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Estimating biomass and litter production: a functional-structural perspective

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Background

- Regional estimates of standing biomass and carbon flows require inventory data
- Inventories were designed for efficient estimates of stemwood volume and growth
- How should the inventories be developed to provide more efficient estimation of total biomass / carbon?

Outline

- Consistencies in tree structure
  - pipe model
  - scaling of crown structure
- Applicability to biomass estimates
- BEF
- Increment and turnover
- Summary

Consistencies in tree structure

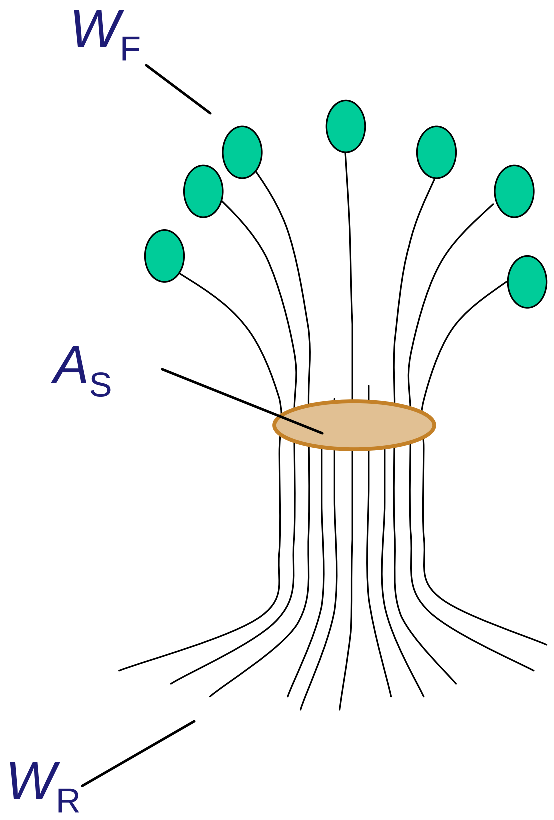
- Trees show regularities in structure
- Basis: efficient use of resources under mutual competition (evolution)

Pipe model: principle

- Shinozaki et al. 1964
- Relates foliage biomass to fine root biomass and sapwood area of stem, branches and coarse roots

