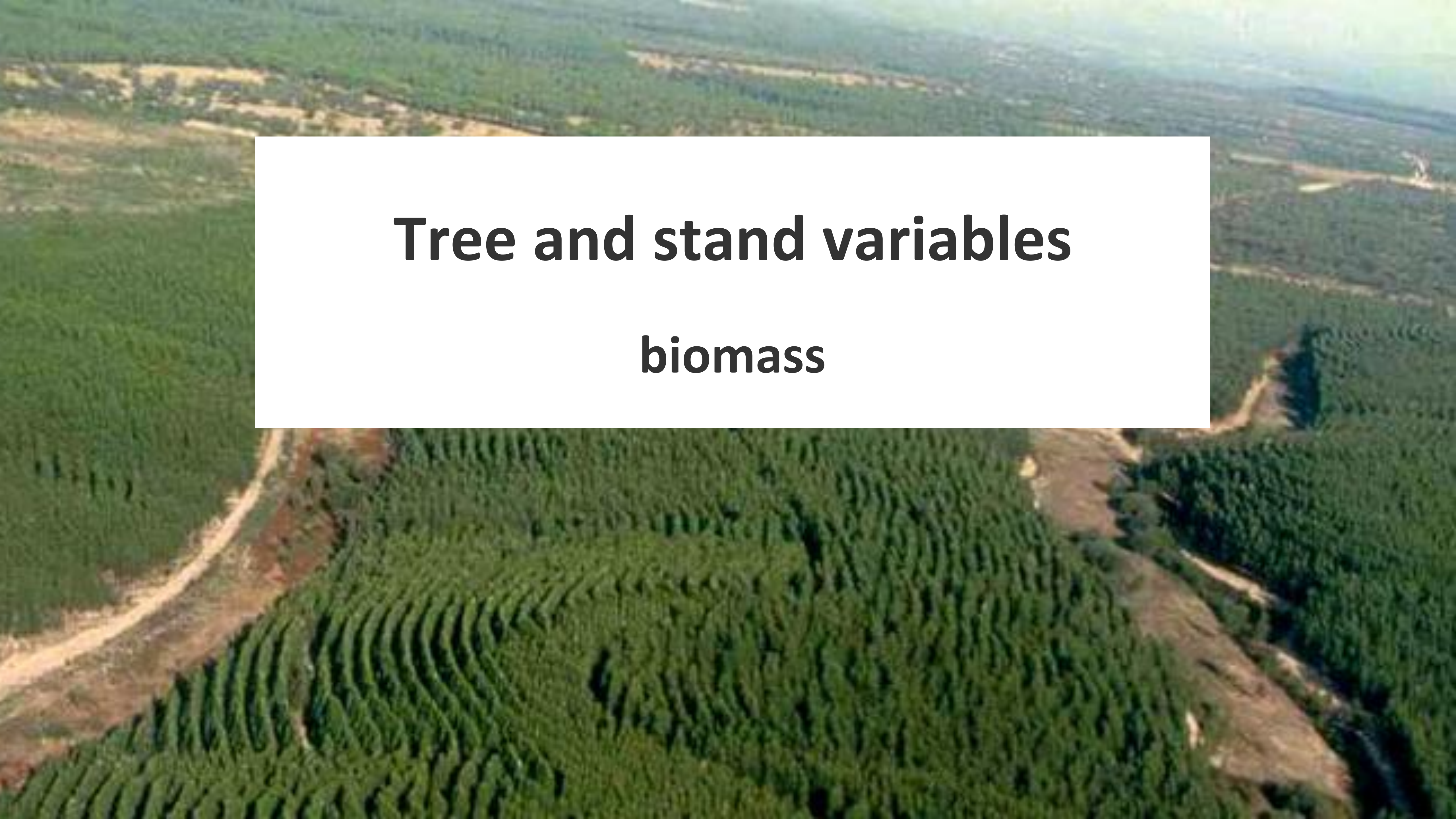
Tree and stand variables

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

- Biomass 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 regios, is marketed on a weight basis

