JACK PINE TAPER MODEL ANALYSIS IN BOREAL FOREST OF ABITIBI-TEMISCAMING

Rouyn-Noranda

Dec. 2007

JACK PINE TAPER MODEL ANALYSIS IN BOREAL FOREST OF ABITIBI-TEMISCAMING

1/ STEM TAPER

2/ SAPWOOD TAPER

3/ EFFECT OF STAND DENSITY ON THE STEM AND SAPWOOD TAPERS


sapwood
heartwood

Introduction

- Why sapwood and heartwood study?
  - for the biologists and ecologists:
    - sapwood area is directly related with leaf area;
    - sapwood volume is a living component of wood that respires and stores waters and nutrients for the tree.
  - for the engineers and technologists of wood:
    - predict wood volume and lumber yield.
    - Sapwood and heartwood proportions are important quality parameters for several processing operations including drying, impregnation, pulping, gluing and finishing.

Introduction

Classification of SPF group

Photo: 8 feets (2,4 meters)

premium

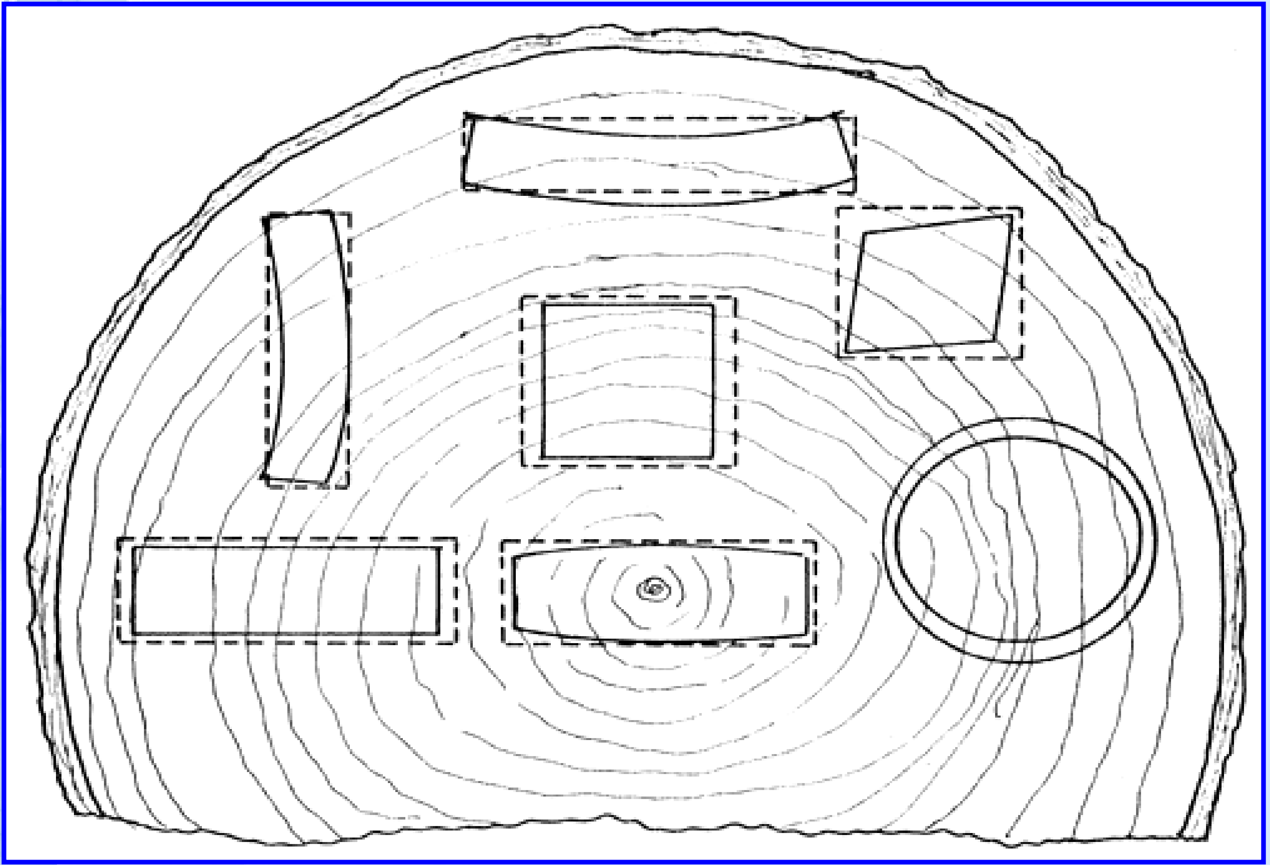
N°2 and best

N°3

Source: Bureau de Promotion des Produits Forestiers du Québec
Quebec Wood Export Bureau

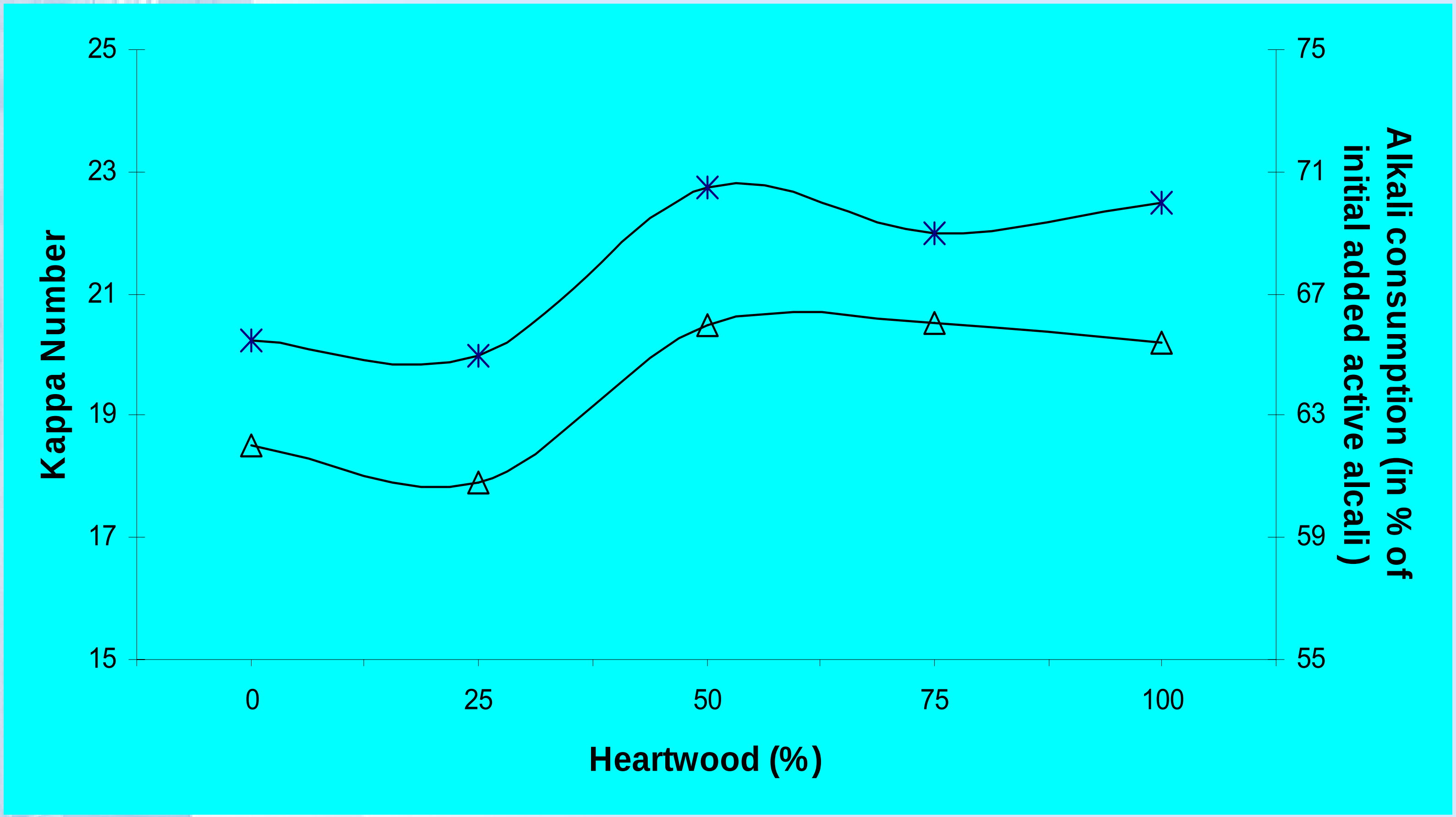
Introduction

Distortions of the wood after drying process according to the place of the piece in the log. (Joly and More-Chevalier. 1980)



Introduction

Effects of *Eucalyptus nitens* heartwood in kraft pulping. (mariani et al., 2005)