$$W_F = r_S A_S$$

$$W_R = r_R A_S$$

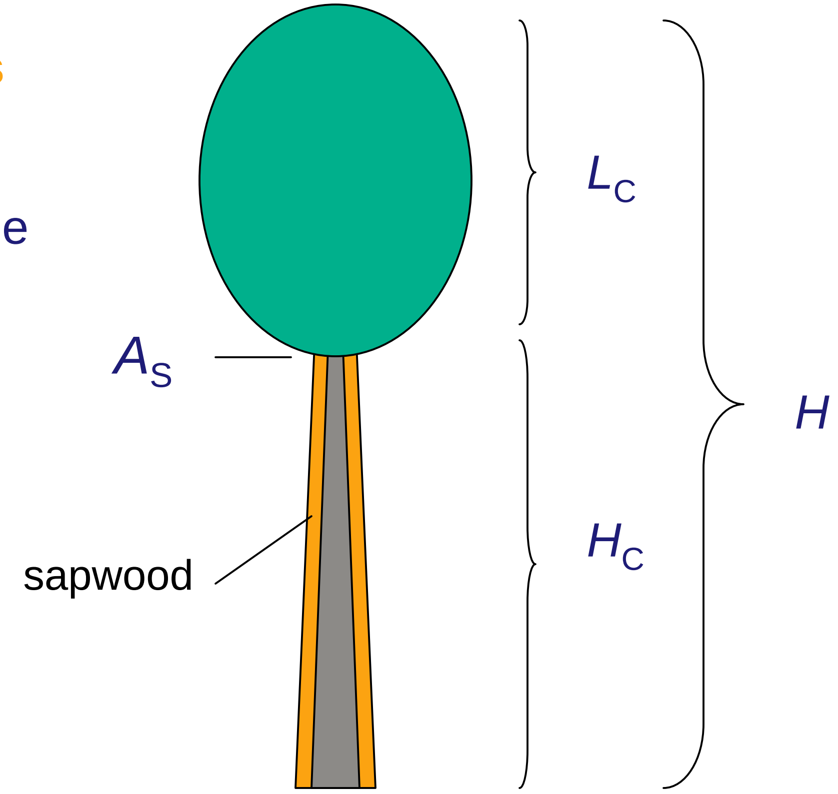


$$r_R = f(site)$$

Pipe model: sapwood mass

- Mass of **live woody parts** (stem, coarse roots, branches) depends on pipe length and sapwood area:

$$W_i = r_i \, j_i \, A_S \, L_i$$



- Parameters:
  - r_i wood density
  - j_i form coefficient

Pipe model: average pipe length

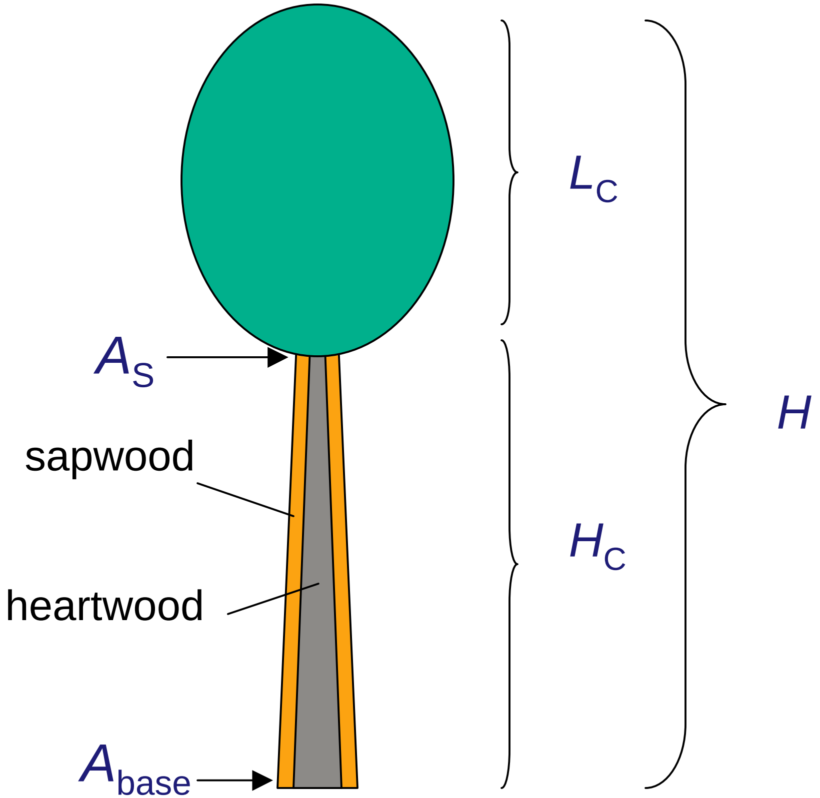
- Stem within crown : $\varphi_C L_C$
- Stem below crown: $\varphi_S H_C = H_C$
- Branches: $\varphi_{B1} H_B = \varphi_{B2} \gamma_B L_C = \varphi_B L_C$
- Coarse roots : $\alpha_T L_{stem}$

Pipe model: bole mass

- W_{bole} = sapwood + heartwood
- $W_{bole} \approx ½\ r_s\ (A_S + A_{base})H_C$
- Stem taper related to r_C (Valentine 1994):

$$A_S = r_C\ A_{base}$$

- $W_{bole} \approx ½\ r_s\ (1+r_C^{-1})\ A_S\ H_C$



$r_C = L_C\ /\ H$

Pipe model: Summary

- All mass components are functions of
  - basal area at crown base (or at stem base as $A_S \approx r_C A_{base}$!)
  - tree height and crown ratio
- Crucial parameters are
  - pipe ratio of foliage and roots
  - wood density
  - form coefficients
- Applies at tree and stand level:
  - Tree or stand basal area; mean height and crown base

