ForHeal Forestry Higher Education Advancement in Laos

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FOREST RESOURCE INVENTORY AND PLANNING

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UNIVERSITY OF HELSINKI · VITRI · UNI FREIBURG · CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE · National University of Laos · Souphanouvong University · Savannakhet University

FOREST MENSURATION

- One of the most fundamental disciplines within forest and related sciences
- Deals with the technical aspects of tree and forest stand measurements
  - measurement of tree variables - DBH, height
  - determination of form factor, age, basal area, tree volume
  - estimation of biomass, total and merchantable stand volume
- Deals with relations among tree/stand variables; instruments and tools
- Provides information at stand, local, regional and national level for forest management planning, forest policy decision, ...

Van Laar, A., Akça A., 2007: Forest Mensuration. Elsevier

ESTIMATION

- Errors
  - Absolute – how far is measurement (y) from true value (Y) $e = y - Y$
  - Relative – expresses how large the absolute error is compared with the true value $e\% = \frac{y}{Y} * 100$
- Systematic error (bias) – consistent, repeatable error associated with faulty equipment or a flawed experiment design (fixed amount or a proportion, the same direction) – removable
- Random error - completely random, it is unpredictable and can't be replicated by repeating the experiment again (produce different values in random directions) – unrecoverable

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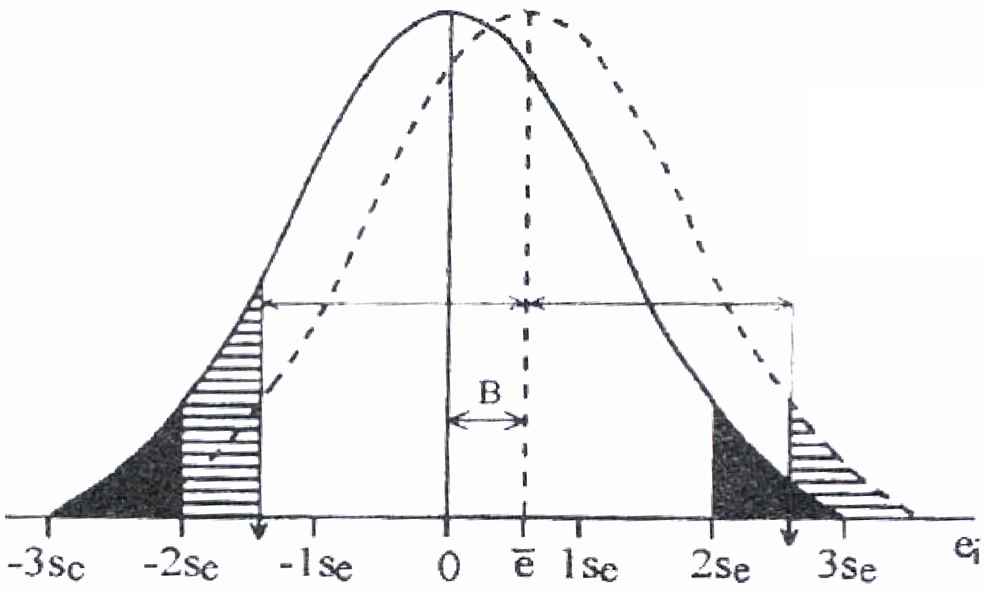
ESTIMATION



- Bias

$$B = \bar{e} = \frac{\sum_{i=1}^{n} e_i}{n} d^2$$

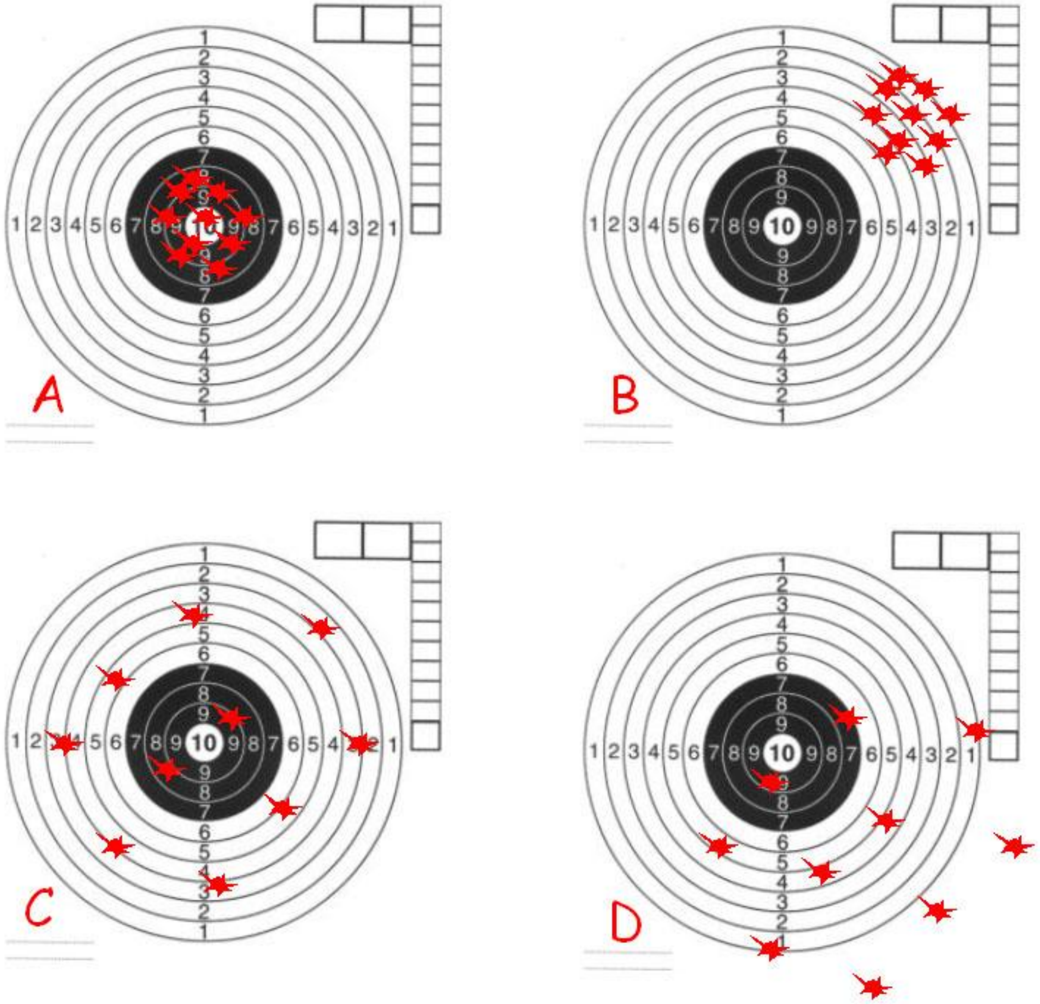
- Precision – expresses closeness of the measurements to their mean (standard devitation)

$$s_e = \sqrt{\frac{\sum_{i=1}^{n} (e_i - \bar{e})^2}{n-1}}$$

- Accuracy – combines bias and prediction and expresses the closeness of the observed measurements to their true value

