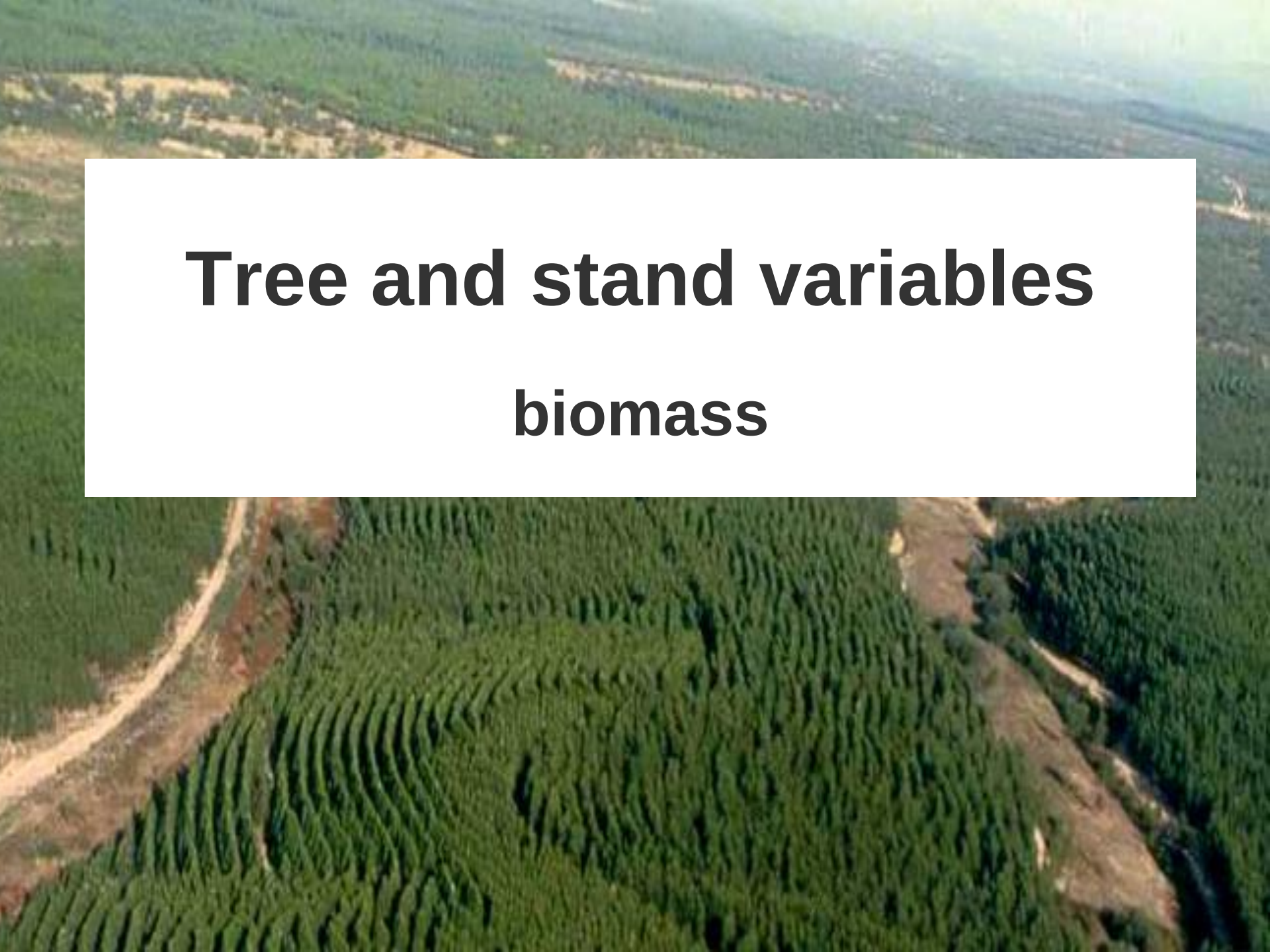


An aerial photograph of a forest landscape. The foreground shows a dense, green forest with a distinct wavy or undulating pattern, possibly due to terrain or tree arrangement. A dirt road or path runs along the left side of this forested area. In the background, the forest continues up a hillside, with some areas appearing less dense or more open. A white rectangular box is superimposed over the center of the image, containing the text "Tree and stand variables" and "biomass" in bold black font.