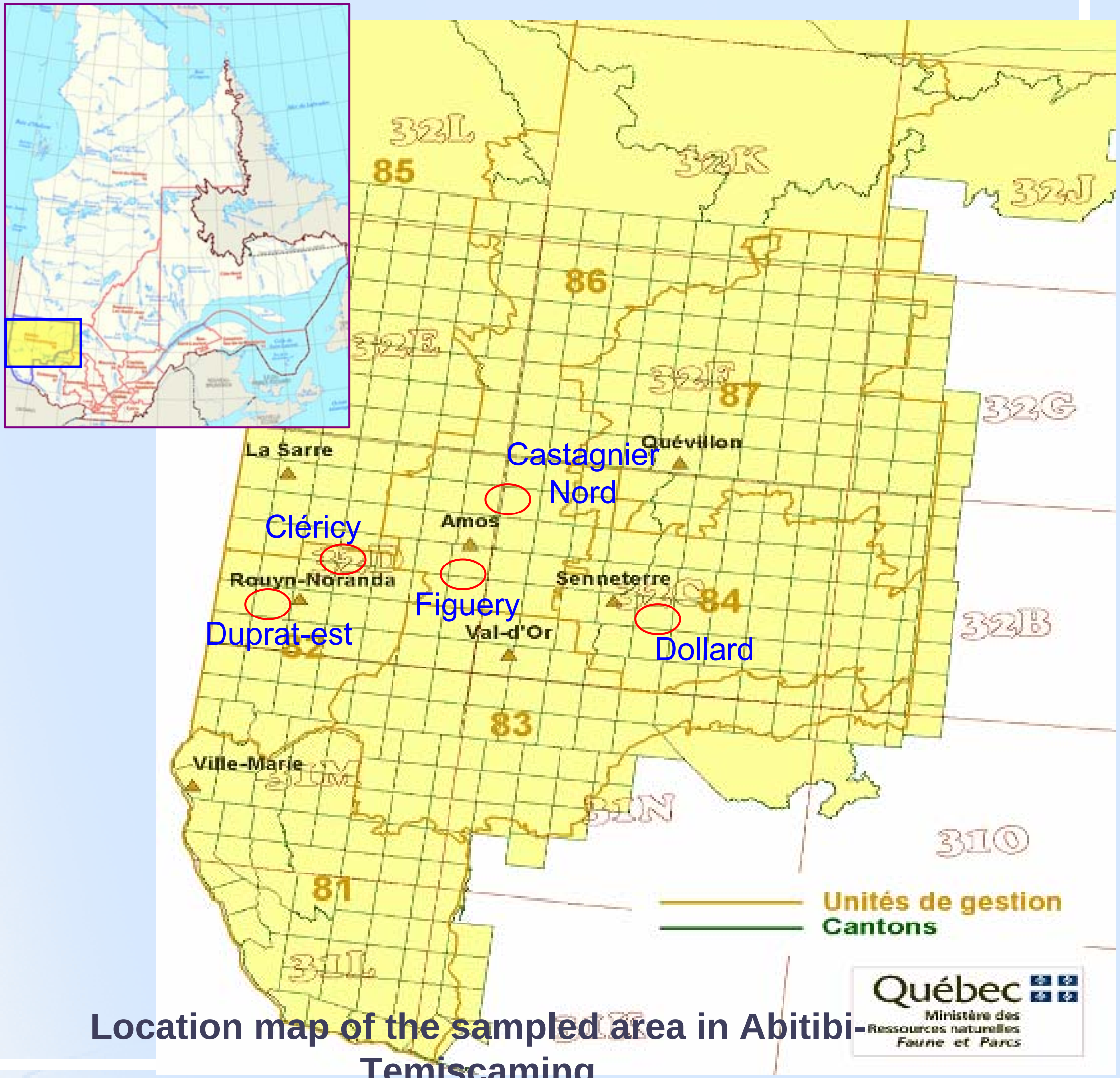
Objectives

- Predict sapwood and heartwood proportion using indirect measures (direct measurement is expensive and destructive)
- Determine how the size and shape of the sapwood and heartwood of Jack pine (*Pinus banksiana* Lamb.) depend on tree size and stem form;
- Focus on the taper analysis which based on allometry theory (relationship between the size and shape of an organisme).
- Analyse the effect of stand density on the shape and the taper of jack pine stem and sapwood.

Materials

DATA:

- 5 stands in Abitibi-Temiscaming boreal's forest
- 60 sampled trees (12 trees/stand);
- Destructive sampling;
- Measurements at 0.30, 1.0, and 1.3 (BH)
- Measurement intervals = 1m (above BH);



Location map of the sampled area in Abitibi-Temiscaming


10m
B55
11m
B55
12m
B55
13m
B55

Materials (continued)

measured parameters:

- DoB_{BH}: Diameter at breast height outside bark (mm);
- DiB_{BH} (also noted D): diameter at breast height inside bark (mm);
- H: total height (m);
- h : Height above ground level (m);
- d : Diameter inside bark at a height « h » (mm);
- CB: height to crown base (m);
- CL: Crown lenght (m);
- D_{HW}: Heartwood diameter (mm) at a height « h »;
- D_{SA}: Sapwood diameter (mm) at a height « h ».

Deducted parametres:

- $\%SA = 100*D_{SA}/d$; $\%HW = 100*D_{HW}/d$;
- sa (Heartwood area (cm^2) at a height « h ») = $\pi D_{HW}^{2}/4$ (excentricity was neglected);
- SA_{BH}: Sapwood area at breast height.

METHODS

METHODS

Part 1: Stem taper analysis

Fitting models tested (9 models):

- Group1: single taper models:
  - *Polynomial*:
    - Model 1: Munro (1966): $\left(\frac{d}{D}\right)^2 = a_1 - a_2 \cdot \left(\frac{h}{H-1.3}\right)$

      a_1 a_2 fitting coefficients to be estimated.
    - Model 2: Kozak et al. (1969) $\left(\frac{d}{D}\right)^2 = b_1 \cdot (T-1) + b_2 \cdot (T^2 - 1)$

      T = h/H, b_1 b_2 fitting coefficients to be estimated
    - Model 3: Bennett and Swindel (1972)

$$\frac{d}{D} = c_1 X + c_2 \frac{(H-h)\cdot(h-1.3)}{D} + c_3 \frac{(H-h)(h-1.3)H}{D} + c_4 \frac{(H-h)(h-1.3)(H+h+1.3)}{D}$$

$X = (H-h)/(H-1.30)$, c_1 c_2 c_3 c_4 fitting coefficients to be estimated

  - *Power function model*:
    - Model 4: Ormerod (1973) $\frac{d}{D} = \left(\frac{H-h}{H-1.3}\right)^{e_1}$

      e_1 coefficients to be estimated.
    - Model 5: Newberry and Burkhart (1986) $\frac{d}{D} = f_1 \left(\frac{H-h}{H-1.3}\right)^{f_2}$

      f_1, f_2 coefficients to be estimated

Part 1: Stem taper analysis (continued)

- Group 2: segmented taper models
  - Model 6: Max and Burkhart (1976); *quadratic-quadratic segmented polynomial model*

$$\left(\frac{d}{D}\right)^2 = h_1(T-1) + h_2(T^2-1) + h_3(h_5-T)^2 \cdot I_1 + h_4(h_6-T)^2 \cdot I_2$$

$$I_1 = \begin{cases} 1 \rightarrow if T \leq h_5 \\ 0 \rightarrow if T > h_5 \end{cases} \qquad I_2 = \begin{cases} 1 \rightarrow if T \leq h_6 \\ 0 \rightarrow if T > h_6 \end{cases}$$

T = h/H, h_1 h_2 h_3 h_4 h_5 h_6 coefficients to be estimated.

  - Model 7: Parresol et al (1987); *quadratic segmented polynomial model*

$$\left(\frac{d}{D}\right)^2 = Z^2(k_1 + k_2 \cdot Z) + (Z - k_5)^2 \cdot [k_3 + k_4(Z + 2k_5)] \cdot I$$

$$I = \begin{cases} 1 \rightarrow if Z \geq k_5 \\ 0 \rightarrow if Z < k_5 \end{cases}$$

Z= *(H-h)/H* , k_1 k_2 k_3 k_4 k_5 coefficients to be estimated.

Part 1: Stem taper analysis (continued)

- Group 3: variable exponent models
  - *Model 8: Kozak (1988)*

$$d = m_1 \cdot D^{m_2} \cdot m_3^{D} \cdot \left[\frac{1-\sqrt{T}}{1-\sqrt{p}}\right]^{\left[m_4 \cdot T^2 + m_5 \cdot Log(T+0.001) + m_6 \cdot \sqrt{T} + m_7 \cdot e^{T} + m_8 \cdot \left(\frac{D}{H}\right)\right]}$$

$T = h/H$, m_1 m_2 m_3 m_4 m_5 m_6 m_7 m_8 coefficients to be estimated

  - *Model 9: Kozak (2004)*

$$d = n_1 \cdot D^{n_2} \cdot H^{n_3} \cdot \left[\frac{1-T^{1/3}}{1-P^{1/3}}\right]^{n_4 \cdot T^4 + n_5 \cdot \left(1/e^{D/H}\right) + n_6 \cdot \left(\frac{1-T^{1/3}}{1-p^{1/3}}\right)^{0.1} + n_7 \cdot \left(\frac{1}{D}\right) + n_8 \cdot H^{1-\left(\frac{h}{H}\right)^{1/3}} + n_9 \left(\frac{1-T^{1/3}}{1-p^{1/3}}\right)}$$

$T = h/H$, n_1 n_2 n_3 n_4 n_5 n_6 n_7 n_8 n_9 coefficients to be estimated

Part 2: Sapwood taper analysis

Fitting models tested (8 models):

- Group1: polynomial models
  - Model 1: Bennett and Swindel (1972)

$$sa/SA_{BH} = X_1 + a_1 X_2/SA_{BH} + a_2 X_3/SA_{BH} + a_3 X_4/SA_{BH}$$

  - Model 2: Bennett and Swindel (1972) modified by Maguire and Batista (1995)

$$sa/SA_{BH} = (b_1 D + b_2 H + b_3 CR) \cdot X_2/SA_{BH} + (b_4 CR) \cdot X_3/SA_{BH} + \left(b_5 (H/D) + b_6 CB\right) \cdot X_4/SA_{BH}$$

$$\begin{cases} X_1 = (H-h)/(H-1.37) \\ X_2 = (H-h)(h-1.37) \\ X_3 = H(H-h)(h-1.37) \\ X_4 = (H-h)(h-1.37)(H+h+1.37) \end{cases}$$

CR: crown ratio = CL/H

$a_1\ a_2\ a_3\ b_1\ b_2\ b_3\ b_4\ b_5\ b_6$ coefficients to be estimated

Part 2: Sapwood taper analysis (continued)

- Group2: segmented polynomial models
  - Model 3: Walters-Hann (1986) *quadratic-quadratic segmented polynomial model*

$$sa/SA_{BH} = 1 + Z_1 + c_1 Z_2 + c_2 Z_3$$

  - Model 4: Walters-Hann (1986) *cubic-quadratic segmented polynomial*

$$sa/SA_{BH} = 1 + Z_1 + f_1 Z_2 + f_2 Z_3 + f_3 Z_4$$

$$\begin{cases} Z_1 = I[A(1+B)-1] \\ Z_2 = X + I[A(X+JB)-X] \\ Z_3 = X^2 + I[JA(2X-J+JB)-X^2] \\ Z_4 = X^3 + I[J^2A(3X-2J+JB)-X^3] \\ J = 0.03(CB-1.37)/(H-1.37) \\ I = \begin{cases} 1 \rightarrow if X > J \\ 0 \rightarrow if X \le J \end{cases} \end{cases}$$

$c_1\ c_2\ \ f_1\ f_2\ f_3$ coefficients to be estimated

$$\begin{cases} A = (X-1)/(J-1) \\ B = (J-X)/(J-1) \\ X = (h-1.37)/(H-1.37) \end{cases}$$