$$m_y = \sqrt{\frac{\sum_{i=1}^{n} {e_i}^2}{n}}$$

ESTIMATION

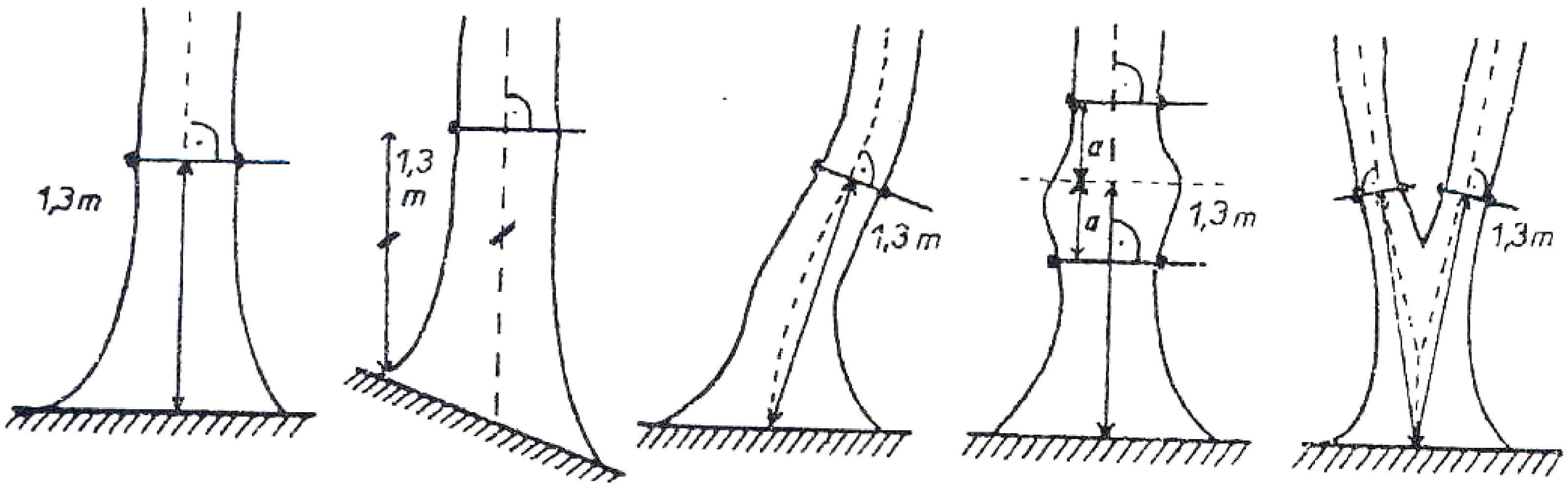


- A – Bias? Precise? Accurate?
- B – Bias? Precise? Accurate?
- C – Bias? Precise? Accurate?
- D – Bias? Precise? Accurate?

- Is it possible to make precise and accurate from imprecise and inaccurate? Which one?

DIAMETER (d, DBH)

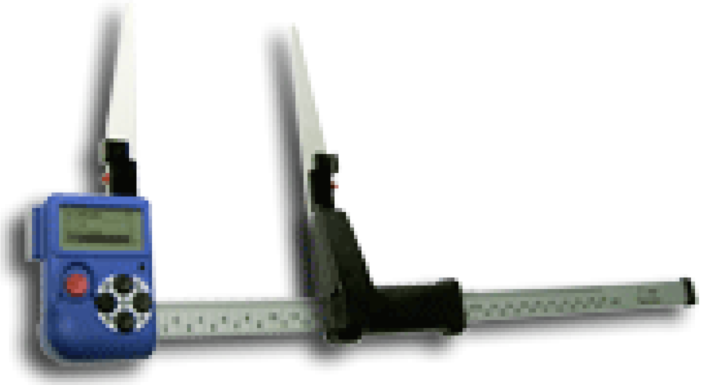
- usually over bark diameter at a fixed distance from the base of the tree – 1.30m or 4.5ft (1.37m); $d_{o.b.}$; $d_{u.b.}$



DIAMETER (d, DBH)

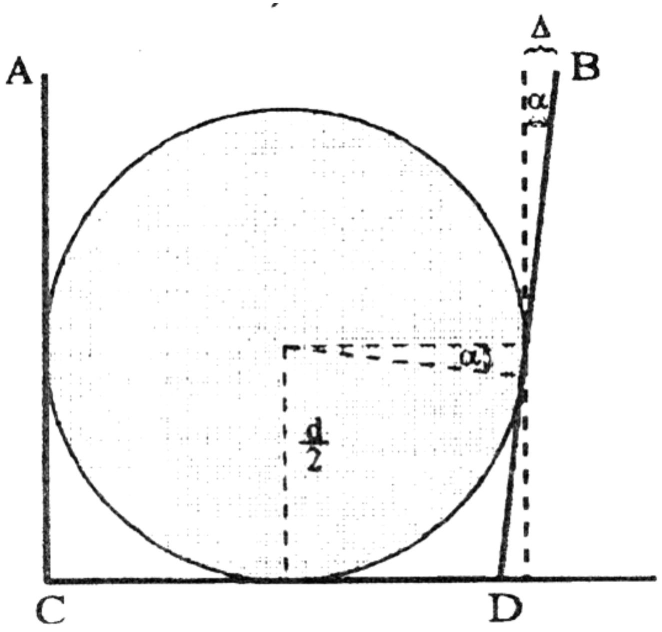
- Calipers

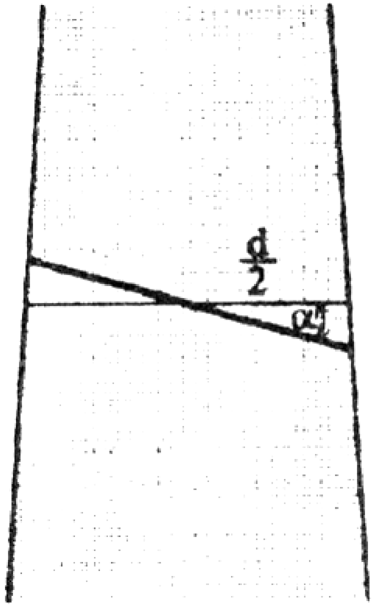


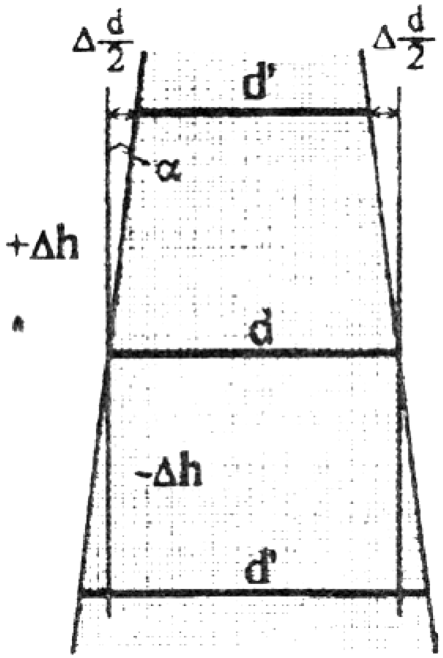



DIAMETER (d, DBH)

- Measurement errors





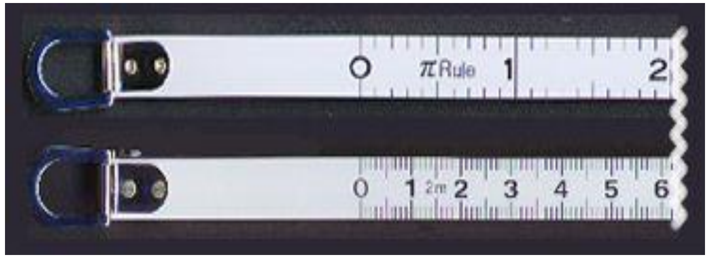


BASAL AREA (g, BA)