Crown structure: allometric scaling

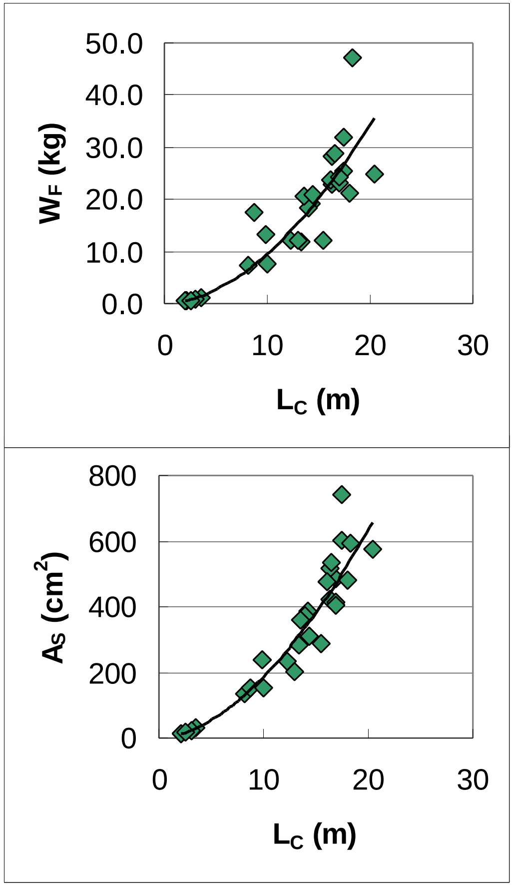
- Theoretical and empirical studies suggest an allometric scaling law between crown length and foliage mass:

$$W_F = \xi L_C^z \quad z = 3$$

Zeide and Pfeifer 1991, Mäkelä & Sievänen 1992, West et al. 1999

- Combined with pipe model:

$$A_S \propto L_C^z$$



Spruce (Kantola and Mäkelä 2003)

Crown structure: allometric scaling

- Growth rates of sapwood area and crown length scale:

$$\frac{\mathrm{d}A_S}{\mathrm{d}t} = z \frac{A_S}{L_C} \frac{\mathrm{d}L_C}{\mathrm{d}t}$$