Tree and stand variables

biomass

Outline

- ✗ Definition of biomass
- ✗ Total biomass and biomass per tree component
- ✗ Direct evaluation of biomass?
- ✗ Indirect evaluation of biomass
 - ✓ Stem biomass (wood and bark)
 - ✓ Crown biomass (branches and leaves)
 - ✓ Root biomass
- ✗ Biomass estimation with allometric equations
- ✗ The special case of cork biomass

Total biomass and biomass per tree component

- ✗ **Biomassa** is defined as “dry weight” (after drying in a stove till constant weight is achieved)
- ✗ It is important to take into account the biomass of the different tree **components**:
 - ✓ Stem, separated into wood and bark
 - ✓ Crown, separated into branches, leaves, flowers and fruits
 - ✓ Roots, separated in main root, thick roots and fine roots
- ✗ Tree total biomass is the sum of all the tree components
 - ✓ For some purposes some components are not taken into account (e.g. flowers and fruits for the Kyoto protocol)
- ✗ Tree total aboveground biomass does not include the roots

Why is biomass estimation it so important?

- ✗ Biomass estimation is the basis for the evaluation of carbon stocks, carbon sequestration and nutrients balance
- ✗ Forest products (wood and non-wood) are many times marketed on a weight basis:
 - ✓ Wood for energy (or even for other purposes)
 - ✓ Cork, one of the most important forest products in Mediterranean regions, is marketed on a weight basis

Biomass – direct evaluation?

- ✗ The evaluation of tree biomass implies the harvest of the tree, including the up-rooting, and the separation of all the tree components
- ✗ Even though, in the field just the fresh weight can be obtained – therefore direct evaluation is not possible...
- ✗ Tree biomass estimation depends on the tree component:
 - ✓ Determination of water content in a sample (by drying the sample in a stove)
 - ✓ Wood and bark biomass may be obtained from volume estimation and wood or bark density
 - ✓ Among other possible methods ...





































Example of data for tree biomass determination

- ✗ These data refer to an eucalyptus tree harvested in a plot with spacing 4X4 m

ENSAIO DE COMPASSO DE VILAR DE LUZ
ABATE DE ÁRVORES DO BLOCO II – JANEIRO 2006

equipa Paulo, Vera, Pedro, Rui data 11/21/06
 compasso 4x4 nº árv. 81

árvore em pé:
 dap cc (cm) 12,2 h total (m) 18,0 hbcopa (m) 15,5 cc (m) 2,5
 ↳ comprimento copa = 18 - 15,5

árvore abatida:
 h total (m) 19,4 hbcopa (m) 16,30 h1º ramo verde (m) 16,30 hdco6 (m) 12,60
 comprimento copa = h total - hbcopa = 3,10 cc3 (m) 1,03

hbc (m) 16,30 hbc+1/3 (m) 17,33 hbc+2/3 (m) 18,36
 dbccc (cm) 39/39 dbcc+1/3cc (cm) 39/30 dbcc+2/3cc (cm) 8/8
 (1) (2) (1) (2) (1) (2)

estrato superior

dbcc+2/3 cc

estrato médio

dbcc+1/3 cc

estrato inferior

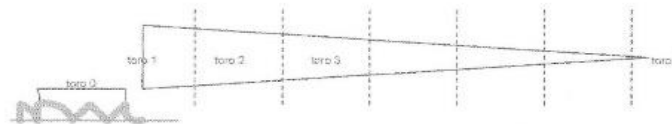
dbcc



3,10 13
 01 103
 00 1
 1

Example of data for tree biomass determination

Número de toros na árvore abatida: cepo + bicada + ____ toros



nº toro	comprimento toro (m)	d1 c/ casca (cm)	d2 c/ casca (cm)	d1 s/ casca (cm)	d2 s/ casca (cm)
0 (cepo)	0,16				
1 (corte a 1.30m)	1,14	14,2	15,5	12,5	14,0
2	3,0	11,9	12,0	10,7	11,0
3	3,0	10,1	10,0	9,5	9,6
4	3,0	8,4	8,9	8,0	8,4
5	3,0	7,2	7,4	6,8	7,0
6	3,0	6,0	5,9	5,5	5,6
7	3,0	4,1	4,1	3,7	3,7
bicada	3,10				
8					
9					
10					
11					

d1, diâmetro na linha; d2, diâmetro na entre-linha.