- Cross-sectional area of the stem, either at breast height or at specified height above the base of the tree
- Derived from the tree diameter or from the stem circumference measured with a tape

$$BA = \frac{\pi}{4} d^2$$

$$\boldsymbol{m_g = 2m_d}$$



$$BA = \frac{C^2}{4\pi}$$

$$\boldsymbol{m_{gc} = 2m_c}$$

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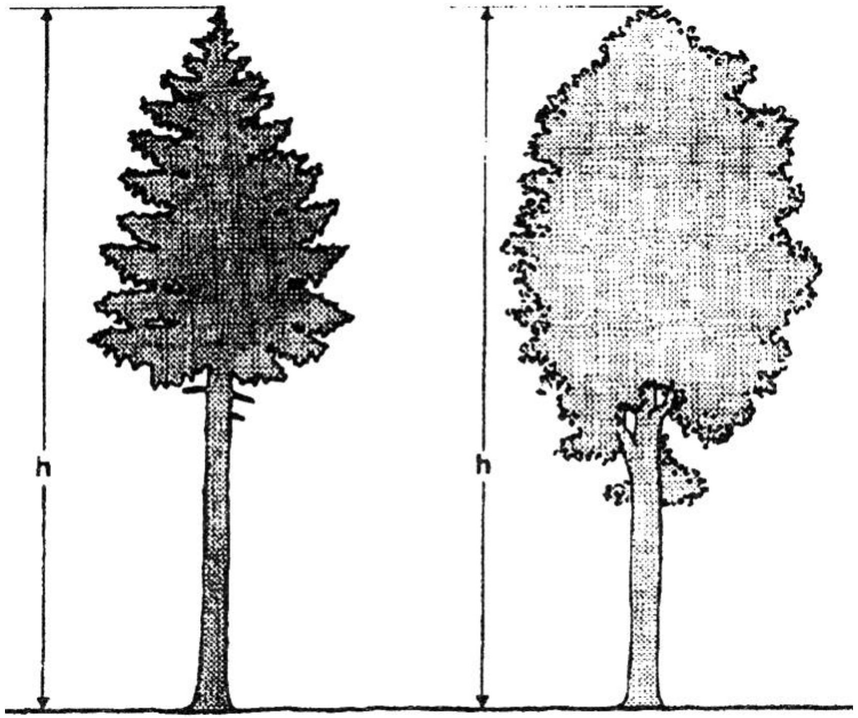
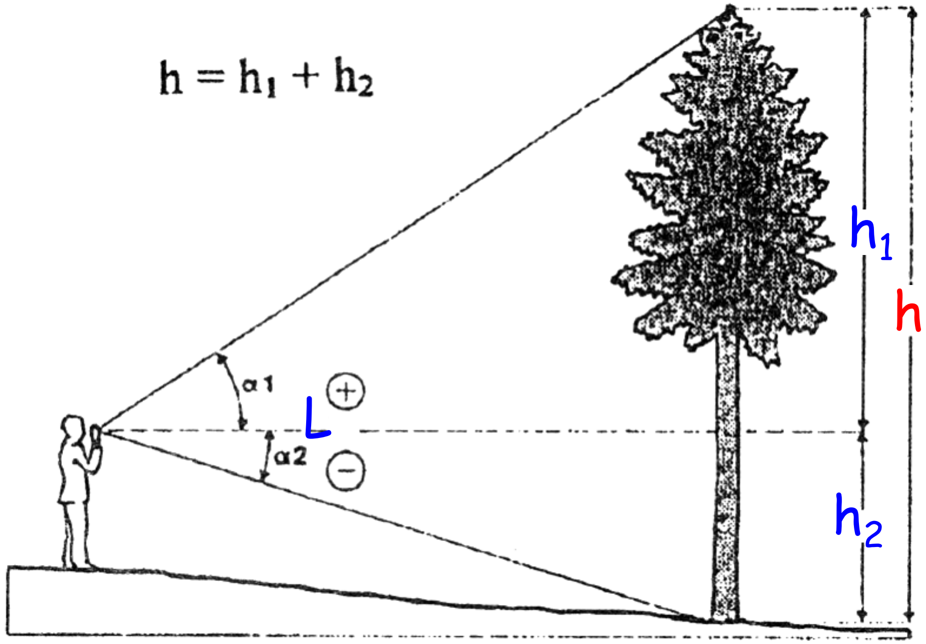
TREE HEIGHT (h)

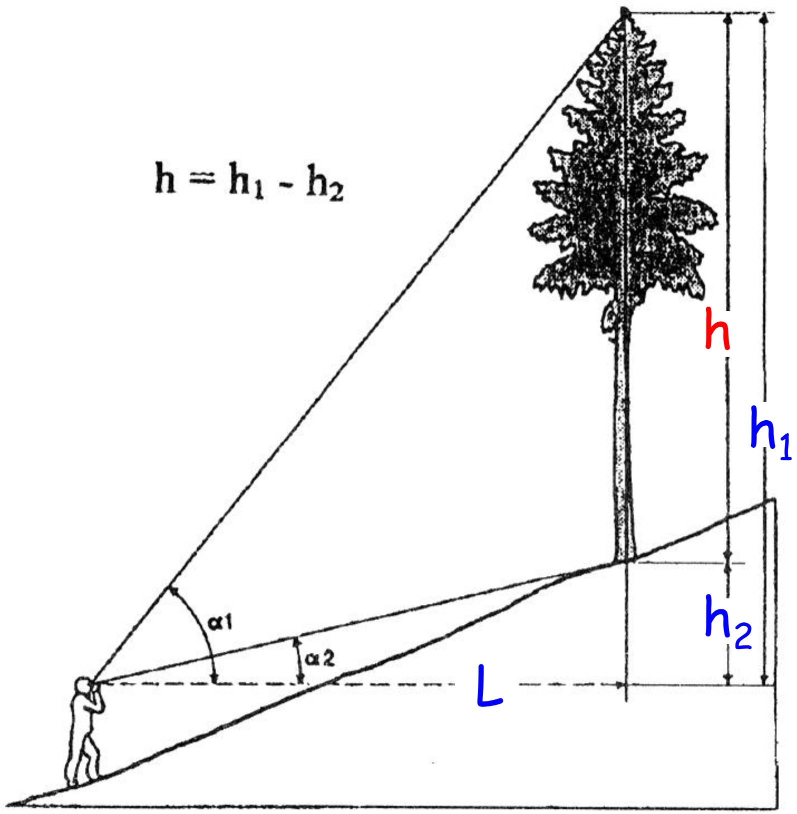
- Distance between the top and base of the tree, measured along a perpendicular dropped from the top
- Merchantable height – upper point of measurement, which coincides with the limit of merchantability



TREE HEIGHT (h)

- Trigonometric principle





Measuring uphill

TREE HEIGHT (h)

- Hypsometers

Vertex (ultrasound)