- Also crown length is a function of sapwood area
- Additional parameter z

Applicability of structural consistencies to biomass estimates

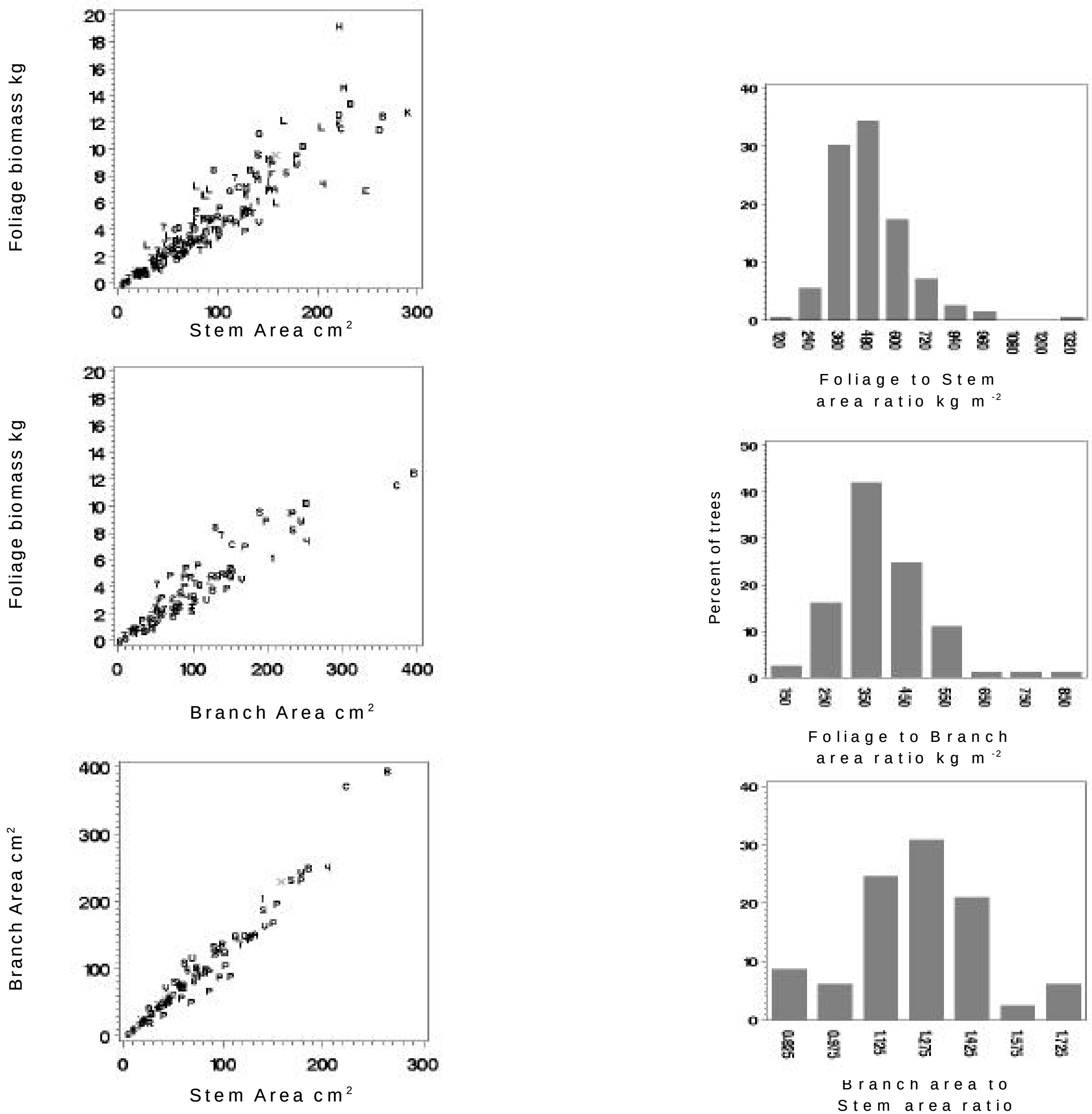
- Parameter estimates available for several species :
  - pine (e.g. Berninger and Nikinmaa 1994, Vanninen 2004)
  - birch (Ilomäki et al. 2003)
  - spruce (Kantola and Mäkelä 2003)
  - loblolly pine (Valentine et al. 1995)

- Constant within stands

- Variation between stands:
  - small temporal trend (e.g. Mäkelä and Vanninen 1998)
  - variation between sites (Berninger et al. manus)
  - geographical trend (Berninger and Nikinmaa 1994)