ENSAIO DE COMPASSO DE VILAR DE LUZ

ABATE DE ÁRVORES DO BLOCO II - JANEIRO 2006

equipa Paula, Vera, Pedro, Rui data 12/06
 compasso 4x4 nº árv. 21

COPA - total

	estrato superior	estrato médio	estrato inferior
folhas verdes (kg)	1,585 - 1,323	2,580 - 0,847	0,660 - 0,069
ramos verdes (kg)	0,120 - 0,013	2,691 - 1,041	2,072 - 1,323

	copa na totalidade
folhas secas (kg)	—
ramos secos (kg)	—
cápsulas (kg)	0,040 - 0,013

COPA - amostras

	estrato superior	estrato médio	estrato inferior
folhas verdes - área foliar (kg)	—	—	—
folhas verdes (kg)	0,137 - 0,013	0,189 - 0,013	0,169 - 0,013
ramos verdes (kg)	0,120 - 0,013	0,286 - 0,013	0,137 - 0,013

	copa na totalidade
folhas secas (kg)	—
ramos secos (kg)	—
cápsulas (kg)	0,040 - 0,013

TRONCO

Recolher da base (inferior) de cada toro 1 rodela de ± 3 cm. Considerar separadamente madeira e casca. Os sacos com as amostras de madeira têm que ser devidamente identificados - compasso, nº árvore, nº toro - mas NÃO precisam de ser pesados (ver CASCA).

CASCA

peso da totalidade da casca por toro (kg):

toro 1 2,486 toro 2 3,618 toro 3 1,92 toro 4 1,394 toro 5 1,157 toro 6 0,824

toro 7 0,258 toro 8 — toro 9 — toro 10 — toro 11 — toro 12 —

peso de cada uma das cascas das rodela (kg):

toro 1 0,120 toro 2 0,055 toro 3 0,025 toro 4 0,018 toro 5 0,017 toro 6 0,012

toro 7 0,004 toro 8 — toro 9 — toro 10 — toro 11 — toro 12 —

3

total = soma das 2
 Falta soma!

Ensaio de Vilar de Luz - Bloco 2

Janeiro 2006

compasso 4x4 árvore número: 21

Data de colocação na estufa: 3/2/06

	peso fresco (g)	data (peso seco)			peso seco final (g)
folhas secas					
ramos secos					
cápsulas	26,2	15,53	15,49		10,44

Estrato inferior da copa

data de colocação na estufa: 3/2/06

	peso fresco (g)	data (peso seco) <u>com casca</u>			peso seco final (g)
folhas	156,4	8/2/06 90,88	9/2/06 90,73	10/2/06 90,74	78,07
ramos	123,6	73,78	73,75		65,07

Estrato médio da copa

data de colocação na estufa: 3/2/06

	peso fresco (g)	data (peso seco) <u>com casca</u>			peso seco final (g)
folhas	176,6	8/2/06 99,88	9/2/06 99,88	10/2/06 99,88	86,96
ramos	272,9	153,85	153,57		143,52

Estrato superior da copa

data de colocação na estufa: 3/2/06

	peso fresco (g)	data (peso seco) <u>com casca</u>			peso seco final (g)
folhas	123,7	8/2/06 72,55	9/2/06 72,48	10/2/06 72,42	59,70
ramos	106,8	59,33	59,25		50,86

Área foliar

	Estrato inferior		Estrato médio		Estrato Superior	
	peso fresco (g)	área foliar (cm ²)	peso fresco (g)	área foliar (cm ²)	peso fresco (g)	área foliar (cm ²)
limbos						
pecíolos						

Estimating biomass with allometric equations

- ✗ The difficulty involved in the direct evaluation of tree biomass implies the use of equations to estimate tree biomass from dbh and height/height of the live crown
- ✗ Let's see an example