Laser Vertex

Suunto

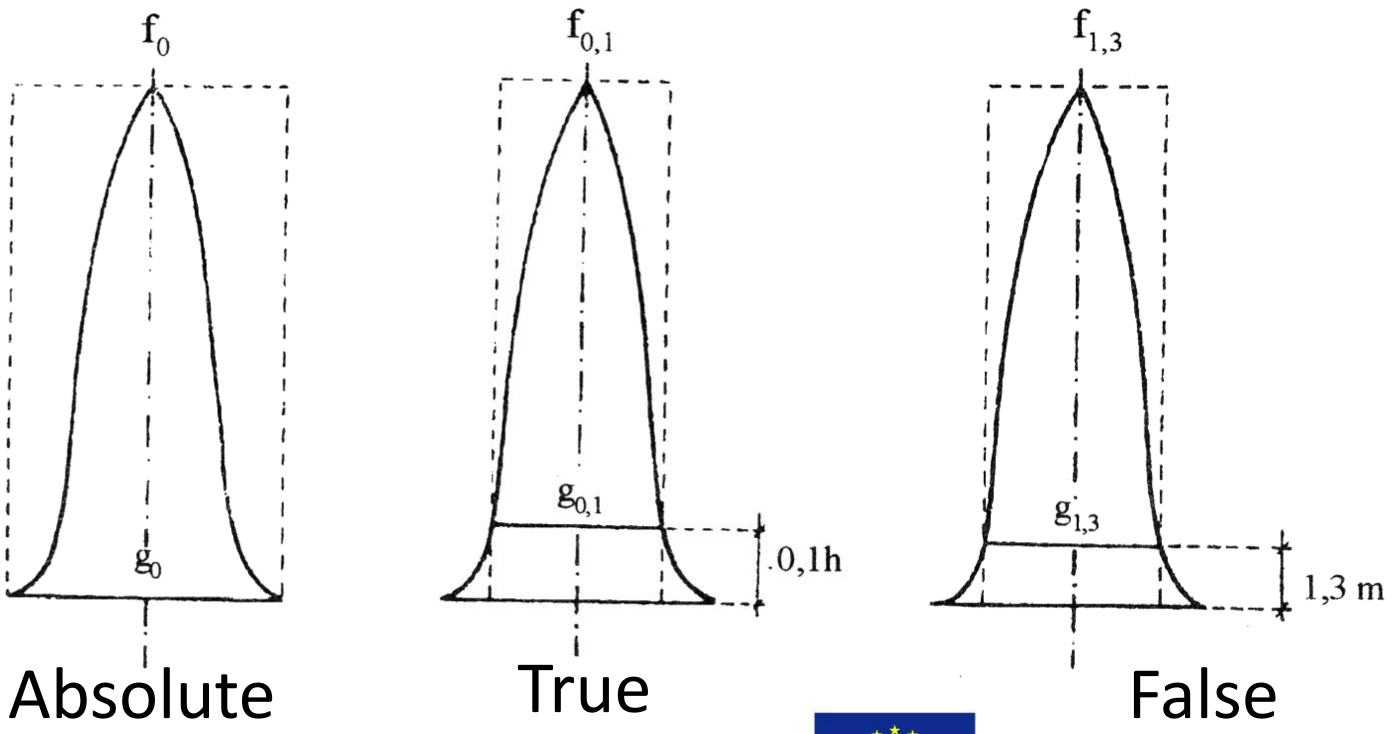
HEC

Silva

FORM FACTOR (f)

- Is definied as stem volume, expressed as a proportionn of the volume of a cylinder of the same height, with a diameter equal to the stem diameter at the selected reference point

$$f = \frac{stem\ volume}{cylinder\ volume}$$

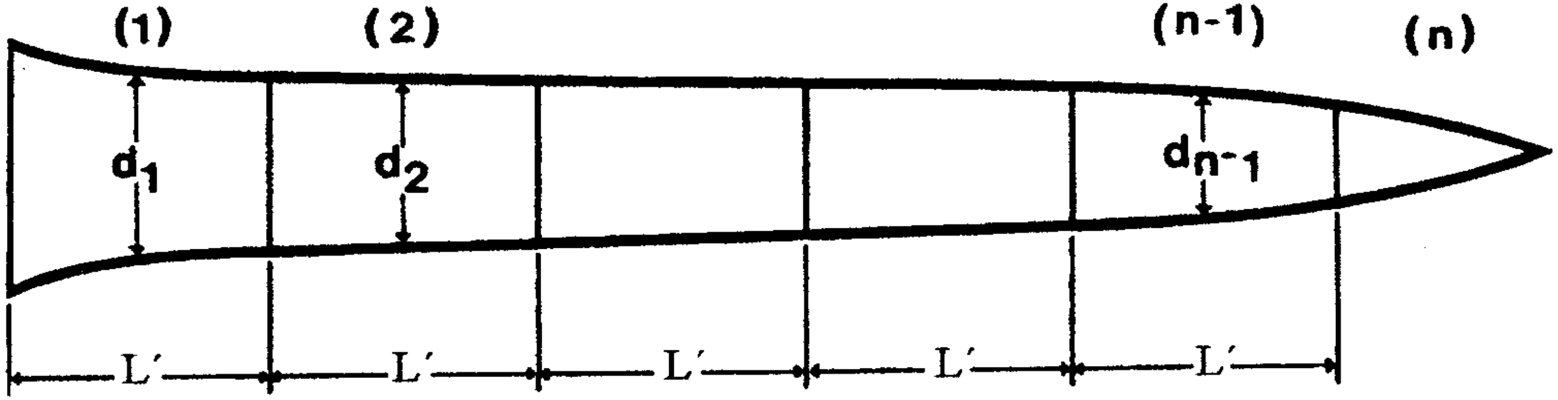


ROUNDWOOD VOLUME (v)

- to estimate parameters of volume equations and to construct volume tables

$$v = g * l = \frac{\pi}{4} d^2 * l$$

$$v = v_1 + v_2 + \cdots v_{n-1} + v_n$$



$$v = L^{'}(g_1 + g_2 \cdots g_{n-1}) + (g_n * l_t)$$

$$v = \frac{\pi}{4} L^{'}(d_1^2 + d_2^2 \cdots d_{n-1}^2) + \frac{\pi}{4} d_n^2 * l_n$$

ROUNDWOOD VOLUME (v)

Huber – cross-sectional area at the midpoint

$$v = g_m * l$$

Smalian – cross-sectional area at the lower and upper end

$$v = \frac{g_u + g_l}{2} * l$$

STACKED WOOD VOLUM (v)

- Volume is determand conversion factor applied to adjust for a free space between the roundwood logs (for example 1x1x1m = approx. 0.60-0.70m^3)
- photos
- weight

$$v = w * \rho$$

for example 1 tonne = 420 – 500 kg/m^3 depending on the moisture (water content) and age

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TREE VOLUME (v)

- Volume
  - stem volume, total tree volume (including branches), merchantable volume
  - over or under bark

$$v = g * h * f$$

- estimation

$$v = 0.785d^2 * h * 0.45$$

TREE VOLUME TABLES AND EQUATIONS

- number of entries and predictor variables of the volume function
  - single-entry volume function – dbh
  - two entries – dbh and height
  - more entries – dbh, height + entry X (diameter at 30% of the height, height above ground of the base of the life crown, etc.)

$$v = a + b * DBH^2 * h$$

$$v = a * DBH^b * h^c$$

$$v = a * DBH^b$$

$$v = a * (DBH^2 * h)^b$$

Merchantable volume proportion V5/V

STAND VOLUME (V)

- Whole stand calipering
- Sampling - representative methods
- Mean tree volume
- Yield tables
- Estimation

STAND VOLUME (V)

- Whole stand calipering
  - DBH measurement of all trees
    - DBH classes (2cm, 4cm, etc.)
    - Individual DBH – electronic caliper
  - Height of samples (approx. 5 per dbh class)
    - Strong correlation between height and DBH
    - Time consuming measurement

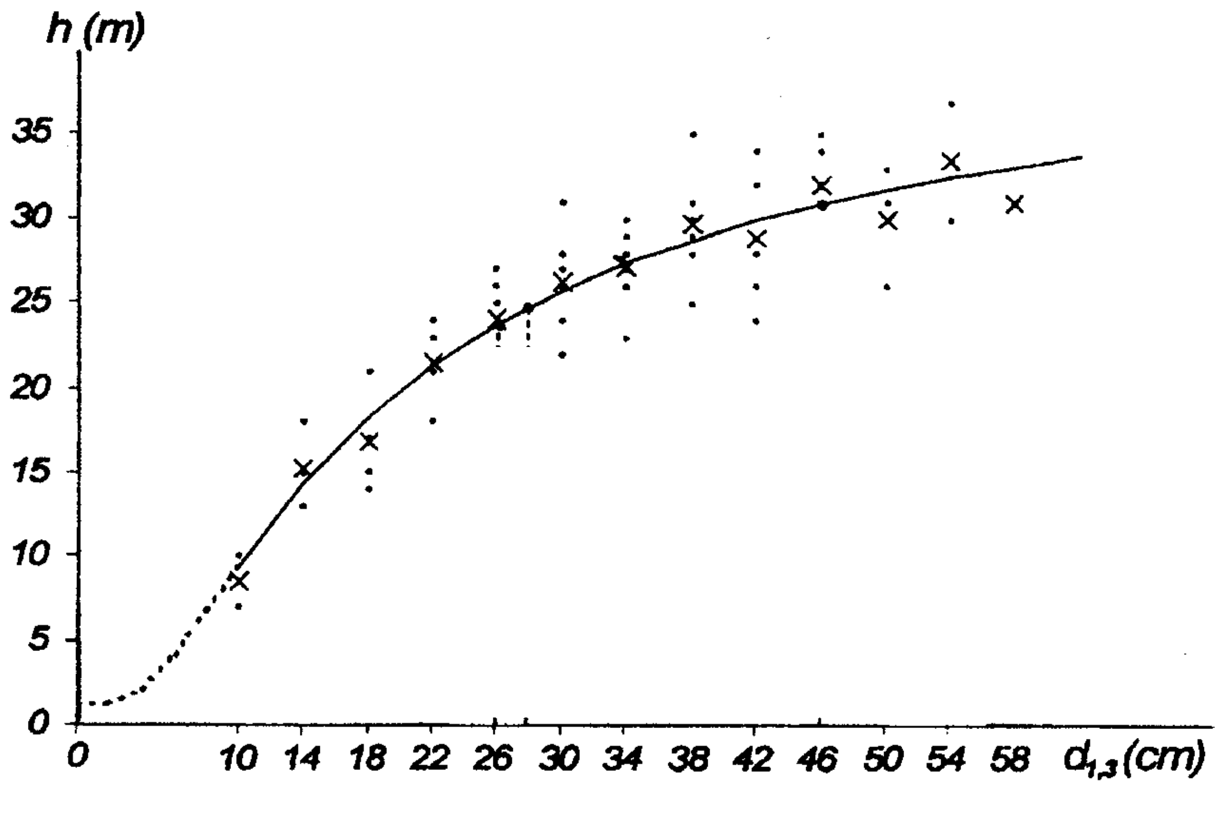
STAND VOLUME (V)