Part 2: Sapwood taper analysis (continued)

– Model 5: Max and Burkhart (1976) *quadratic-quadratic segmented polynomial model*

$$sa/SA_{BH} = e_1(X-1) + e_2(X^2-1) + e_3(J-X)^2 I$$

$$I = \begin{cases} 0 \rightarrow if X > J \\ 1 \rightarrow if X \leq J \end{cases}$$

J=0.90H

X= (h-1.37)/(H-1.37)

e_1 e_2 e_3 *coefficients to be estimated*

Part 2: Sapwood taper analysis (continued)

- Group 2: variable exponent models

- Model 6: Kozak (1988)

$$\frac{sa}{SA_{BH}} = X^{C}$$

$$\begin{cases} X = \left(1-\sqrt{Z}\right)/\left(1-\sqrt{p}\right) \\ Z = h/H \\ p = \left(1.37/H\right) \\ C = h_1 Z + h_2 Z^2 + h_3 Ln(Z+0.001) + h_4\sqrt{Z} + h_5\left(D/H\right) \end{cases}$$

$h_1\ h_2\ h_3\ h_4\ h_5$ *coefficients to be estimated*

- Model 7 : Kozak (1988) modified by Maguire and Batista (1995)

$$\frac{sa}{SA_{BH}} = X^{C}$$

$$C = k_1 Z + k_2\sqrt{Z} + k_3\left(D/H\right) + k_4 CL + k_5 CR + k_6 CB$$

$k_1\ k_2\ k_3\ k_4\ k_5\ k_6$ *coefficients to be estimated*

Part 2: Sapwood taper analysis (continued)

- group 3: trigonometric taper model
  - Thomas-parresol (1991)

$$sa/SA_{BH} = m_1(X-1) + m_2 \sin\left(3\pi/2\, X\right) + m_3 \cot an\left(\pi X/2\right)$$

$$X = h/H$$

m_1 m_2 m_3: coefficients to be estimated;

Used statistical analysis methods

- taper analysis : →proc nlin; (SAS Institute Inc. 2001) method of iteration: GAUSS-NEWTON;
- multicollinearity diagnostic : condition number < $\sqrt{1000}$;
- generalized coefficient of determination: $R_g^2 = 1 - \frac{\sum(pred - obs)^2}{\sum(pred - \overline{obs})^2}$
- The Akaike information criterion: $AIC = 2k + \ln(RSS / n)$
- Autocorrelation…?;
- smoothing curve: Locally-Weighted Scatterplot Smoothing (LOWESS) technique ;

RESULTS

RESULTS

Stem taper analysis: fit statistics for the models

model	MODELING DATA SET (n= 44 trees)				condition number	AIC	VALIDATION DATA SET (n= 16 trees)		
	MSE	R^2_g	ME	SD			R^2_g	ME	SD
1	0.0039	0,9634	-0,0021	0,0410	32,5950	-5758,69	0,9591	-0,0026	0,0435
2	0.0039	0,9615	-0,0046	0,0428	16,5020	-5744,14	0,9575	-0,0055	0,0450
3	0.0014	0,9691	0,0004	0,0375	32,5950	-5740,14	0,9696	0,0015	0,0375
4	0.0017	0,9617	0,0019	0,0420	32,5950	-6585,49	0,9580	0,0008	0,0439
5	0.0039	0,9353	0,0592	0,1100	32,5950	-5757,95	0,9309	0,1185	0,1116
6	0.0036	0,9670	-0,0011	0,0387	88,6350	-5814,85	0,9642	-0,0019	0,0405
7	0.0119	0,9619	0,0651	0,0518	45,6610	-4599,42	0,9571	0,0645	0,0543
8	0.0032	0,9687	0,0010	0,0375	16,5000	-5945,16	0,9694	0,0017	0,0375
9	0.0035	0,9625	0,0008	0,0412	32,4780	-5840,45	0,9647	0,0021	0,0404

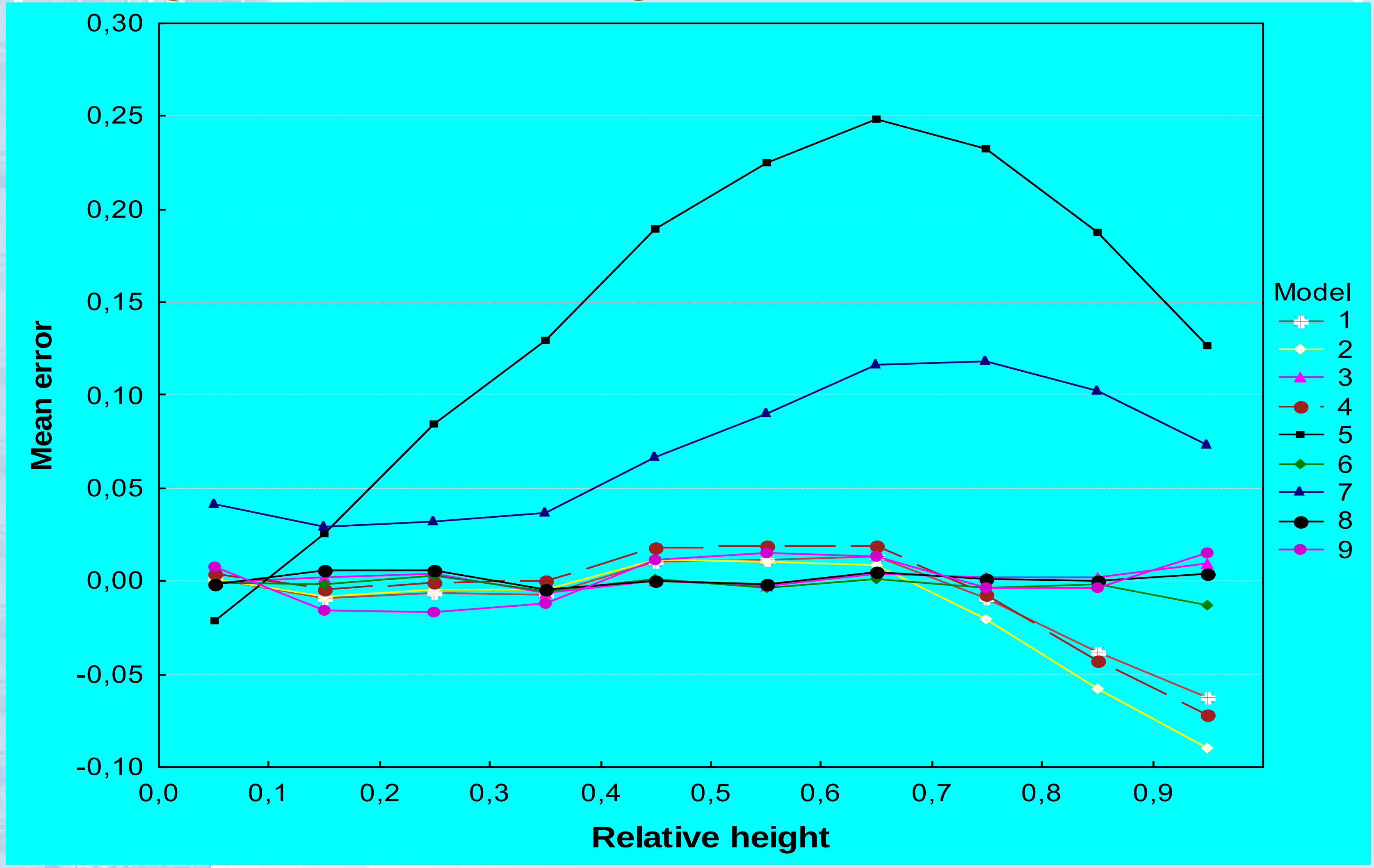
RESULTS

Stem taper analysis: parameter estimates for the tested models

MODEL	Parameter	estimation	SE	MODEL	Parameter	estimation	SE
1	a1	1.0969	0.00335	7	k1	2.6659	0.1581
	a2	1.0376	0.00661		k2	-1.8050	0.3047
					k3	-3.9328	7.6041
2	b1	-1.1664	0.0188		k4	2.2167	3.3049
	b2	0.0676	0.0156		k5	0.5914	0,3548
3	c1	0.9985	0.00185	8	m1	0.7317	0.1711
	c2	0.1031	0.00456		m2	1.1509	0.1247
	c3	-0.0101	0.000343		m3	0.9931	0.00698
	c4	0.00470	0.000149		m4	-0.8970	0.2838
					m5	0.2730	0.0685
4	e1	0.5337	0.00328		m6	-2.5968	0.5465
					m7	1.4468	0.3087
5	f1	1.0055	0.00302		m8	0.1864	0.0182
	f2	1.0440	0.00913				
				9	n1	0.2258	0.0478
6	h1	-5.6553	2.0912		n2	0.3466	0.0557
	h2	2.6557	1.1546		n3	1.5771	0.1056
	h3	-3.2925	1.0984		n4	0.5976	0.0462
	h4	1.4934	0.2427		n5	-1.0097	0.0662
	h5	0.7931	0.0471		n6	1.2253	0.0257
	h6	0.3542	0.0481		n7	3.5362	0.3259
					n8	0.0232	0.00137
					n9	-0.4636	0.0135