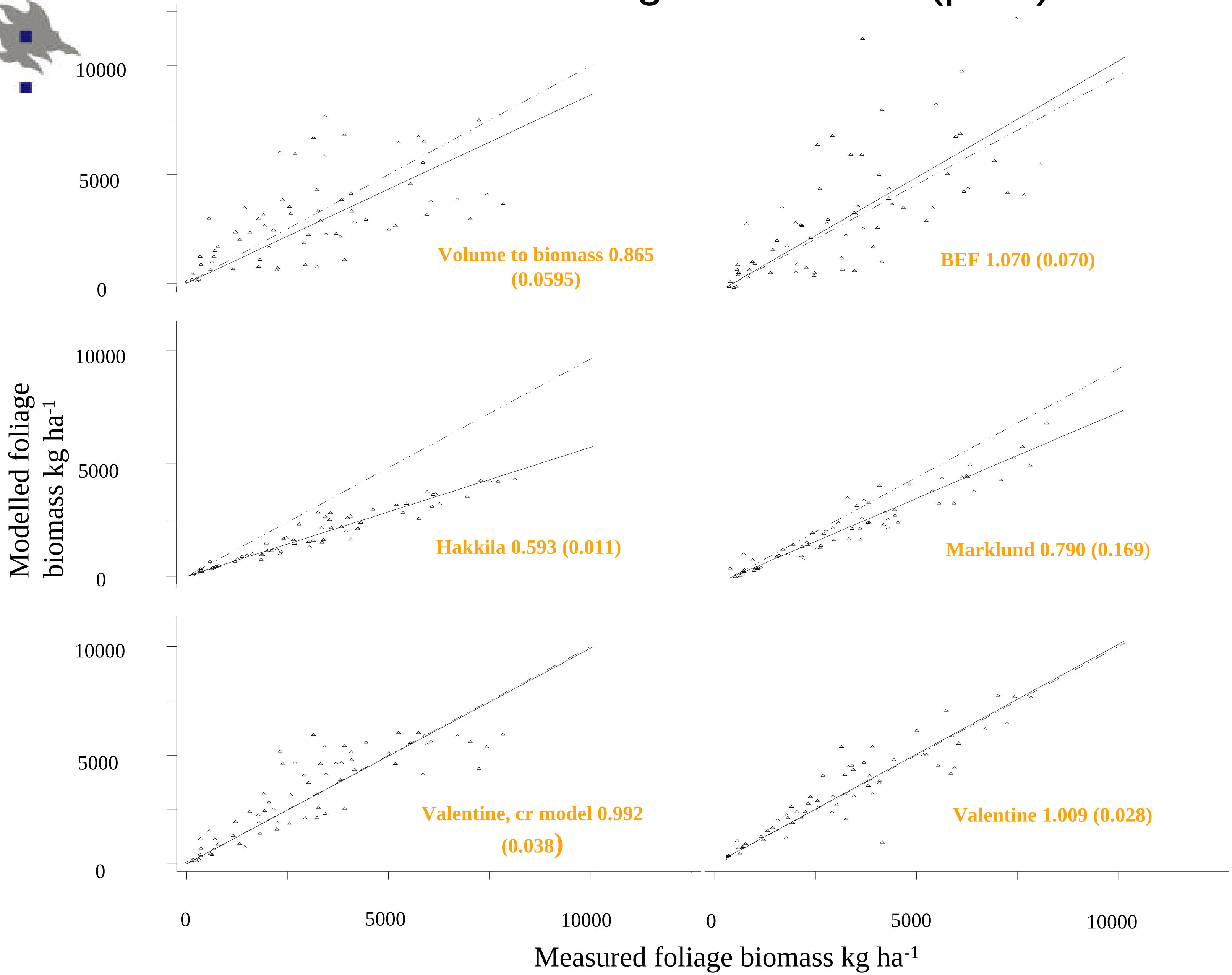
Variation in pipe ratio (pine)

Berninger et al. manus.



Stand level: foliage estimates (pine)

Lehtonen 2004



BEF from the pipe model

- Pipe model assumptions lead to a formula for Biomass Expansion Factor (BEF) where ***A_S* cancels out**:

Coarse roots — Stem — Branches — Foliage & fine roots

$$BEF = \frac{(1+\alpha_T)\,\rho_S\,[\tfrac{1}{2}(1-r_C^2)/r_C + r_C\varphi_C] + r_C\,\rho_B\,\varphi_B + (\rho_F+\rho_R)/H}{[\tfrac{1}{2}(1-r_C^2)/r_C + r_C\varphi_C]}$$