- Height curve fitting

$$h = 1.3 + a * e^{DBH/d}$$

$$h = 1.3 + \frac{DBH^2}{b_0 + b_1 * DB + b_2 * DBH^2}$$

$$h = b_0 + b_1 * ln(BDH)$$



STAND VOLUME (V)

- Volume of individual tree
  - DBH and fitted height
  - Using volume equation or volume tables
- Stand volume = sum of volume of individual trees

- Most precise method
- Electronic devices, softwares

STAND VOLUME (V)

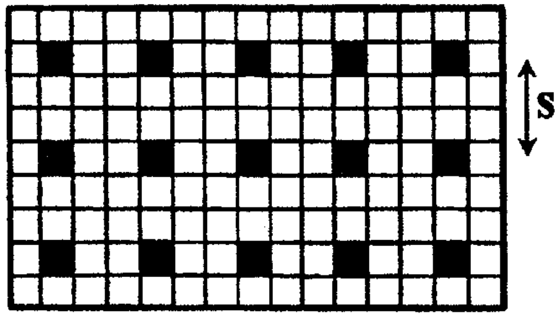
- Sampling
  - Especially for large fprest units - to spare time and money
  - Effective in evaluation of development
- Consists of *n* sampling units on which tree are measured or estimated

N = 135; n = 15 (I = 11 %)

$$n = \frac{t_{\propto}^{2} * \sigma_{x}^{2}}{\Delta_{\bar{x}}\%}$$

$$\mu - \bar{x} = \Delta_{\bar{x}}\%$$

$$V = V_{SP}\frac{100}{I\%}$$



t_{α} – reliability coeficient (1.96)
σ_{x} – variability
Δ_{x} – accetable error

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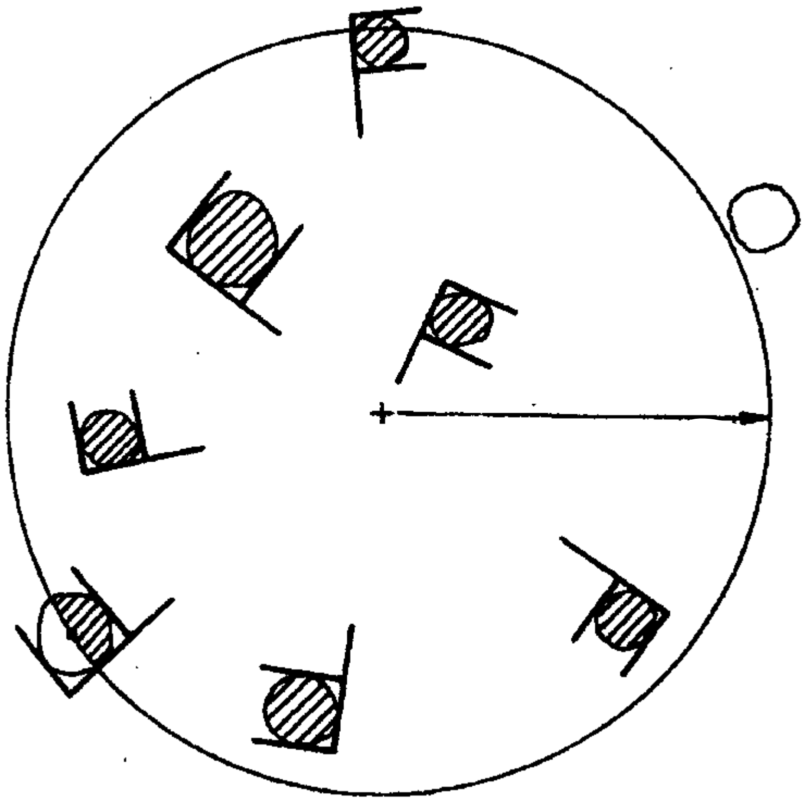
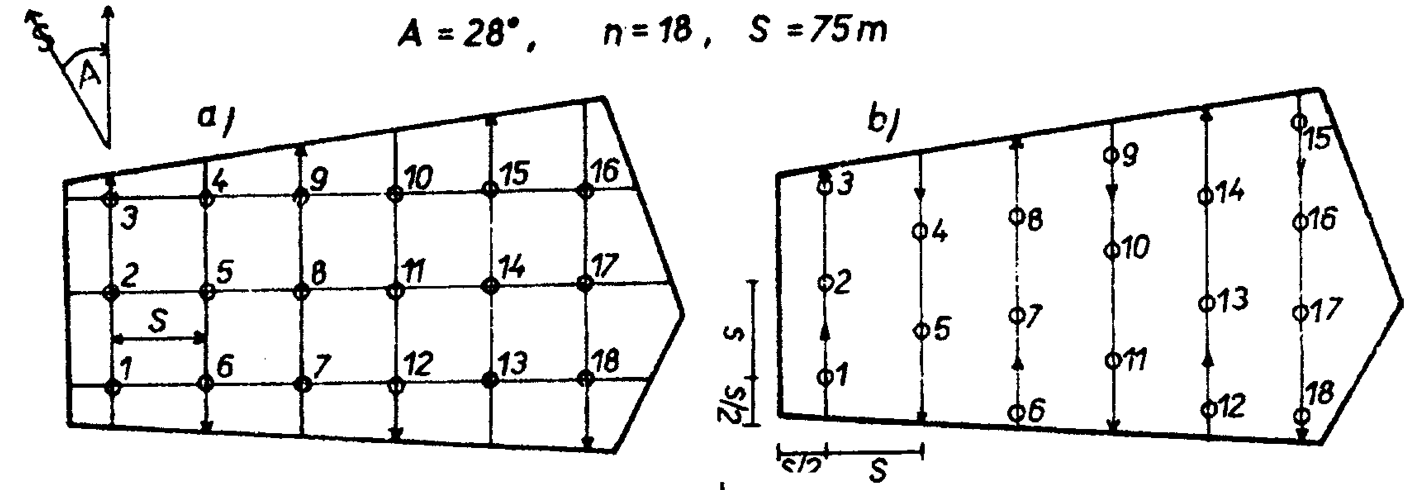
STAND VOLUME (V)