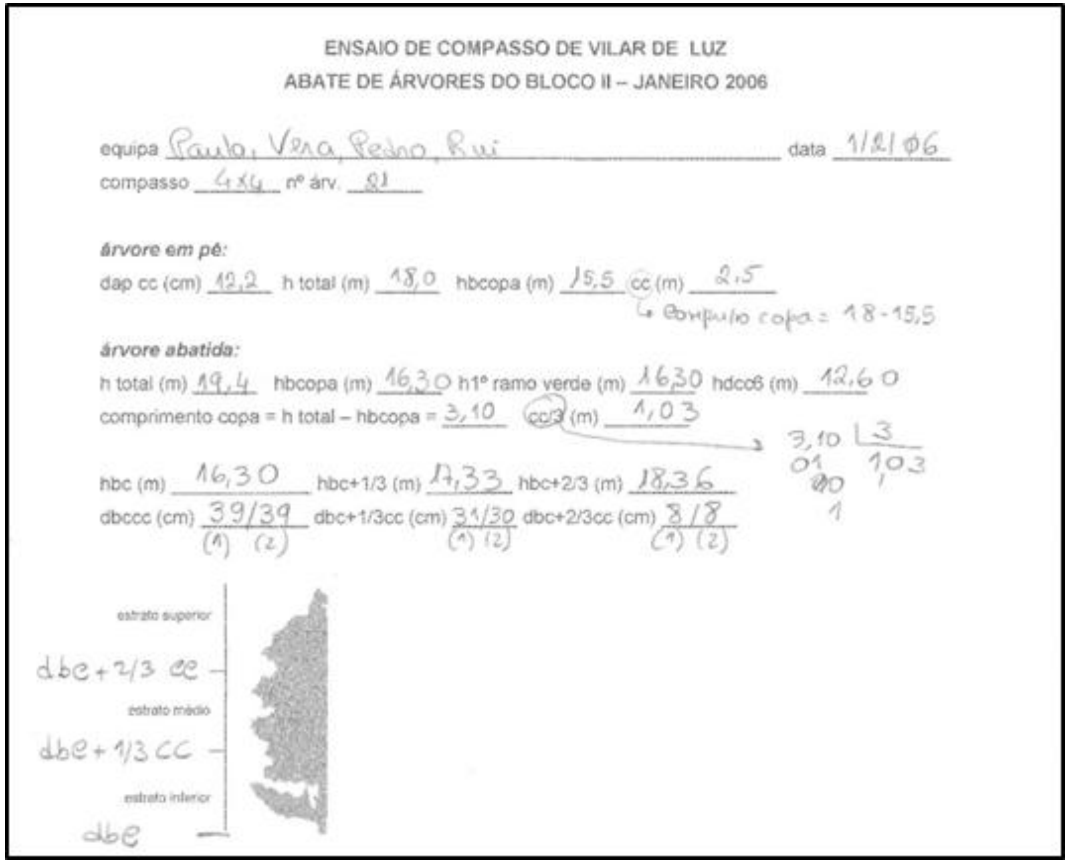
Biomass – direct evaluation?

- The evaluation of tree biomass implies the harvest of the tree, including the up-rooting, and the separation of all the tree components
- Ecen 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 …


STIHL

Example of data for tree biomass determination

- These data refere 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 Paula, Vera, Pedro, Rui data 1/2/06
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

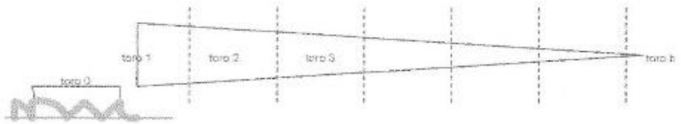
árvore abatida:
h total (m) 19,4 hbcopa (m) 16,30 h1º ramo verde (m) 16,30 hdcc6 (m) 12,60
comprimento copa = h total – hbcopa = 3,10 cc/3 (m) 1,03

3,10 | 3
01 1,03
10
1

hbc (m) 16,30 hbc+1/3 (m) 17,33 hbc+2/3 (m) 18,36
dbccc (cm) 39/39 (1) (2) dbc+1/3cc (cm) 31/30 (1) (2) dbc+2/3cc (cm) 8/8 (1) (2)

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 bicada	3,10	4,1	4,1	3,7	3,7
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 1/2/06

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

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

peso de cada uma das cascas das rodelas (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 ______

total = soma das 2
Falta somar!