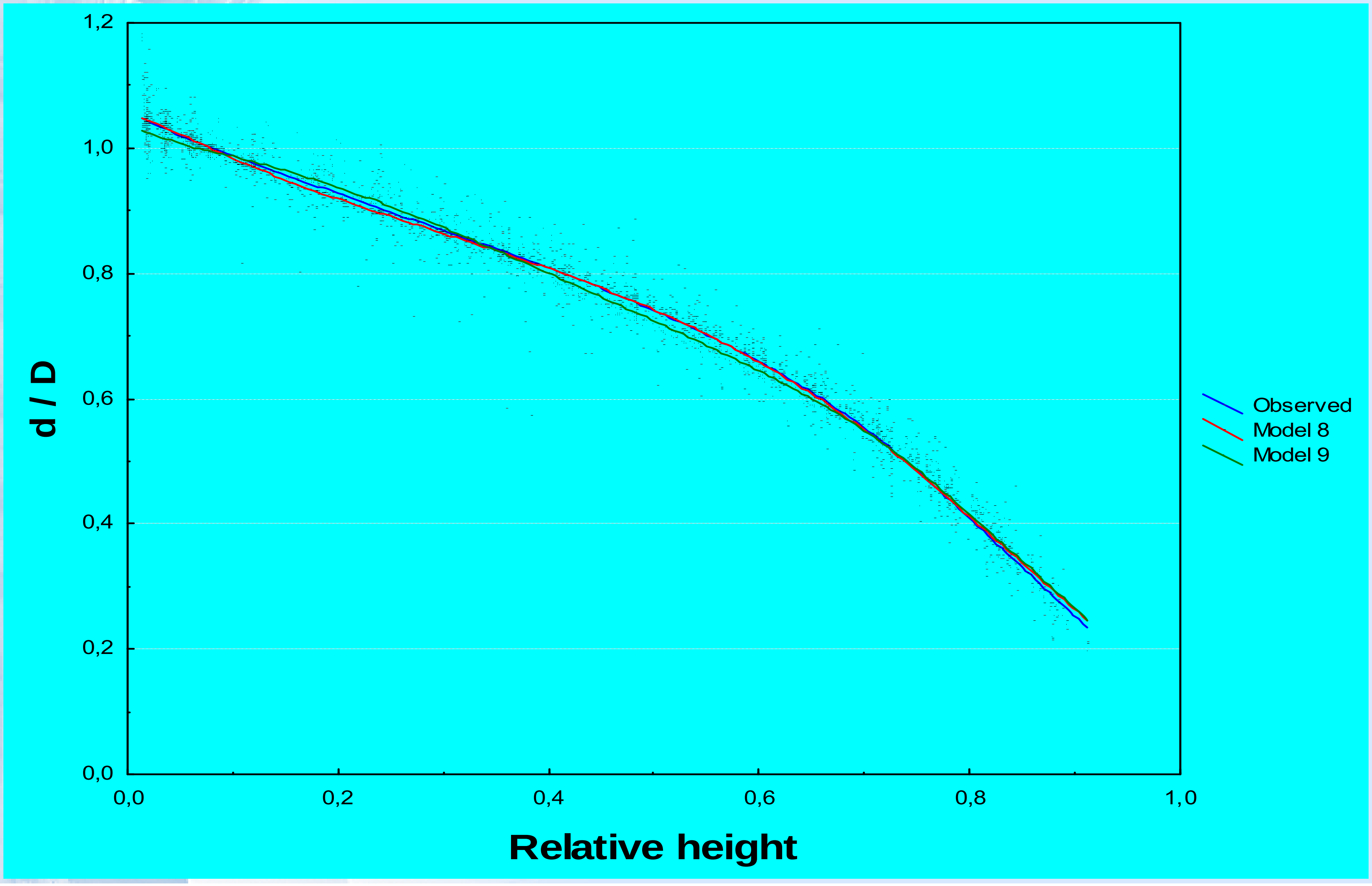
RESULTS

Stem taper analysis: mean error by relative height for the modeling data set



RESULTS

which model should be chosen?



RESULTS

Recommended model

- *Model 8: Kozak (1988)*

$$d = m_1 \cdot D^{m_2} \cdot m_3^D \cdot \left[\frac{1-\sqrt{T}}{1-\sqrt{p}}\right]^{\left[m_4 \cdot T^2 + m_5 \cdot Log(T+0.001) + m_6 . \sqrt{T} + m_7 \cdot e^T + m_8 \cdot \left(\frac{D}{H}\right)\right]}$$

m_1= 0.7317, m_2= 1.1509, m_3 = 0.9931, m_4 = - 0.8970, m_5= 0.2730, m_6 = - 2.5968
m_7 = 1.4468, m_8 = 0.1864

- *No Risk of multicollinearity (Condition Number = 16,50 < $\sqrt{1000}$)*
- *Model Application: Counting collected wood volume*

$$V = \frac{\pi}{4} \int_{0.3}^{H} d^2 \cdot dh$$

RESULTS

Sapwood taper analysis: fit statistics for the models

	FITTING DATA SET						VALIDATION DATA SET		
	MSE	R^2_g	ME	SD	condition number	AIC	R^2_g	ME	SD
model1	0.0109	0,8767	0,0002	0,1041	37,3450	-4698,96	0,4306	0,6704	0,3292
model2	0.0111	0,8712	0,7136	0,2659	30,3390	-4679,50	0,4796	-18,9516	16,8036
model3	0.0116	0,8662	0,0052	0,1049	29,8120	-4622,37	0,8439	-0,0101	0,1184
model4	0.012	0,8511	0,7260	0,2845	***	-4533,81	0,8278	-0,0020	0,1237
model5	0.0117	0,8656	-0,0073	0,1075	7417,1928	-4619,06	0,8436	-0,0108	0,1186
model6	0.0304	0,8163	0,7163	0,2755	34,3317	-3621,50	0,8604	0,0049	0,1112
model7	0.0307	0,8263	0,0024	0,1128	659,0128	-3614,69	0,8571	-0,0112	0,1151
model8	0.0142	0,8509	0,7266	0,2853	29,4489	-4407,68	0,8286	0,0108	0,1278

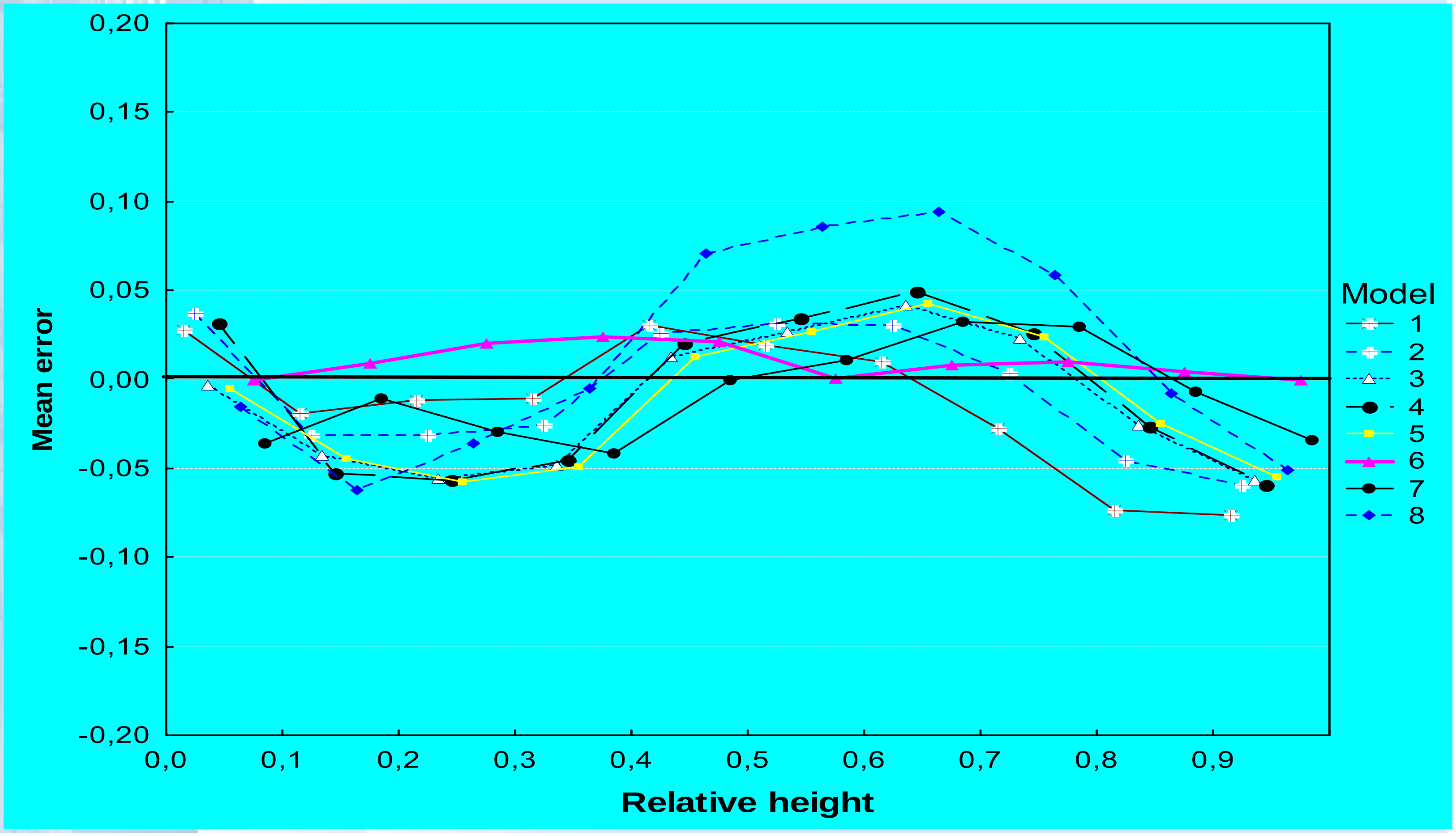
RESULTS

Sapwood taper analysis: parameter estimates for the tested models

Model	Parameters	estimation	SE	Model	Parameters	estimation	SE
1	a1	0.4931	0.1049	**6**	h1	-6.0846	0.7944
	a2	-0.0803	0.00803		h2	3.5706	0.3537
	a3	0.0389	0.00348		h3	-0.0134	0.0360
					h4	3.3460	0.4820
2	b1	0.000028	5.977E-6		h5	0.0257	0.00429
	b2	-0.00047	0.000084				
	b3	0.6242	0.6212	**7**	k1	2.9063	0.2214
	b4	-0.0296	0.0411		k2	-3.5461	0.3246
	b5	0.0976	0.0766		k3	0.0184	0.00447
	b6	0.000988	0.000489		k4	-0.0874	0.0154
					k5	3.2762	0.3582
3	c1	-1.2225	0.0521		k6	0.0614	0.00762
	c2	15.7784	1.5609				
				8	m1	-1.1487	0.0118
4	e1	-0.7846	0.0312		m2	-0.0242	0.00941
	e2	-0.2091	0.0369		m3	-0.00005	0.000567
	e3	0.000077	0.000054				
5	f1	-1.1467	0.0916				
	f2	37.3927	7.1629				
	f3	318.9	125.1				