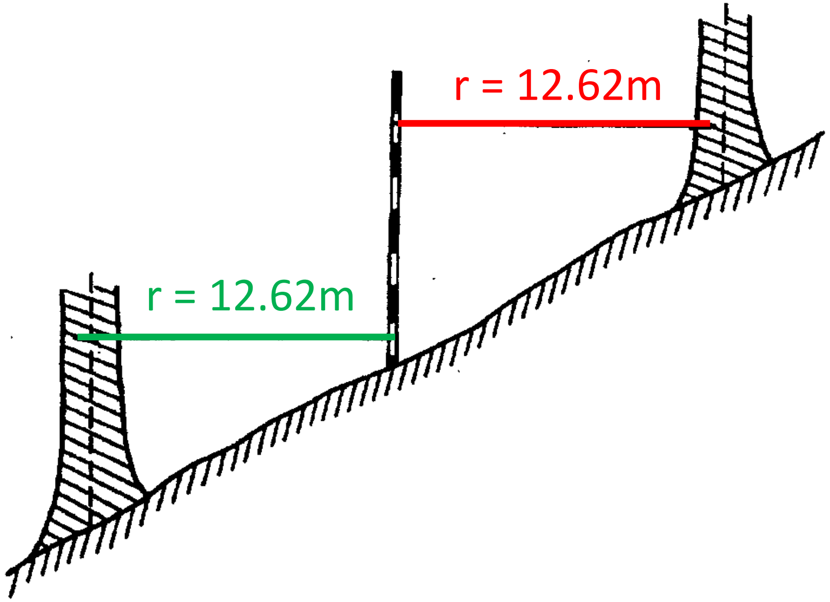
- Sampling methods
  - plot sampling
  - point sampling
  - multistage sampling
  - ...
- Plot size
  - given radius (r = 7, 10, 13m ...)
  - given area (a = 100, 500m^2, ...)
  - Optimal size prduce higher precision for a given costs
- Plot shape
  - circular
    - smallest perimeter for a given plot size
    - no right angles (one man work
    - plot boundaries located by optical devices (Vertex)
  - square (research)
  - rectangular (plantation)

STAND VOLUME (V)

- Plot sampling

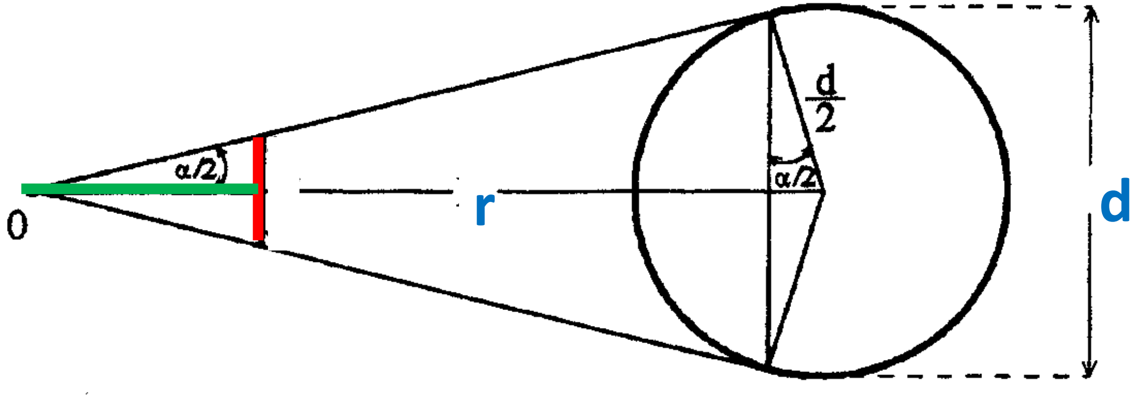






STAND VOLUME (V)

- Point sampling (angle count sampling, relascope sampling)
- Imaginary plot boundaries



A rod with a length of *c* units and cross-arm (blade) of 1 unit ➡

$$\frac{d_i}{r_i} = \frac{1}{c}$$

STAND VOLUME (V)

Plot area

$$A = \pi * c^2 * d_i^2$$

Total basal area (***G**$_i$*) of all ***n**$_i$* trees with DBH = ***d**$_i$*

$$G_i = \pi * c^2 * d_i^2$$

Converted into basal area (***G**$_i$*) of all ***n**$_i$* trees with DBH = ***d**$_i$* per unit area (ha)

$$G_i(m^2/ha) = n_i \frac{2500}{c^2}$$

Basal area per unit (ha) of all counted trees ($N = \Sigma n_i$)

$$G(m^2/ha) = N * BAF$$

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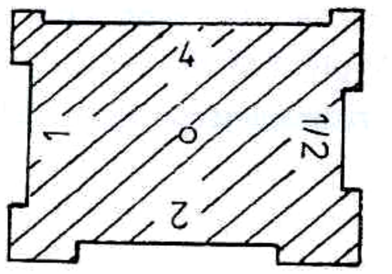
STAND VOLUME (V)



- BAF (depends on tree diameters on the forest stand)

$$BAF = \frac{0.4046(estimated\ G/ha)}{n(predefined\ avg.number\ of\ trees\ to\ be\ counted)}$$

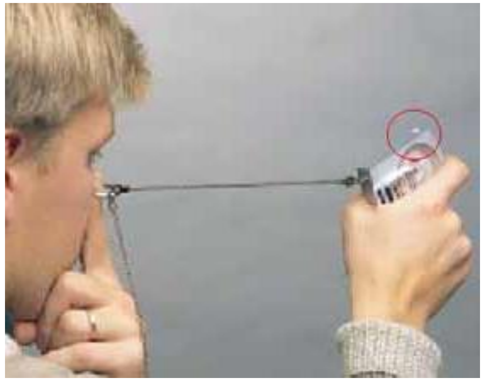
- How to derive BAF of any instrument

$$BAF = 2500 * \left(\frac{15}{500}\right)^2 = 2.25$$

STAND VOLUME (V)

- Tree counting
  - IN = 1
  - Boundary = 1/2
  - OUT = 0

OUT IN BOUNDARY



- Volume

$$V = G * H * F$$

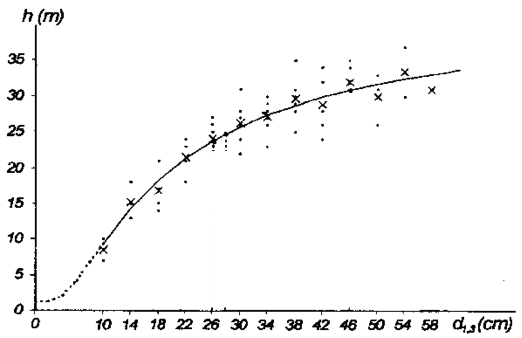
MEAN DIAMETER, MEAN HEIGHT

- Quadratice mean diameter

$$d_g = \sqrt{\frac{\sum_{i=1}^{n} d_i^2}{n}}$$

$$d_g = \sqrt{\frac{\sum_{i=1}^{k} n_i * d_i^2}{\sum_{i=1}^{k} n_i}}$$ for gouped data

- Mean height – height of the tree with the quadratice mean diameter – derived from the height curve



STAND DENSITY

- Current stocking (basal area) per hectare expressed as a percentage of volume (basal area), which is considered as a „normal“ per hectare for a given species, age, thinning regime, ...