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) com casca				peso seco final (g)
		8/2/06	9/2/06	10/2/06		
folhas	156,4	90,88	90,73	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) com caixa				peso seco final (g)
		8/2/06	9/2/06	10/2/06		
folhas	176,6	99,88	99,88	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) com caixa				peso seco final (g)
		8/2/06	9/2/06	10/2/06		
folhas	123,7	72,55	72,48	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 envolved 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 na example

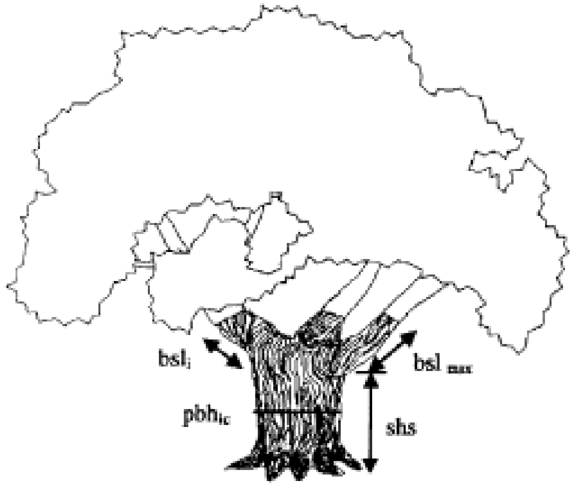
Tree component	Parameter estimations
Wood $ww = kw\ d^{aw}\ h^{bw}$	$kw = 0.0101$ $aw = \begin{cases} \text{se } hdom \le 10.710 & \dfrac{hdom}{-0.6653 + 0.6243\ hdom} \\ \text{se } hdom > 10.710 & 1.7788 \end{cases}$ $bw = 1.3638$
Bark $wb = kb\ d^{ab}\ h^{bb}$	$kb = 0.0006$ $ab = \begin{cases} \text{se } hdom \le 18.269 & \dfrac{hdom}{-0.6970 + 0.4586\ hdom} \\ \text{se } hdom > 18.269 & 2.3784 \end{cases}$ $bb = 1.0616$
Leaves $wl = kl\ d^{al}\ cl^{bl}$	$kl = 0.0295$ $al = \begin{cases} \text{se } hdom \le 7.387 & \dfrac{hdom}{-1.0312 + 0.7069\ hdom} \\ \text{se } hdom > 7.387 & 1.7627 - 0.01065\ hdom \end{cases}$ $bl = 0.6430$
Branches $wbr = kbr\ d^{abr}\ cl^{bbr}$	$kbr = 0.0237$ $abr = \begin{cases} \text{se } hdom \le 8.8348 & \dfrac{hdom}{-0.9130 + 0.7043\ hdom} \\ \text{se } hdom > 8.8348 & 1.6640 \end{cases}$ $bbr = 0.6067$
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 refered 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: $msh = shs + \frac{\sum_{1}^{nb} bsl_i}{nb}$
- Total stripped height: $sh_{tot} = shs + \sum_{1}^{nb} bsl_i$
- Maximum stripped height: $sh_{max} = shs + bsl_{max}$
- Mean stripping coefficient: $sc_{med} = \frac{msh}{pbh_{ic}}$
- Maximum stripping coefficient: $sc_{max} = \frac{sh_{max}}{pbh_{ic}}$
- Stem stripped surface: $sss = pbh_{ic}\ shs$
- Total stripped surface: $ss_{tot} = sss + \sum_{1}^{nb} (bsp_i \cdot bsl_i)$
- Maximum stripped surface: $ss_{max} = pbh_{ic} \cdot sh_{max}$
- Perimeter at breast height measured outside cork: $pbh_{oc} = pbh_{ic} + 2\pi\ (ct/100)$
- Cork biomass by unit of stripped surface: $wss = w / ss_{tot}$