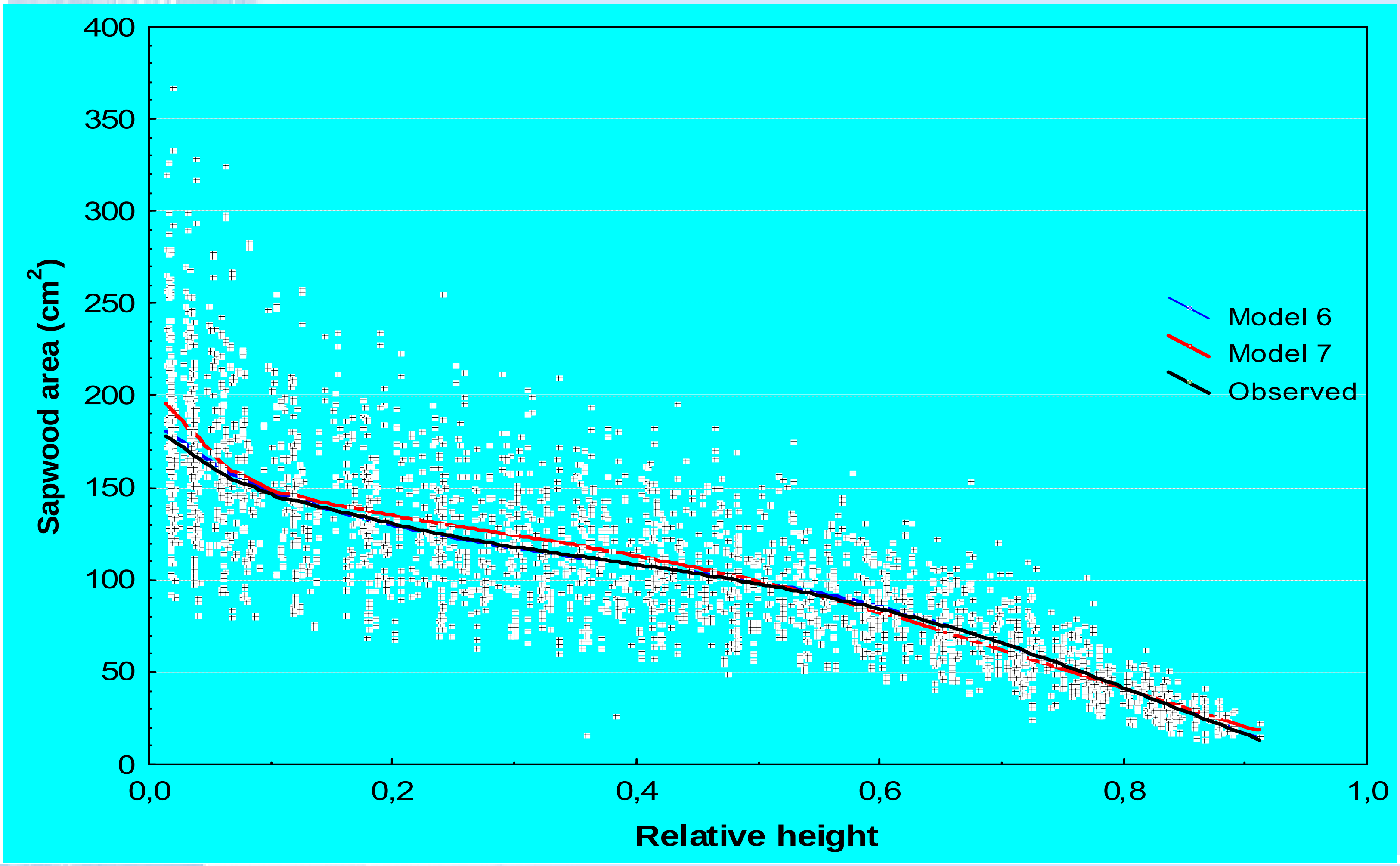
RESULTS

Sapwood taper analysis: mean error by relative height for the modeling data set



RESULTS

Sapwood taper analysis: Smooth curve of observed and predicted profile



Recommended model

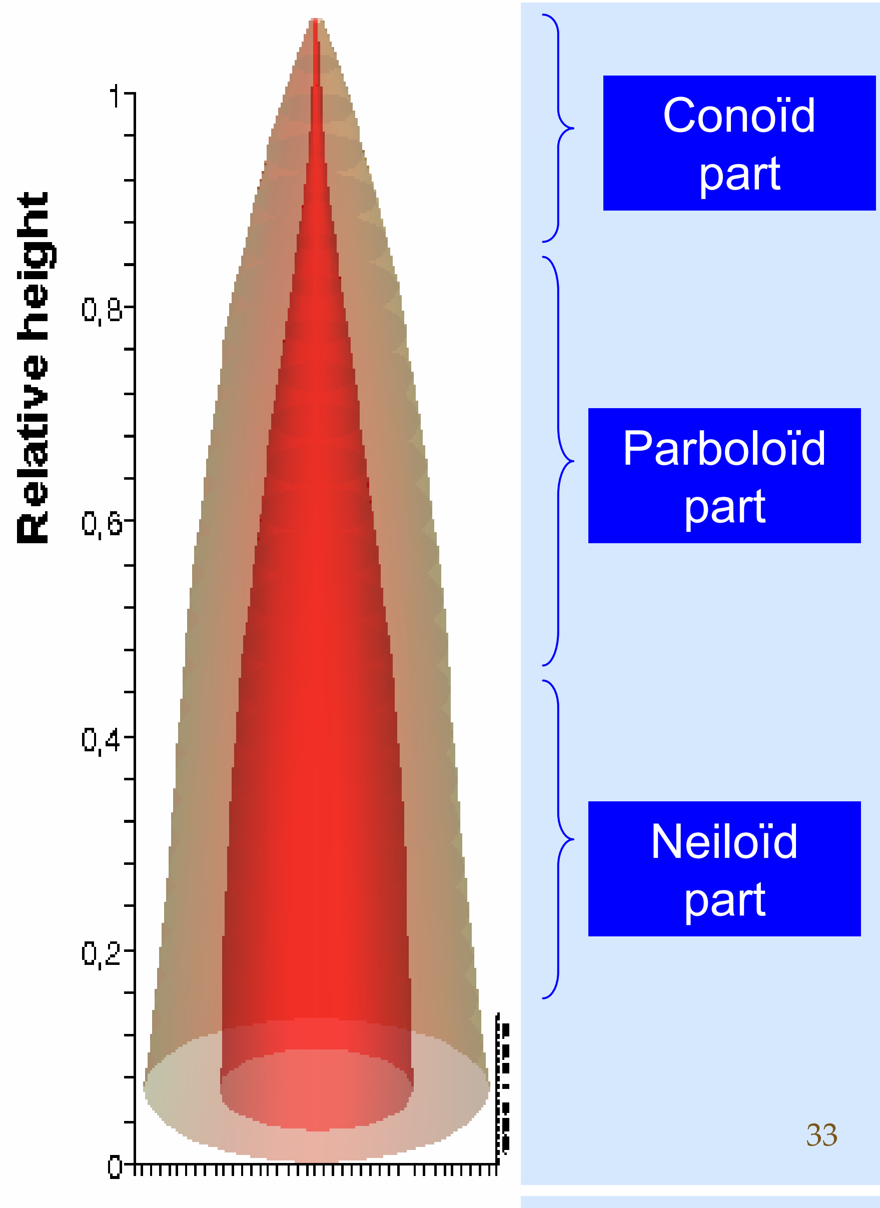
- *Model 6: Kozak (1988)* $sa/SA_{BH} = X^{C}$

$$\begin{cases} X = \left(1-\sqrt{Z}\right)/\left(1-\sqrt{p}\right) \\ Z = h/H \\ p = \left(1.37/H\right) \\ C = h_1 Z + h_2 Z^2 + h_3 Ln(Z + 0.001) + h_4\sqrt{Z} + h_5\left(D/H\right) \end{cases}$$

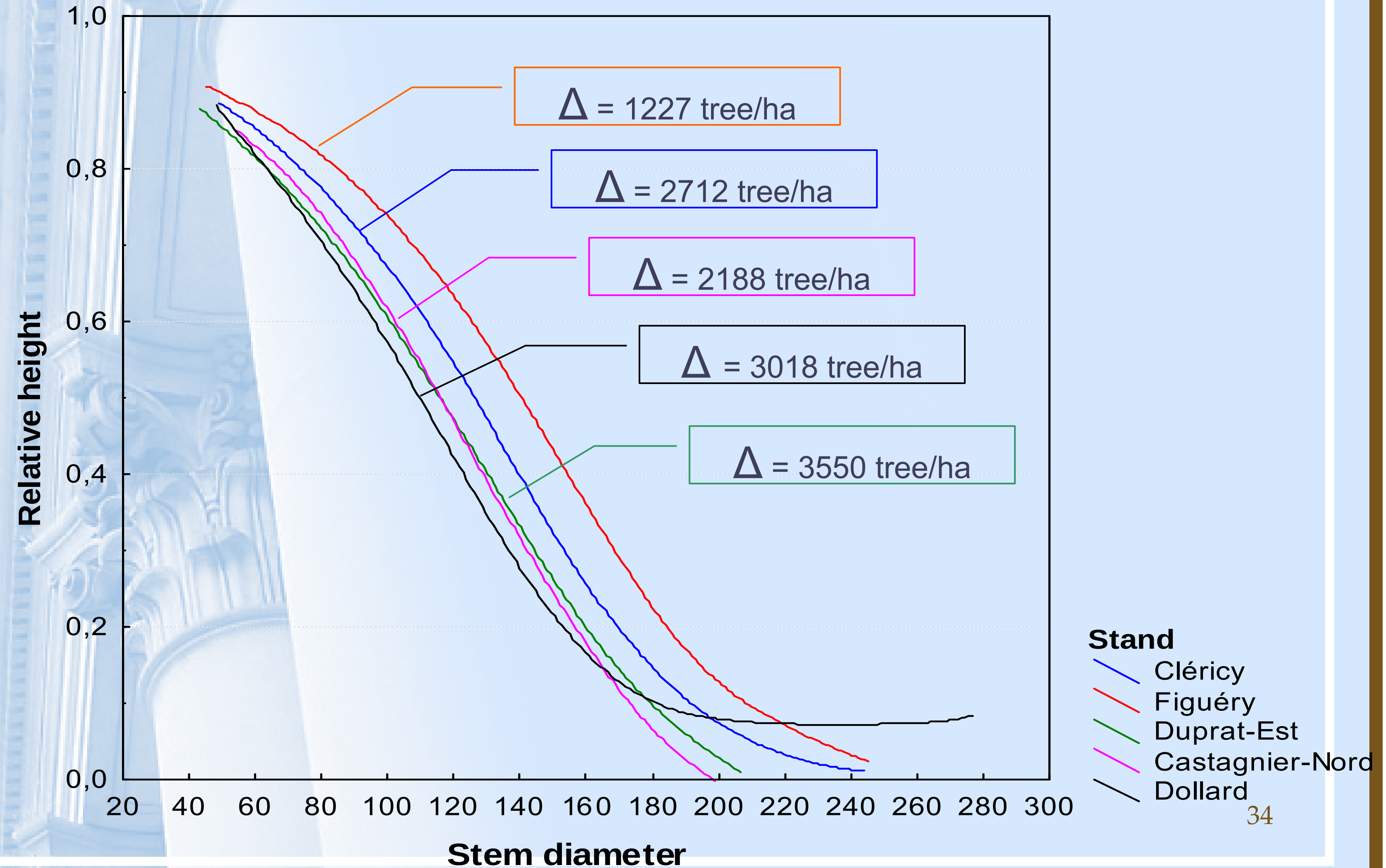
h_1= -6.0846, h_2= 3.5706, h_3= -0.0134, h_4= 3.3460, h_5= 0.0257

