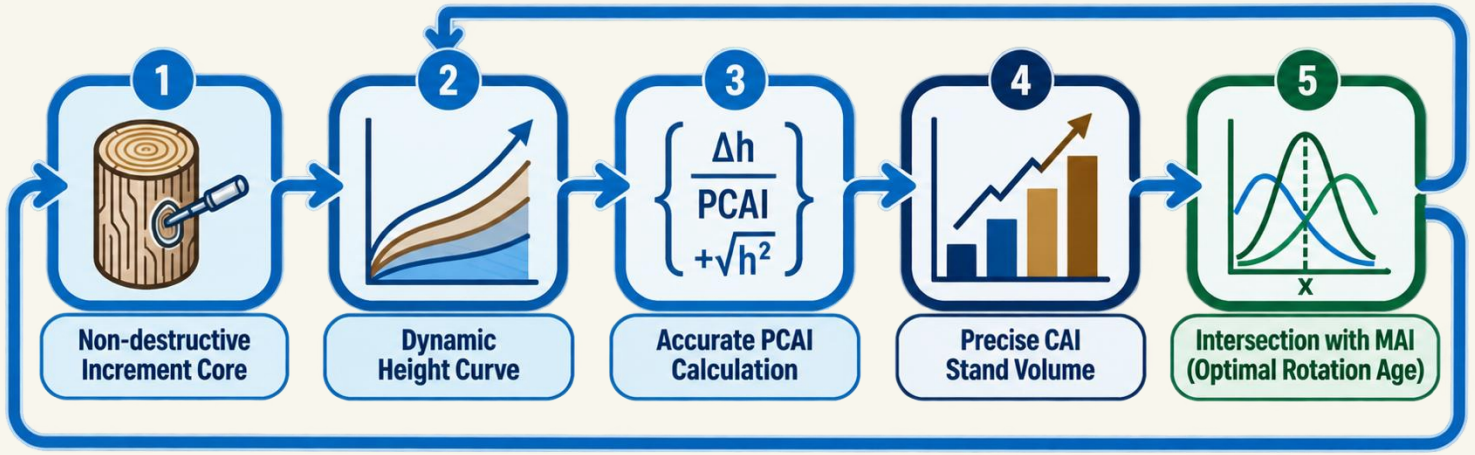
KEY POINT

Measure the tree's condition and structure, not only its age.

Synthesis: The Non-Destructive Blueprint

A practical workflow links growth theory, field measurement and model selection.

By utilising size-based dynamic height curves to estimate Δh, foresters can accurately calculate the CAI of standing volumes. This solves a century-old mensuration problem, pinpointing the biologically optimal rotation age through precise mathematics, entirely non-destructively.



The workflow

1. Measure radial growth without cutting trees.
2. Estimate height increment with a suitable curve.
3. Calculate PCAI and stand volume.
4. Compare results with MAI and rotation analysis.
5. Validate the method for the local forest.

REFLECTION

How can non-destructive methods improve both forest monitoring and sustainable management?