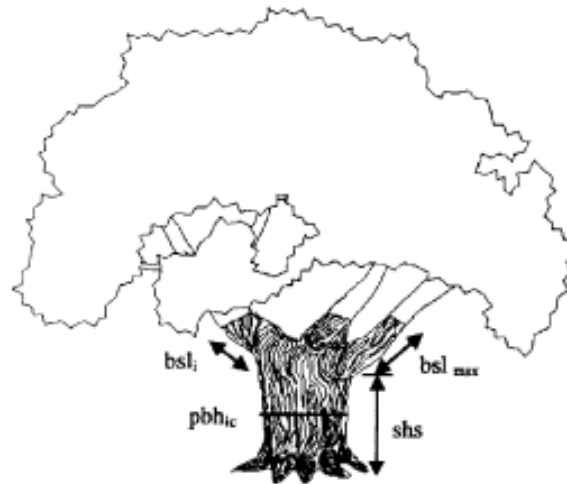
Tree component	Parameter estimations
Wood	$kw = 0.0101$ $ww = kw \ d^{aw} \ h^{bw}$ $aw = \begin{cases} \text{se } hdom \leq 10.710 & \frac{hdom}{-0.6653 + 0.6243 \ hdom} \\ \text{se } hdom > 10.710 & 1.7788 \end{cases}$ $bw = 1.3638$
Bark	$kb = 0.0006$ $wb = kb \ d^{ab} \ h^{bb}$ $ab = \begin{cases} \text{se } hdom \leq 18.269 & \frac{hdom}{-0.6970 + 0.4586 \ hdom} \\ \text{se } hdom > 18.269 & 2.3784 \end{cases}$ $bb = 1.0616$
Leaves	$kl = 0.0295$ $wl = kl \ d^{al} \ cl^{bl}$ $al = \begin{cases} \text{se } hdom \leq 7.387 & \frac{hdom}{-1.0312 + 0.7069 \ hdom} \\ \text{se } hdom > 7.387 & 1.7627 - 0.01065 \ hdom \end{cases}$ $bl = 0.6430$
Branches	$kbr = 0.0237$ $wbr = kbr \ d^{abr} \ cl^{bbr}$ $abr = \begin{cases} \text{se } hdom \leq 8.8348 & \frac{hdom}{-0.9130 + 0.7043 \ hdom} \\ \text{se } hdom > 8.8348 & 1.6640 \end{cases}$ $bbr = 0.6067$
Total aboveground biomass	$w = ww + wb + wl + wbr$

Equations to estimate total biomass and biomass per tree component for eucalyptus in Portugal (António et al., 2007)

The special case of cork

- ✗ Equations to predict tree cork weight started to appear in the 50's and from then several new equations have been developed (Natividade, 1950; Ferreira et al., 1986; Montero, 1988; Ferreira e Oliveira, 1991; Costa, 1992; Sousa, 1997)
- ✗ All the equations published till the year 2000 referred to fresh weight and not to air dried or dry weight
- ✗ The available models can be very simple, using just d or c as regressor variable or more complex requiring a much larger number of variables
- ✗ All the models predict cork weight for 9 years old cork, except the model developed by Vázquez and Pereira (2005) that includes a dummy variable for 10 years old cork

The special case of cork



-
- Mean stripped height: $msh = shs + \frac{\sum_{i=1}^{nb} bsl_i}{nb}$
 - Maximum stripped height: $sh_{max} = shs + bsl_{max}$
 - Maximum stripping coefficient: $sc_{max} = \frac{sh_{max}}{pbh_{ic}}$
 - Total stripped surface: $ss_{tot} = sss + \sum_{i=1}^{nb} (bsp_i \cdot bsl_i)$
 - Perimeter at breast height measured outside cork: $pbh_{oc} = pbh_{ic} + 2\pi \text{ (ct/100)}$
 - Cork biomass by unit of stripped surface: $wss = w / ss_{tot}$
 - Total stripped height: $sh_{tot} = shs + \sum_{i=1}^{nb} bsl_i$
 - Mean stripping coefficient: $sc_{mod} = \frac{msh}{pbh_{ic}}$
 - Stem stripped surface: $sss = pbh_{ic} \cdot shs$
 - Maximum stripped surface: $ss_{max} = pbh_{ic} \cdot sh_{max}$
-

The special case of cork

Models for use immediately before the stripping process

With no bough information

$$\ln w = 2.3665 + 2.2722 \ln(\text{pbh}_{\text{oc}}) + 0.4473 \ln(\text{shs})$$

With the number of stripped boughs

$$\ln w = 2.1578 + 1.5817 \ln(\text{pbh}_{\text{oc}}) + 0.5062 \ln(\text{nb}) \\ + 0.6680 \ln(\text{shs})$$