- Best validation results

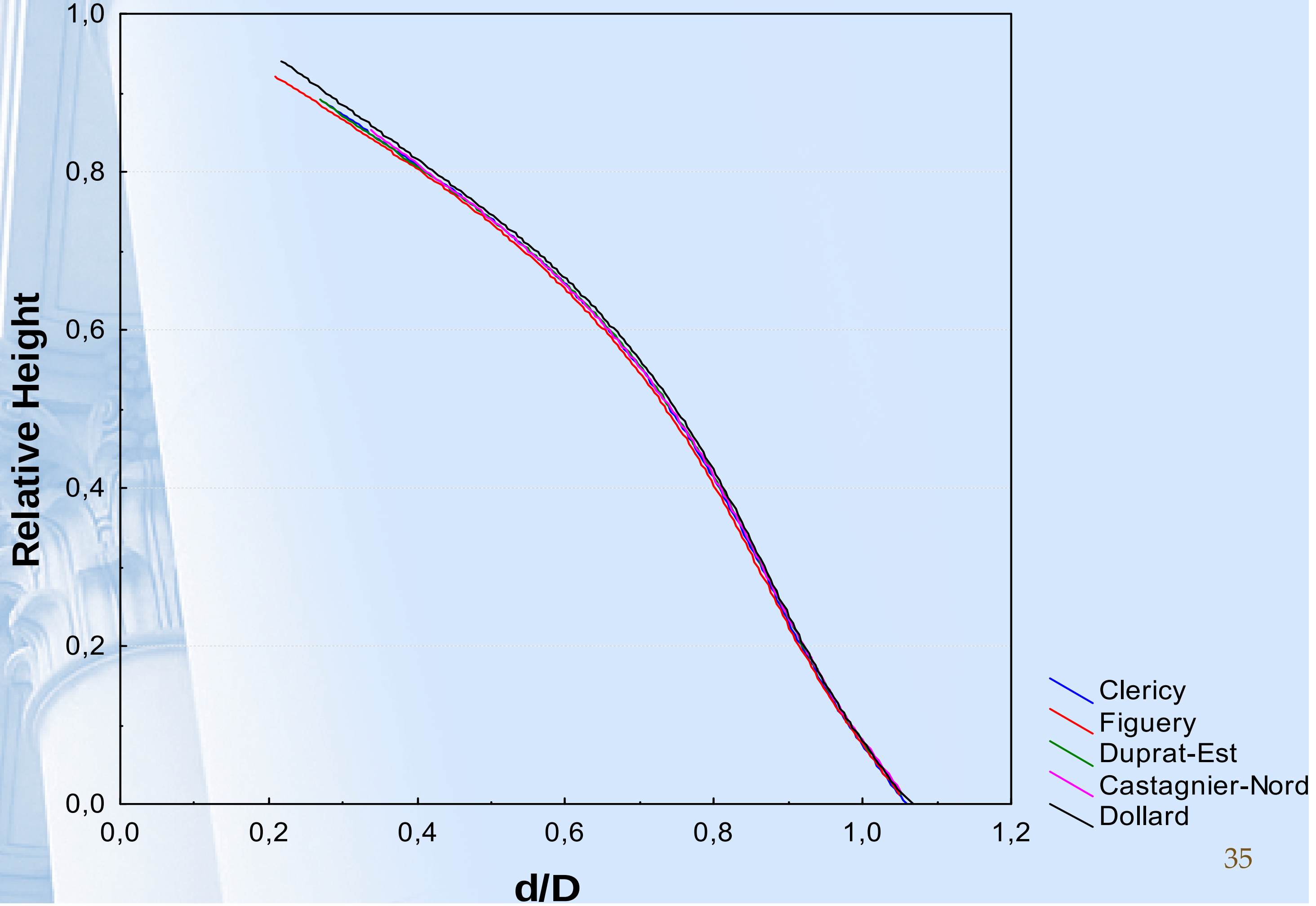
Heartwood-Sapwood taper: 3-D view



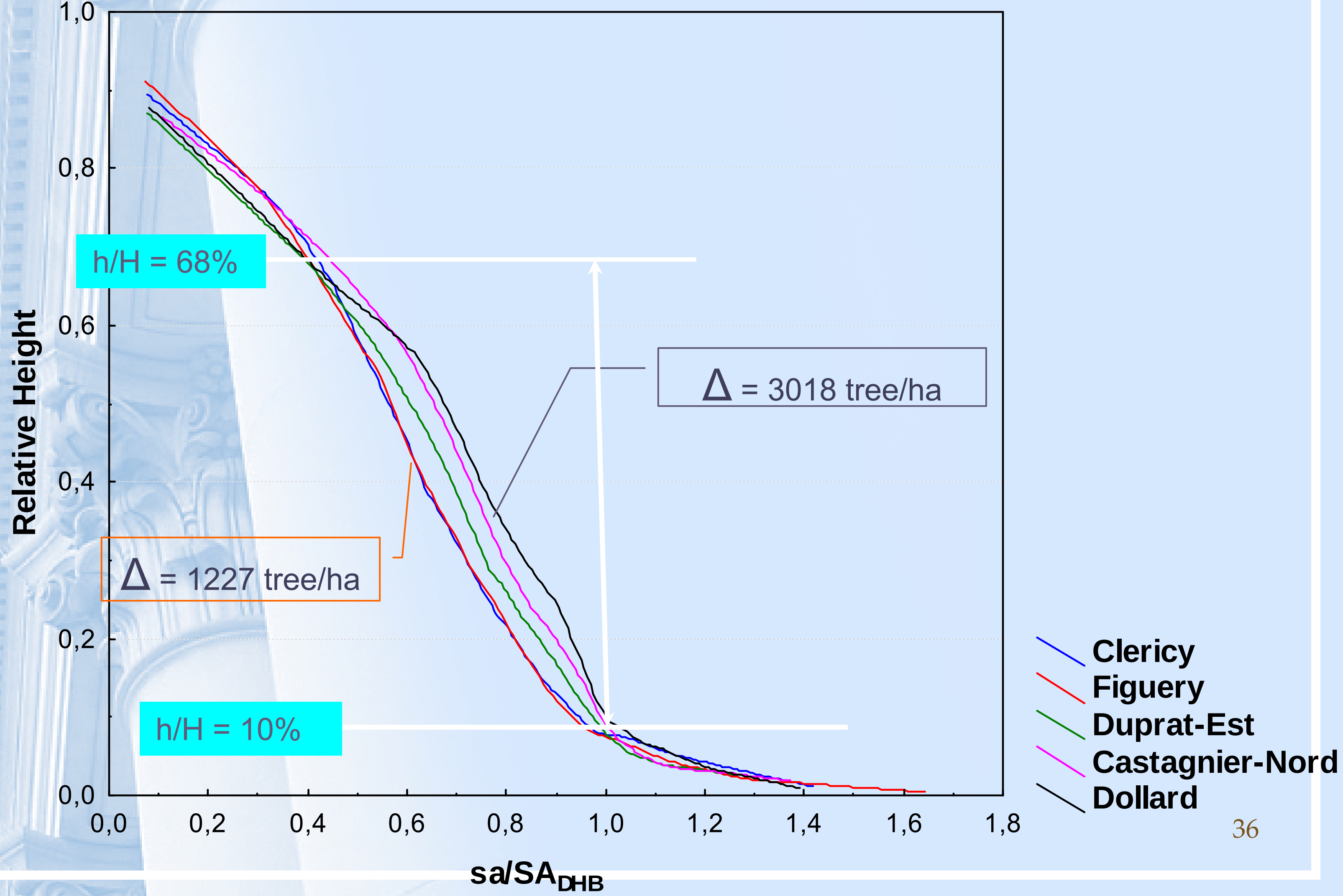
Effect of stand density on jack pine taper



Effect of stand density on jack pine tree shape



Effect of stand density on sapwood shape



CONCLUSION

- A better fitting of the stem and the sapwood taper was obtained with allometric based models;
- Stand density effect on tree shape: NO;
- Stand density effect on tree taper: YES;
- Stand density effect on sapwood taper: YES;
- Stand density effect on sapwood shape : YES.

Acknowledgements

- Ahmed KOUBAA – UQAT
- Suzanne BRAIS – UQAT

Thanks to ours partners !