The special case of cork

Models for use immediately before the stripping process

With no bough information

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

With the number of stripped boughs

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

With the measurement of the tallest stripped bough

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

With the measurement of all stripped boughs

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

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

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

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

With the number of stripped boughs

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

With the measurement of the tallest stripped bough

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

With the measurement of all stripped boughs

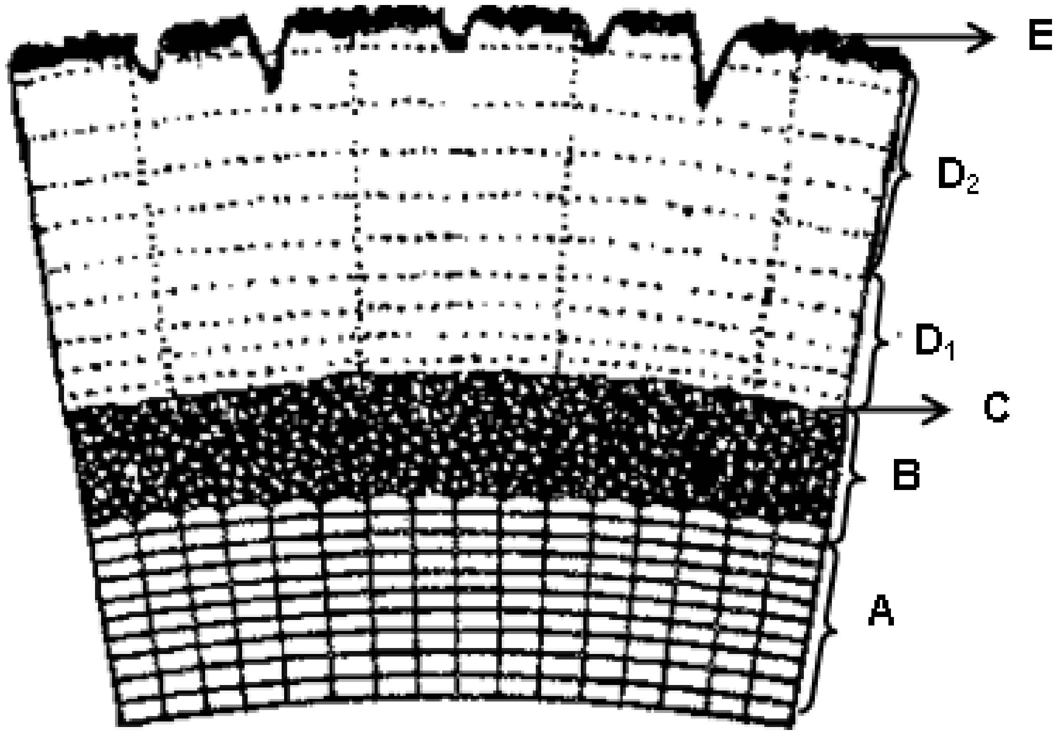
$$\ln w = 1.8276 + 0.8338 \ln(\mathrm{ss}_{tot}) + 0.3143 \ln(\mathrm{pbh}_{ic}) + 0.4562 \ln(\mathrm{ct})$$