With the measurement of the tallest stripped bough

$$\ln w = 2.0135 + 0.7549 \ln(\text{sh}_{\text{max}} \text{pbh}_{\text{oc}}^2) + 0.0836 \text{nb}$$

With the measurement of all stripped boughs

$$\ln w = 1.8875 + 0.6575 \ln(\text{sh}_{\text{oc}} \text{pbh}_{\text{oc}}^2) + 0.1499 \text{shs}$$

The special case of cork

Models for use after the stripping process or at an intermediate age of the cork cycle production

With no bough information

$$\ln w = 3.0071 + 2.0039 \ln(\text{pbh}_{\text{ic}})$$

$$\ln w = 2.7506 + 1.9174 \ln(\text{pbh}_{\text{ic}}) + 0.4682 \ln(\text{shs})$$

With the number of stripped boughs

$$\ln w = 2.2137 + 0.9588 \ln(\text{sss}) + 0.6546 \ln(\text{nb})$$

With the measurement of the tallest stripped bough

$$\ln w = 2.3305 + 0.6602 \ln(\text{sh}_{\text{max}} \text{pbh}_{\text{ic}}^2) + 0.0937 \text{nb}$$

With the measurement of all stripped boughs

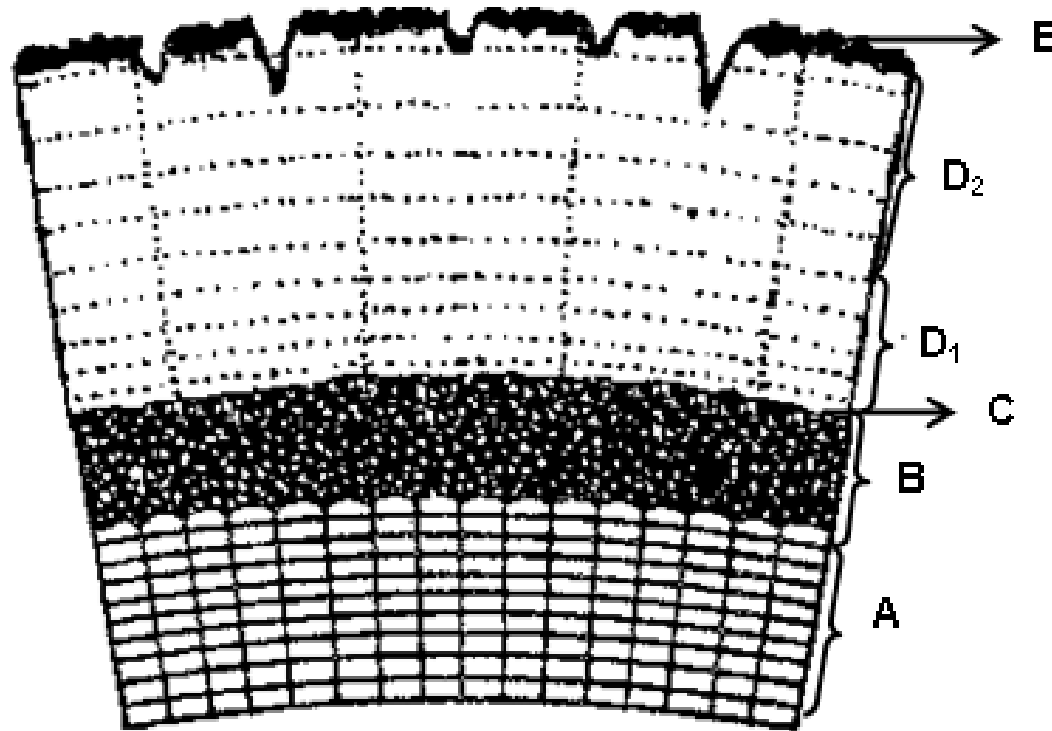
$$\ln w = 1.8276 + 0.8338 \ln(\text{ss}_{\text{tot}}) + 0.3143 \ln(\text{pbh}_{\text{ic}}) \\ + 0.4562 \ln(\text{ct})$$

$$\ln w = 1.8489 + 0.5975 \ln(\text{sh}_{\text{tot}} \text{pbh}_{\text{ic}}^2) + 0.4423 \ln(\text{ct}) \\ + 0.2536 \ln(\text{shs})$$