$$\rho = \frac{V_{real}}{V_{model}} = \frac{G_{real}}{G_{model}}$$

- Ratio of current and model number of trees (plantation)

$$\rho = \frac{N_{real}}{N_{model}}$$

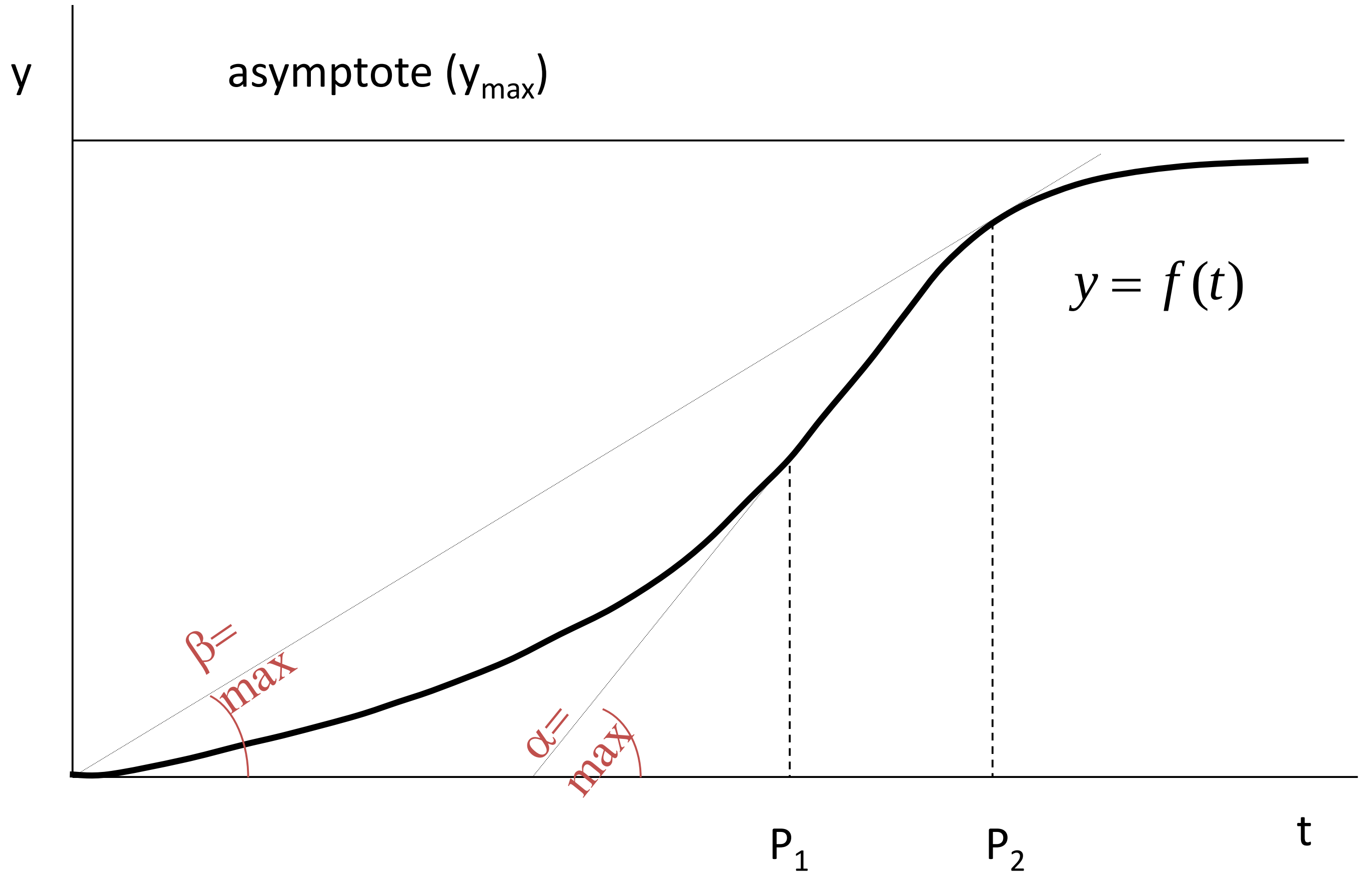
GROWTH

- enlargement of dimension of live system by assimilation activity (Bertalanfy 1951)
- growth values y (parameters) can growth
  - t – age
  - U – environment (water, precipitation, temperature, nutrients, CO2, …)

$$y = \mathrm{f}(t, U) \quad \Rightarrow \quad y = \mathrm{f}(t)$$

GROWTH

- growth curve
  - sustainable increasing (no decline) – at least monotonous
  - S - shape
  - asymptotic behaviour
    - when t = 0 then y = 0
    - when t = tmax then y = ymax
  - at least one inflexion point



GROWTH

- Korf (1939)

$$y = A * e^{\frac{k}{(1-n)t^{n-1}}}$$

- Richards & Chapmann (1959)

$$y = y_{\max} * e^{a\left(1-e\frac{c}{1-m}t^{-m}\right)}$$

INCREMENT

- enlargement of growth value (i_y) – diameter, height, basal area, volume
  - current - difference of value (*y*) in different times – time period (*t1 – t2*)
    - annual (CAI)
    - periodic (CPI) for period *n*

$$CAI = y_t - y_{t-1}$$

$$CPI = y_t - y_{t-n}$$

  - mean - divide of value (y) and time period (n) when this value has grown
    - annual (MAI) - mean anual growth during the whole growth period (life) from age 1 to age t (present age)
    - periodic (MPI)
    - Final (FMI) - volume

$$\mathrm{MAI} = \frac{y_t}{t}$$

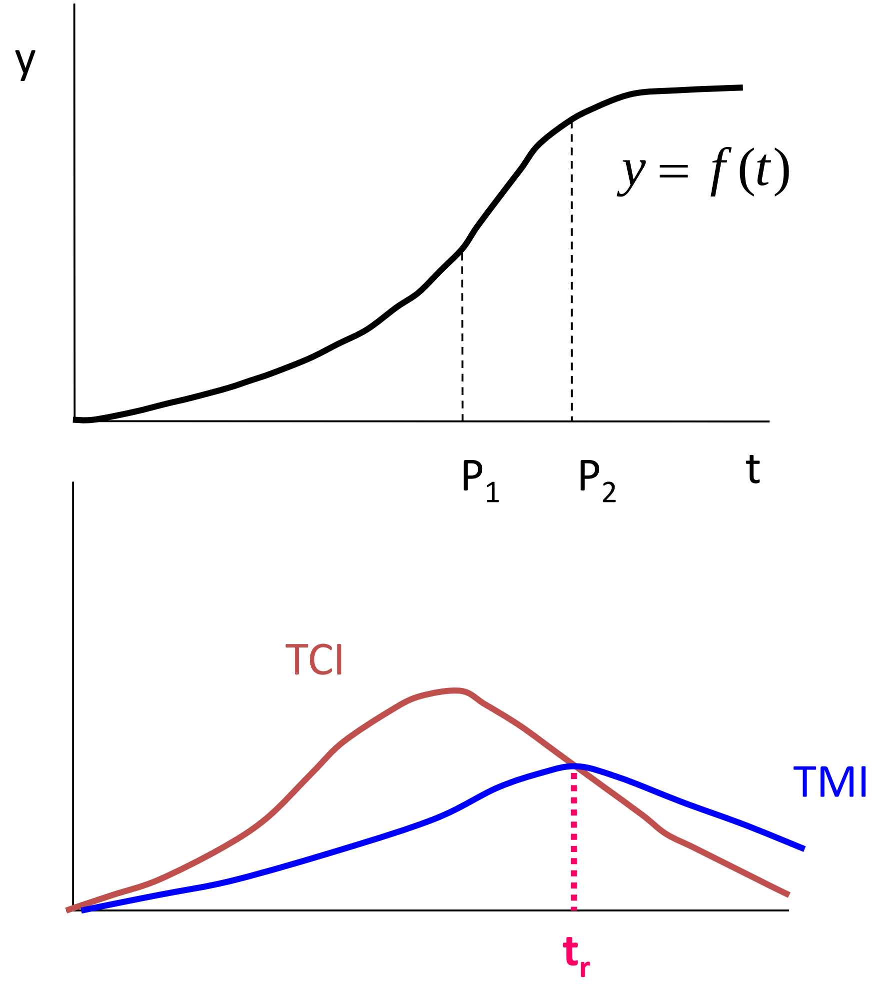
$$FMI = \frac{y_r}{r} = \frac{V_r}{r}$$

INCREMENT

- Total volume production (TVP) – the total production of timber volume from a forest stand from the time of establishment up to a given age