Stem volume

BEF from the pipe model

- BEF from height, crown ratio, and parameters

- Biomass components from BEF and volume *V*

$$W_i = \mathrm{BEF}_i\, V$$

- For trees or stands

BEF from the pipe model: parameters

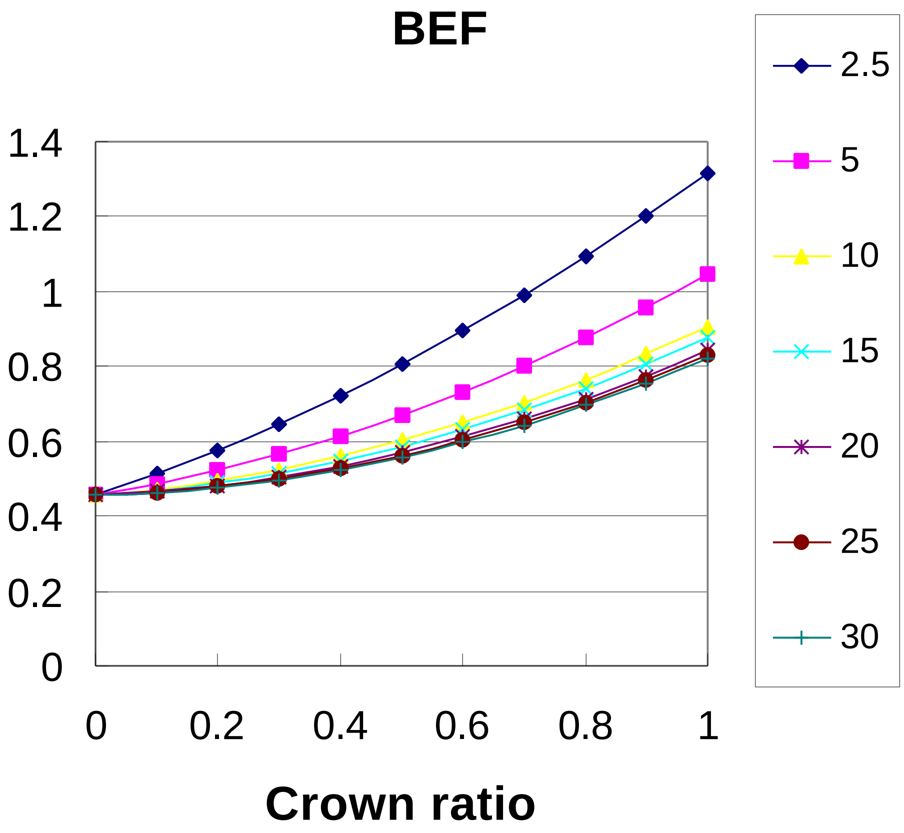
Pine:
Vanninen 2003

Birch:
Ilomäki et al. 2003

Parameter	Unit	Pine	Birch
pipe ratio, foliage	kg/m^2	450	255
pipe ratio, fine roots	kg/m^2	135-360	NA
wood density, stem	kg/m^3	400	480
wood density, branches	kg/m^3	400	550
stem form in crown	-	0.5	0.44
branch form	-	0.33	0.16
coarse root fraction	-	0.3	NA

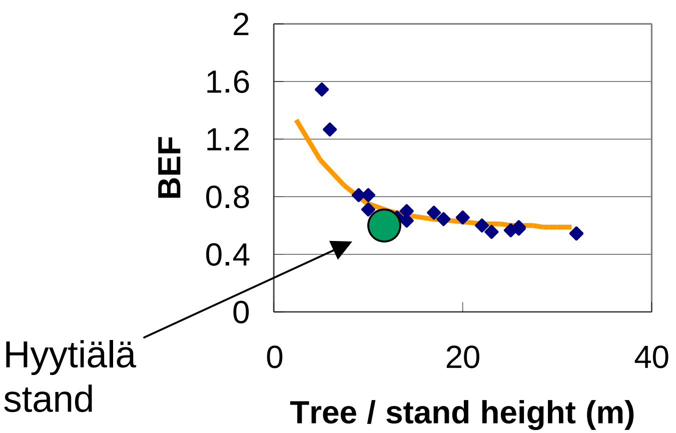
BEF from the pipe model: example (pine)