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

The special case of cork

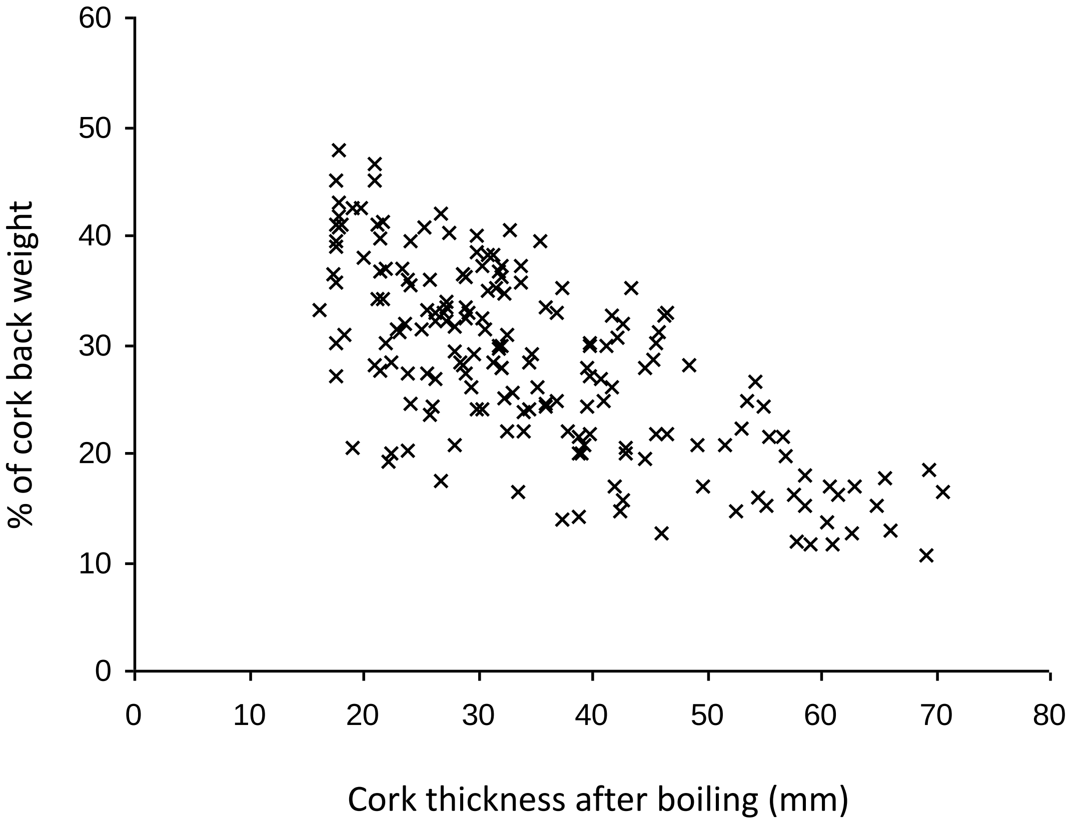
- Paulo and Tomé (2010) proposed a method for the prediction or cork dry weight with t years of age from a cork measurement undertaken at any cork age
- The method is based on the follwoing:
  - Estimation of the proportion of cork back weight
  - Homogeneity of cork density if cork back is excluded
  - 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 tc 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. $wc=0.1036\ du^{1.3395}\ hdv^{0.6709+0.1466\ \ln(nbrd1)}$
  4. $wc=0.0303\ [\ln(cc_9)]^{1.0667}\ du^{1.3178}\ hdv^{0.6703+0.1570\ \ln(nbrd1)}$

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 compelte 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:

$$cc_9 = 4.572 + 1.058 \ \mathrm{ct}_9$$

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

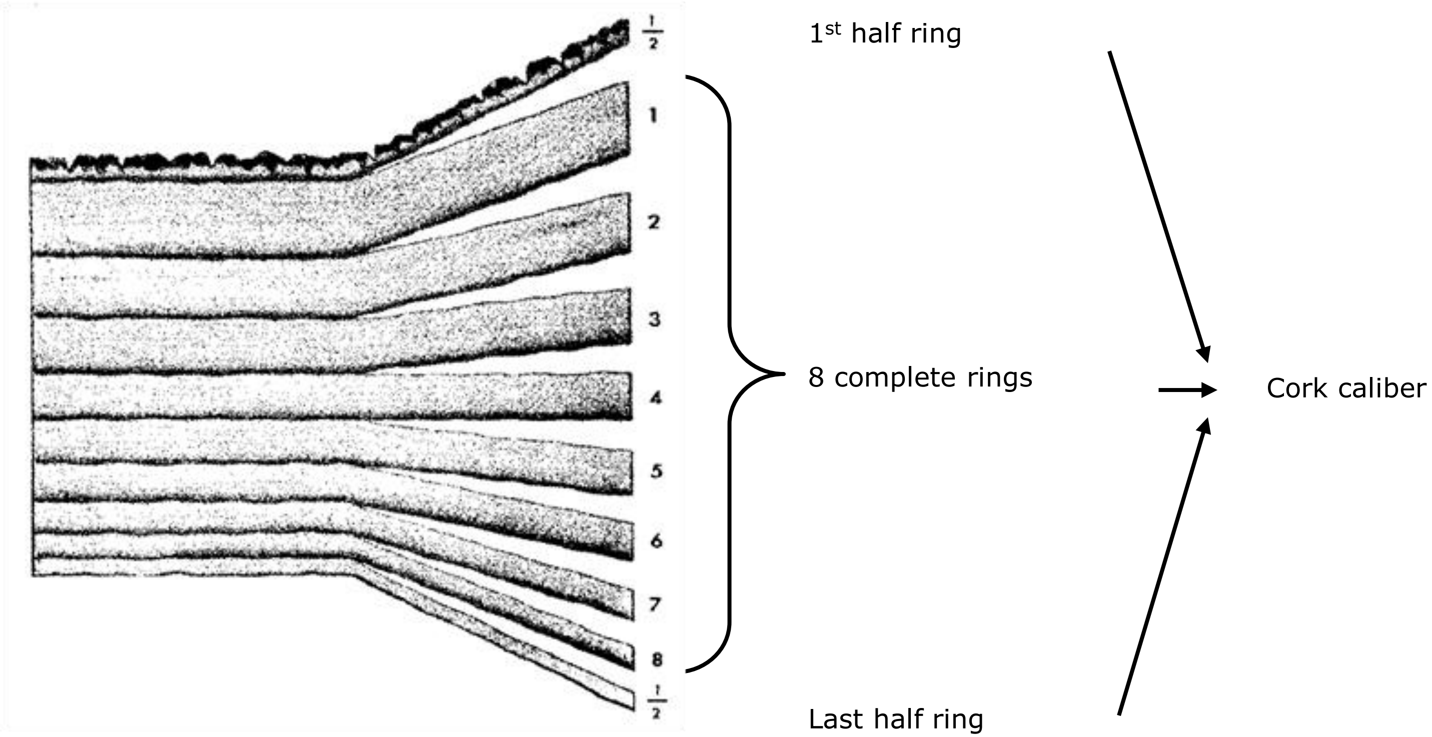
1. Estimate $\mathrm{ct}_{\mathrm{tc}}$:

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

2. Estimate $\mathrm{cc}_{\mathrm{tc}}$:

$$cc_{tc} = 4.572 + 1.058 \ \mathrm{ct}_{\mathrm{tc}}$$

The special case of cork



Schematicrepresentation 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)

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

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

   $ct_7=(cc_7-4.572)/1.058=14.58$ mm

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

   $cc_9=4.572+1.058\ ct_9=4.572+1.058(18.17)=23.80$ 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

$wc_{9\_b}=wc_9(1-0.33)=121.2823–121.2823(0.33)=$

$=121.2823-40.0232=81.2592$ kg

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

$ct_{11}=ct_7(1+19.5(7-1)^{-1.088})/(1+19.5(11-1)^{-1.088})=21.24$ mm

$cc_{11}=4.572+1.058\ ct_{11}=4.572+1.058(21.24)=27.04$ mm

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

$wc_{11}=wc_{9\_b}(cc_{11}/cc_9)+wc_9(0.33)=$

$=81.2592(27.04/23.80)+40.0232=132.3445$ kg