The special case of cork

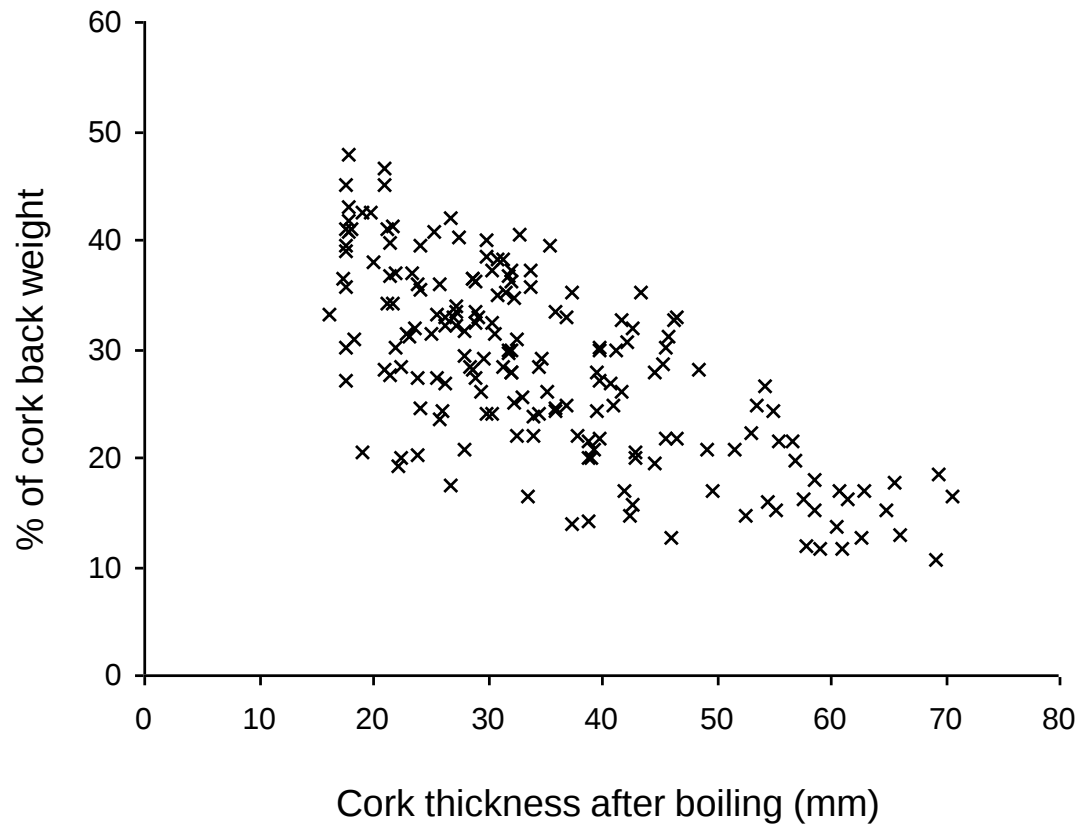
- ✗ Paulo and Tomé (2010) proposed a method for the prediction of cork dry weight with t years of age from a cork measurement undertaken at any cork age
- ✗ The method is based on the following:
 - ✓ Estimation of the proportion of cork bark weight
 - ✓ Homogeneity of cork density if cork bark is excluded
 - ✓ Use of a cork growth model to predict cork thickness at t years of age

The special case of cork



Structure of a 9 years old cork: A – wood; B – phelogen; C – cork belly; D1 e D2 – cork annual rings; E – cork back (adapted from Natividade, 1950)

The special case of cork



Relationship between cork back weight and cork thickness after boiling

The special case of cork

✗ The application of the method consists in:

1. Estimate 9 years cork weight (wcm_9)
2. Estimarte the % of cork back weight in a 9 years old cork ($cb\%$)
3. Estimate 9 years cork weight without the cork back (wcm_{9_b}):

$$wc_{9_b} = wc_9 \left(1 - \frac{cb\%_9}{100} \right) = wc_9 - \underbrace{wc_9 \frac{cb\%_9}{100}}_{\text{biomass of cork back}}$$