Fondation de l'Université du Québec en Abitibi-Témiscamingue

Chaire en aménagement forestier durable

Centre technologique des résidus industriels

NSERC CRSNG

Chaires de recherche du Canada

Développement économique Canada / Canada Economic Development — Canada

Développement économique, Innovation et Exportation — Québec

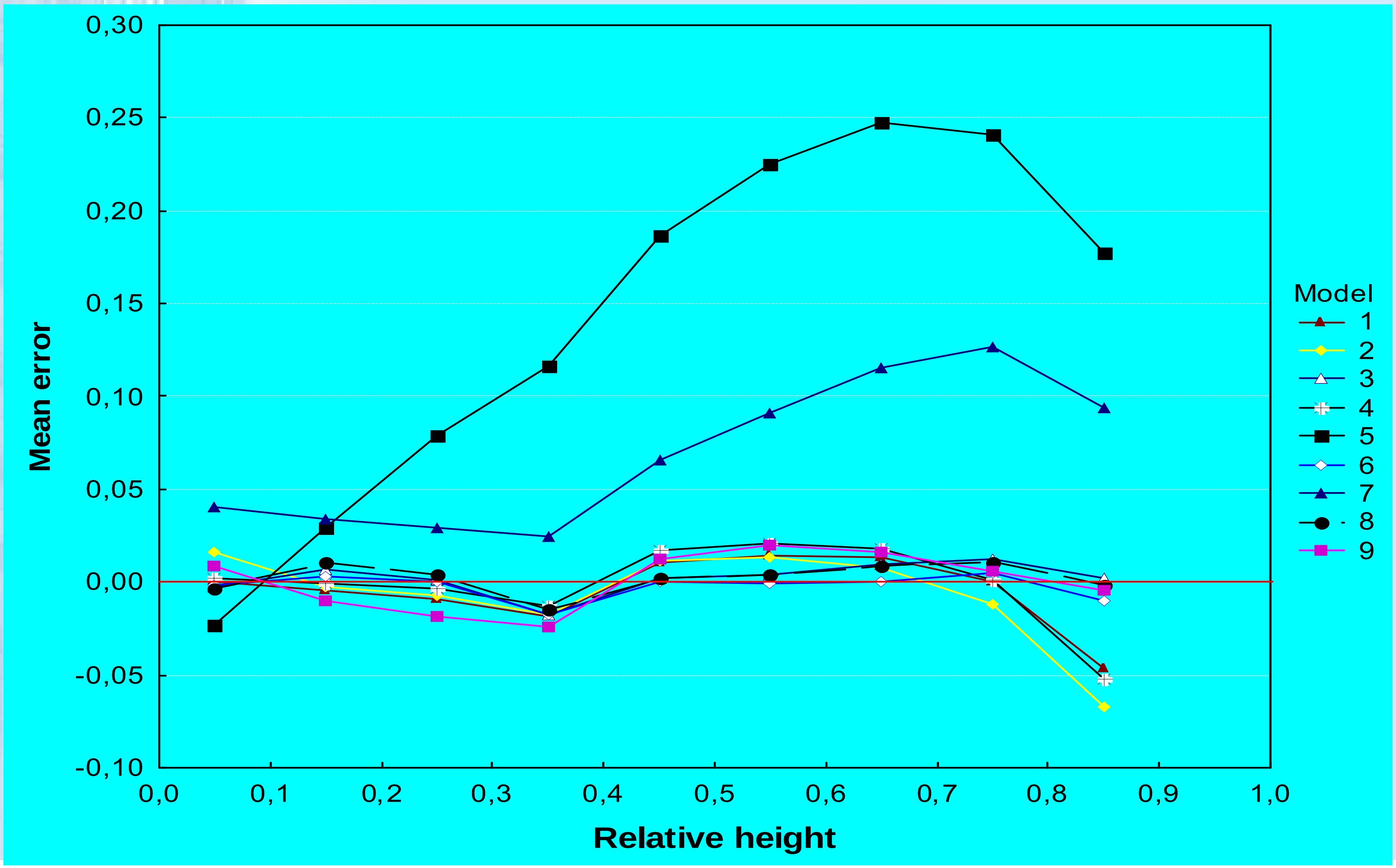
Ressources naturelles et Faune — Québec

Fonds de recherche sur la nature et les technologies — Québec

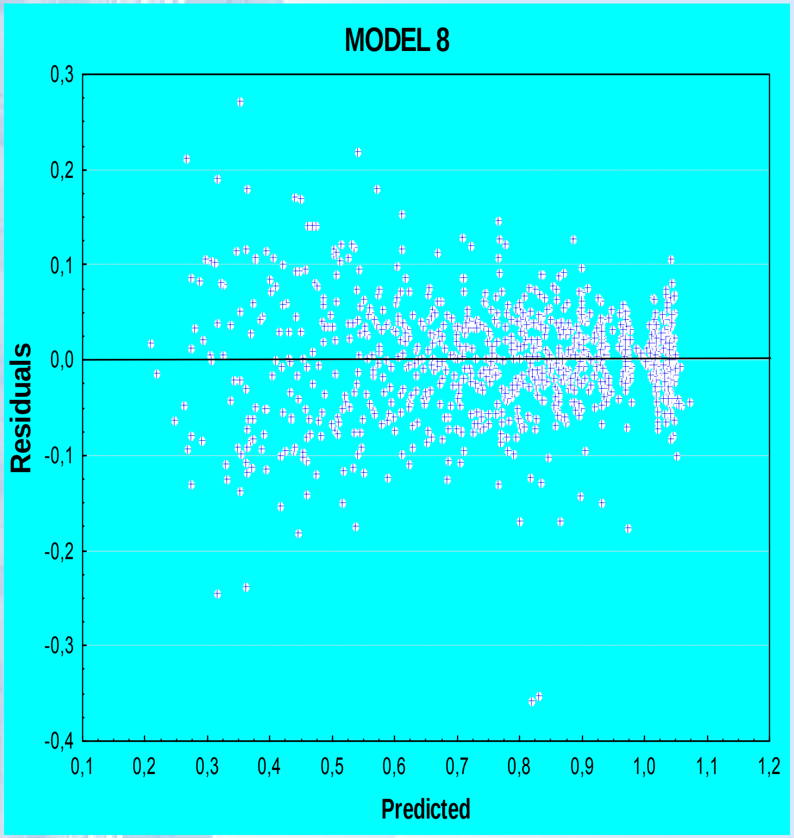
Merci pour votre attention!