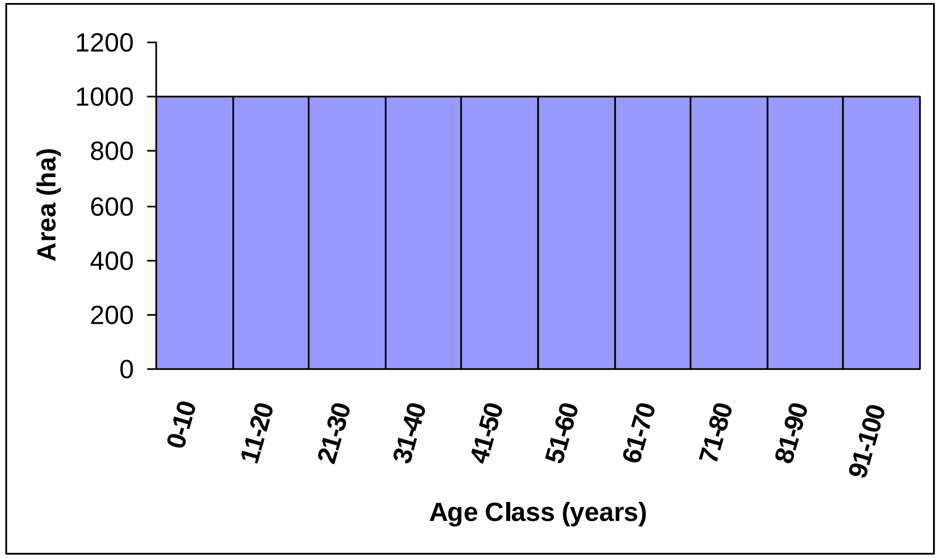
$$TCI = \frac{y_t - y_{t-n}}{n} = \frac{TVP_t - TVP_{t-n}}{n}$$

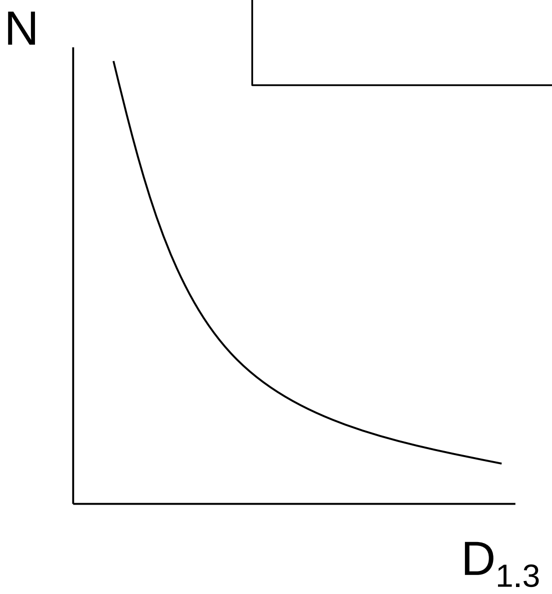
$$TMI = \frac{y_t}{t} = \frac{TVP_t}{t}$$



FOREST PLANNING

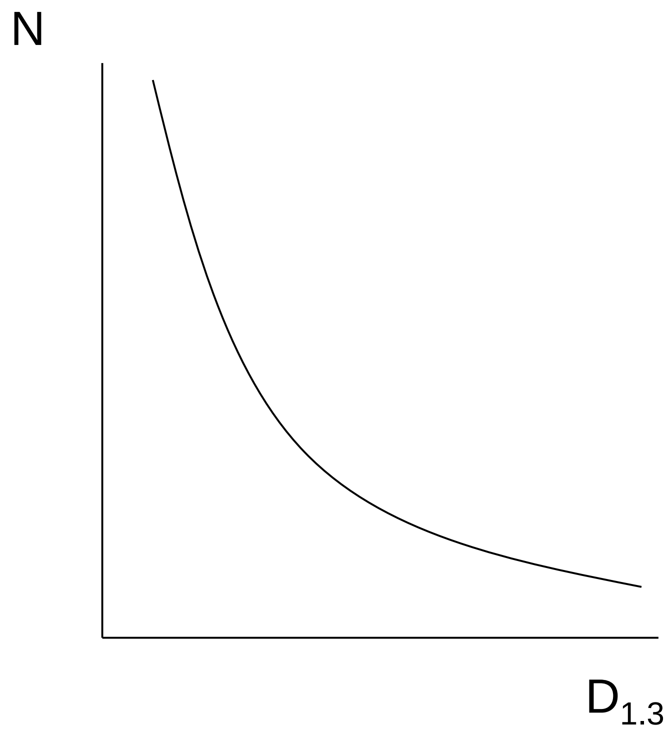
- Forest models
  - Normal (regulated) forest
  - Selection forest
- The idea is to secure balanced and sustainable harvest for a long time
- Cut = increment





FOREST PLANNING

- Selection forest
  - DBH distribution, no age
  - Target diameter, no rotation age
  - Permanent ingrowth (I)
  - Inventory on permanent plots



$$TCI = V_t - V_{t-n} + Cut - I$$

OPTIMAL SOLUTION

- To find optimal solution
  - Maximise production or minimise costs
  - Take into acount constraints
- LP models
  - very general optimization technique
  - designed and used primarily to solve managerial problems
  - applied to many different problems inclusive forest planning

Buongiorno J., Gilless J., 2003: Decision Methods for Forest Resource Management. Academic Press

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OPTIMAL SOLUTION

- Poet and his wood
  - he was allowed to buy (10 years ago) a cabin and 90 ha of woods
  - he needs to walk the woods to keep his inspiration alive (muses do not always respond = sales from the woods can replenish empty wallet)
  - he does not want to spend more than half of his time in the woods (the rest is for prose and sonnets)

OPTIMAL SOLUTION

- He has read about linear programming and desided to allocate scarce resources to optimize certain objectives
- Data
  - **40** ha of the land are covered with red-pine
  - **50** ha contain mixed hardwoods
  - since he bought these woods he has spent approx. **800** days managing the red-pine and **1500** days on the hardwoods
  - the total revenue **$36,000** from red-pine land and **$60,000** from the hardwoods

OPTIMAL SOLUTION

- Problem formulation
  - the poet's objective is to maximize his revenues from the property (finite revenues = mean revenues per unit of time - year)

Max Z = $ of revenues per year

  - Revenues (Z) arise from managing red-pine, or hardwoods, or both. Therefore, set of decision variables is:

X_1 = the number of hectares of red-pine to manage

X_2 = the number of hectares of hardwoods

  - We seek the values of $\boldsymbol{X_1}$ and $\boldsymbol{X_2}$ that make $\boldsymbol{Z}$ as large as possible

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OPTIMAL SOLUTION

- Objective function
  - the expresses the relationship between Z and the decision variables X_1 and X_2
  - he has earned **$36,000** on **40** ha of red-pine and **$60,000** on **50** ha of hardwoods during the last 10 years (average earnings have been **90$/ha/y** for red-pine, **120$/ha/y** for hardwoods)

$$\text{Max } Z = 90\ X_1 + 120\ X_2$$

($/y) ($/ha/y) ($/ha/y)

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OPTIMAL SOLUTION

- Land constraints
  - the area managed in each forest type cannot exceed the area available

$X_1 \leq$ 40 ha of red pine

$X_2 \leq$ 50 ha of hardwoods

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OPTIMAL SOLUTION

- Time constraints
  - expression of the constraint limiting this time no more than 180 days:

$$2 \quad X_1 \quad + \quad 3 \quad X_2 \leq 180$$

(d/ha/y) (ha) (d/ha/y) (ha) (d/y)

- Non negativity constraints
  - none of the decision variables may be negative, since they refer to areas

$$X_1 \geq 0 \quad \text{and} \quad X_2 \geq 0$$

OPTIMAL SOLUTION

- Final model
  - find the variables X_1 and X_2, which measure the number of hectares of red-pine and of hardwoods to manage, such that

$$\text{Max } Z = 90\,X_1 + 120\,X_2$$

subject to:

$X_1 \leq 40$

$X_2 \leq 50$

$2X_1 + 3X_2 \leq 180$

$X_1, X_2 \geq 0$