4. Estimate the t years cork weight:

$$wc_t = \underbrace{wc_{9_b} \frac{cc_{tc}}{cc_9}}_{\text{biomass of cork tissue}} + \underbrace{wc_9 \frac{cb\%_9}{100}}_{\text{biomass of cork back}}$$

cc_{tc} is cork thickness after boiling of a tc years cork and cc_9 is the respective thickness with 9 years of age

The special case of cork

✗ Model to estimate the % of cork back weight (Paulo and Tomé, 2010):

✓ $cb\% = \exp(-(cc_{tc}/19.4629)^{0.4744})$

cb% – percentage of cork back weight; cc_t – cork thickness after boiling for a t_c years cork (mm)

The special case of cork

✗ Models to estimate 9 years cork weight (Paulo and Tomé, 2010):

1. $wc = 0.0203 \, du^{1.9843}$

2. $wc = 0.0372 \, nbrd_1^{0.2811} du^{1.7825}$

3. $wc = 0.1036 \, du^{1.3395} hdv^{0.6709+0.1466 \ln(nbrd_1)}$

4. $wc = 0.0303 [\ln(cc_9)]^{1.0667} du^{1.3178} hdv^{0.6703+0.1570 \ln(nbrd_1)}$

wc – cork dry weight (kg); du – underbark diameter (cm); $nbrd_1$ – number of debarked 1st order branches; hdv – vertical debarking height (m); cc_9 – cork thickness after boiling at 9 years of age (mm)

The special case of cork

✗ Estimate the thickness of cork with 9 years using a cork growth model (Almeida and Tomé, 2010):

1. Estimate the thickness of the complete cork rings (ct_{tc} ; cc_{tc} is the caliber of boiled cork):

$$ct_{tc} = \frac{cc_{tc} - 4.572}{1.058}$$

2. Estimate the cgi (cork growth index or thickness of the first complete 8 rings)

$$cgi = ct_9 = ct_{tc} \frac{1 + 19.50(tc - 1)^{-1.088}}{1 + 19.50(9 - 1)^{-1.088}} = \frac{cc_{tc} - 4.472}{1.058} \frac{1 + 19.50(tc - 1)^{-1.088}}{1 + 19.50(9 - 1)^{-1.088}}$$

ct_{tc} is the thickness of complete rings in a cork with tc years; cc_{tc} is the respective caliber

The special case of cork

3. Estimate the caliber of a cork with 9 years:

$$cc_9 = 4.572 + 1.058 \text{ } ct_9$$

- ✗ Estimate the tickness of a cork with t_c years using the cork growth model (Almeida and Tomé, 2010):