- Parameters from Vanninen 2003

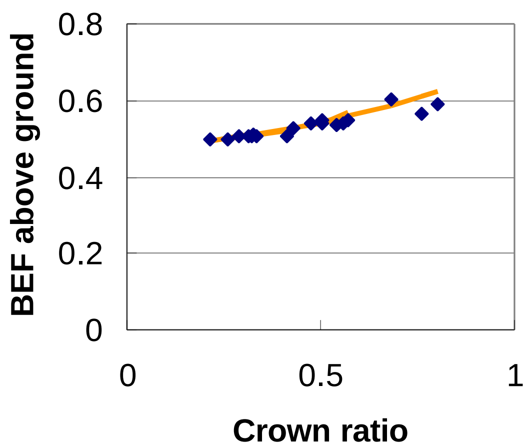


BEF from the pipe model: pine and birch

Dominant pine trees
along an age gradient,
MT & CT
Vanninen et al. 1996



Birch in varying
densities
Ilomäki et al. 2003



Increment and turnover

- NPP = Increment + Turnover

- Increment from consecutive estimates of mass:

$$\Delta W_i = \mathrm{BEF}_{i,t+1}\, V_{t+1} - \mathrm{BEF}_{i,t}\, V_t$$

- Component turnover from specific turnover

$$S_i = s_i\, \mathrm{BEF}_i\, V$$

- Foliage and fine roots: mean life span is a useful concept

- Branches: not straightforward

Increment and turnover: Branch turnover

- **Pipe model** and **allometric scaling** of crown lead to an estimate of specific branch turnover rate (Valentine and Mäkelä manus):

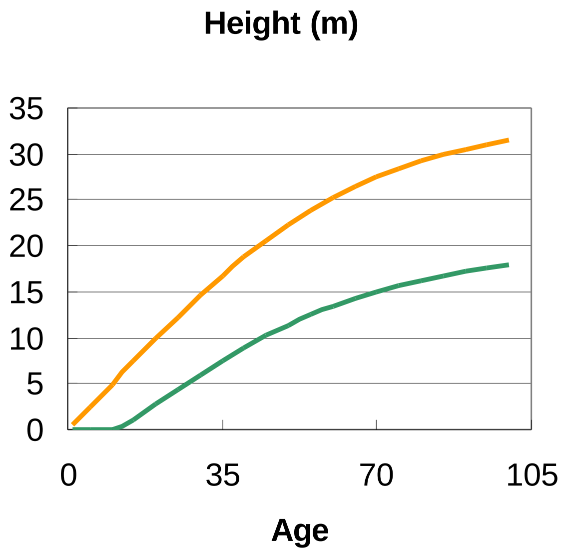
Scaling parameter

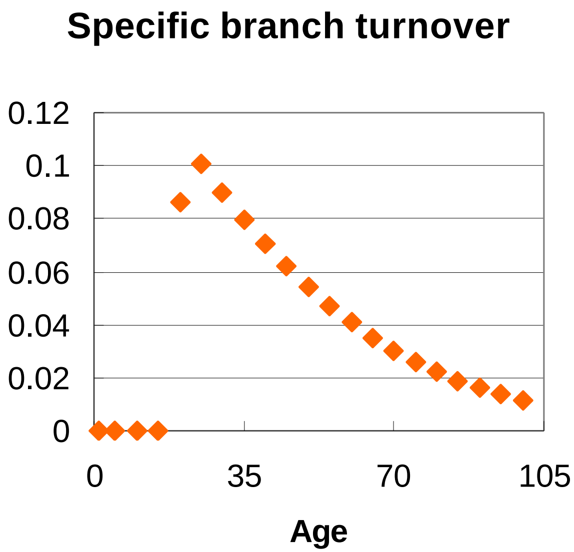
$$s_B = \frac{(1+z)}{L_C} \frac{dH_C}{dt}$$

Crown length

Crown rise

Increment and turnover: Hypothetical example





Scots pine

Summary

- Structural consistencies are a powerful tool for estimating biomass, biomass increment and turnover
- Even estimates of GPP obtainable provided that live tissue specific respiration rates are available
- Requirements for wider application
  - crown ratio from inventories
  - more information on the natural variation of parameters
  - allows for focused measurements with physical meaning
- But: BEF estimates rather stable under variation of parameters and tree attributes