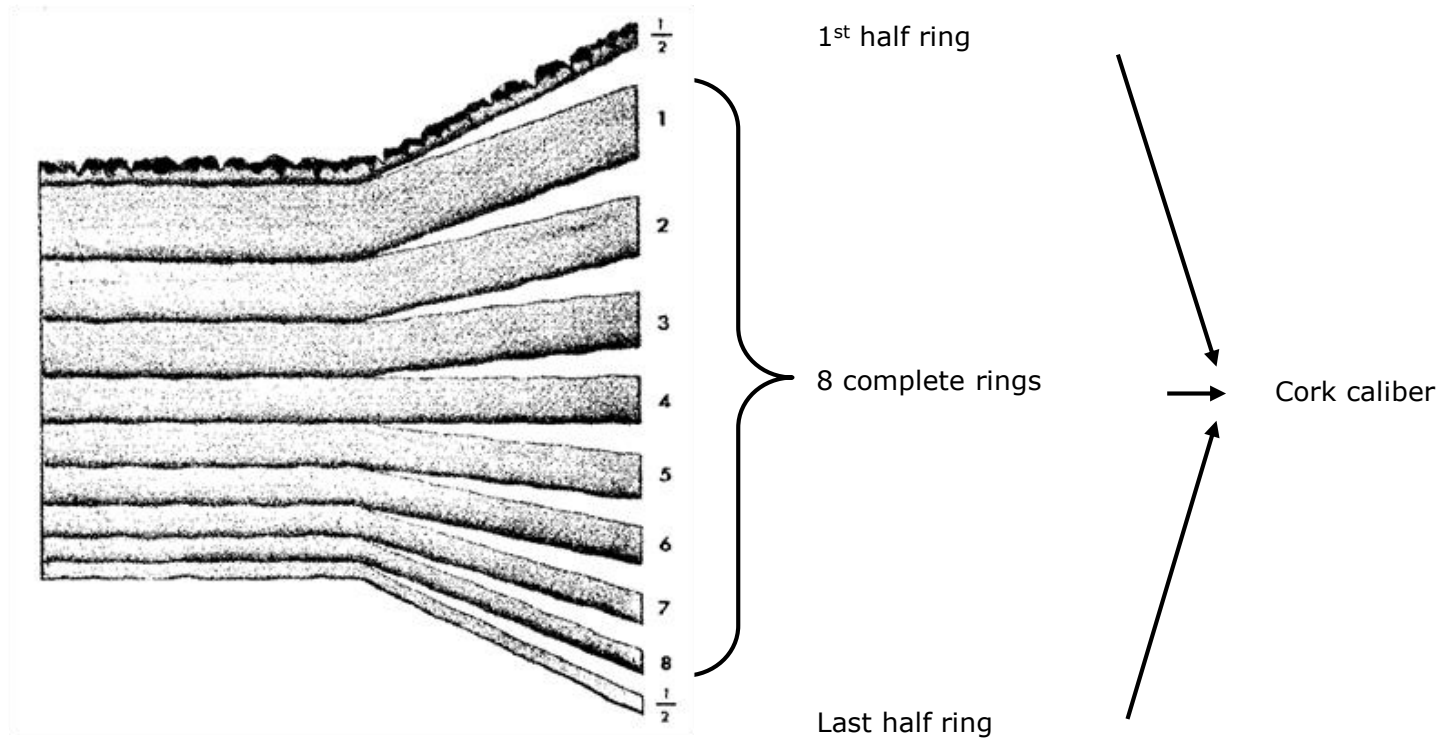
1. Estimate ct_{t_c} :

$$ct_{t_c} = ct_9 \frac{1 + 19.50(9 - 1)^{-1.088}}{1 + 19.50(t_c - 1)^{-1.088}}$$

2. Estimate cc_{t_c} :

$$cc_{t_c} = 4.572 + 1.058 \text{ } ct_{t_c}$$

The special case of cork



Schematic representation of a sample of a 9 years old cork, showing the 8 complete rings and the 2 half rings (adapted from Natividade, 1940)

The special case of cork

✗ As an example, let's calculate the weight of a 11 years old cork from a tree with $du=80$ cm in which the cork caliber at 7 years was measured as 20 mm

1. Weight of the 9 years old cork (tree growth not considered)

$$wc_9 = 0.0203(80)^{1.9843} = 121.2823 \text{ kg}$$

2. Caliber of the 9 years old cork (cc_9)

$$ct_7 = (cc_7 - 4.572) / 1.058 = 14.58 \text{ mm}$$

$$cgi = ct_9 = ct_7(1 + 19.5(7-1)^{-1.088}) / (1 + 19.5(9-1)^{-1.088}) = 18.17 \text{ mm}$$

$$cc_9 = 4.572 + 1.058 \text{ } ct_9 = 4.572 + 1.058(18.17) = 23.80 \text{ mm}$$

3. % of cork back weight in a 9 years old cork ($cb\%9$)

$$cb\%9 = \exp(-(cc_9 / 19.4629)^{0.4744}) = 0.33$$

The special case of cork

4. Weight of a 9 years old cork without the back weight

$$\begin{aligned}wc_{9_b} &= wc_9(1-0.33) = 121.2823 - 121.2823(0.33) = \\ &= 121.2823 - 40.0232 = 81.2592 \text{ kg}\end{aligned}$$

5. Caliber of the 11 years old cork (cc_{11})

$$\begin{aligned}ct_{11} &= ct_7(1+19.5(7-1)^{-1.088}) / (1+19.5(11-1)^{-1.088}) = 21.24 \text{ mm} \\ cc_{11} &= 4.572 + 1.058 ct_{11} = 4.572 + 1.058(21.24) = 27.04 \text{ mm}\end{aligned}$$

6. Weight of the 11 years old cork (wc_{11})

$$\begin{aligned}wc_{11} &= wc_{9_b}(cc_{11}/cc_9) + wc_9(0.33) = \\ &= 81.2592(27.04/23.80) + 40.0232 = 132.3445 \text{ kg}\end{aligned}$$