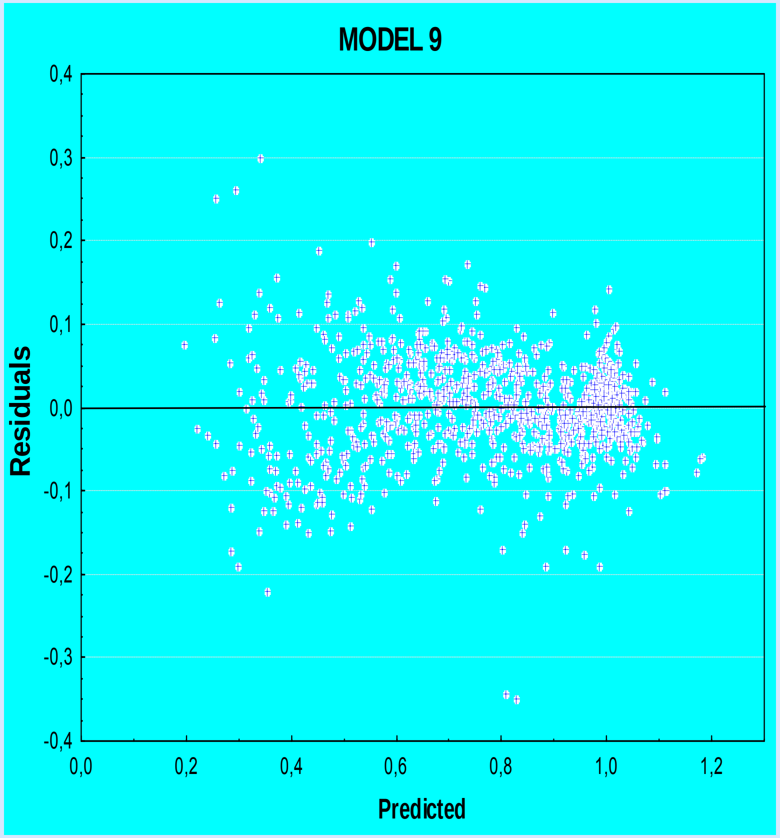
RESULTS

Stem taper analysis: mean error by relative height for the validation data set

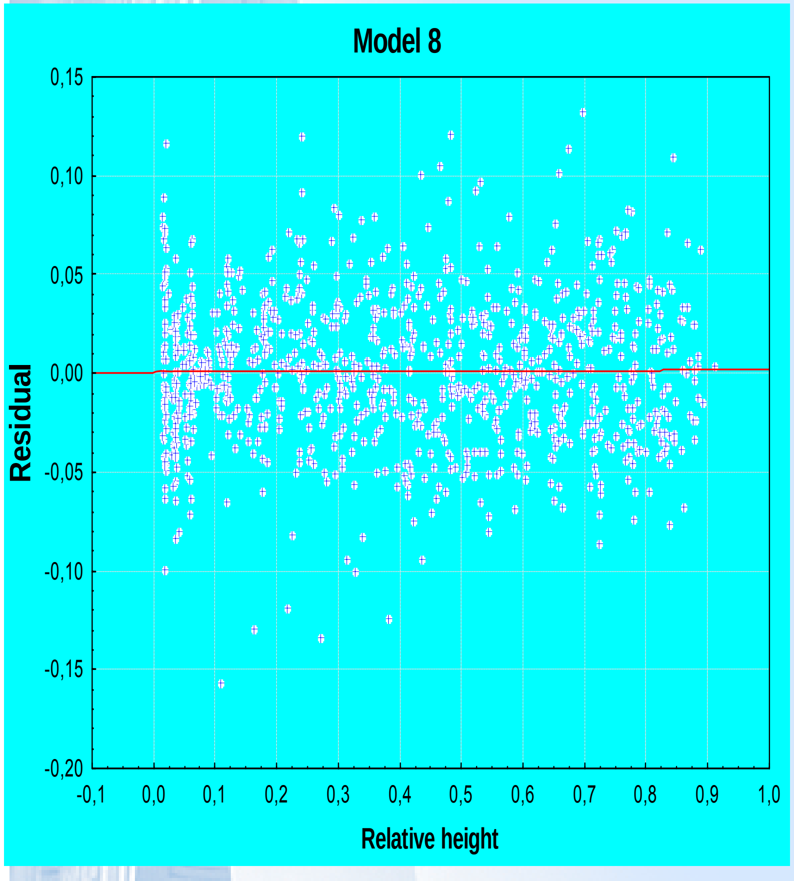


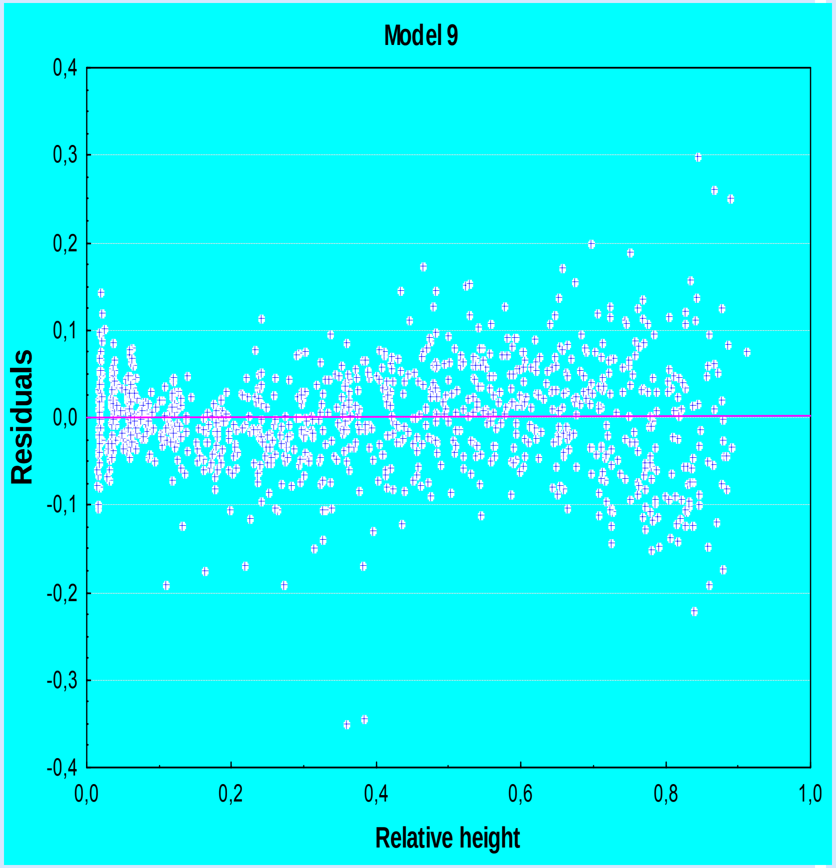
Residual *versus* predicted values





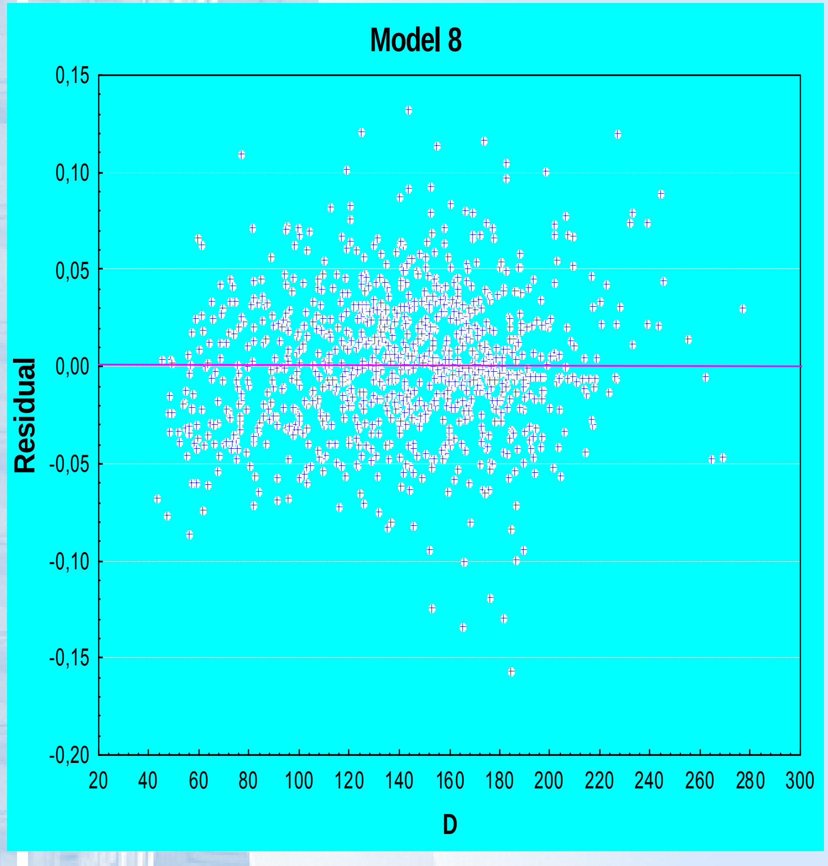
Residual *versus* independant variable (h/H)

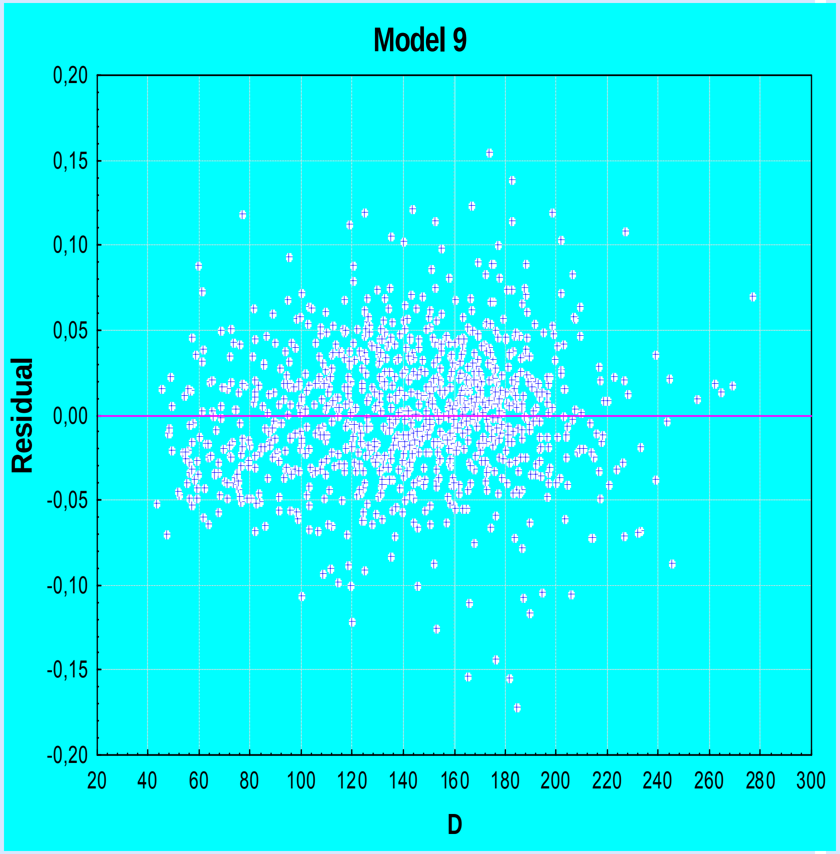




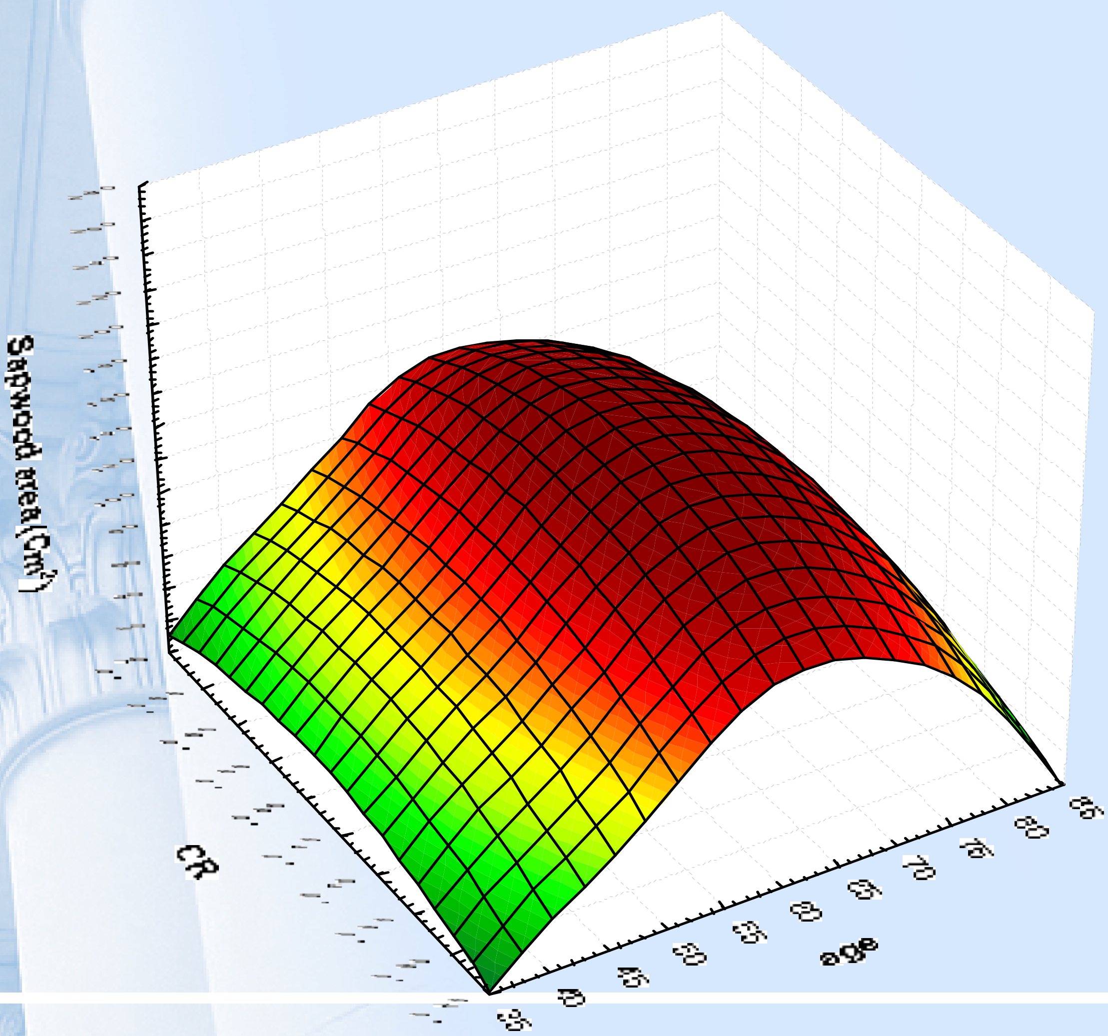
RESULTS

Residual *versus* independant variable (D)



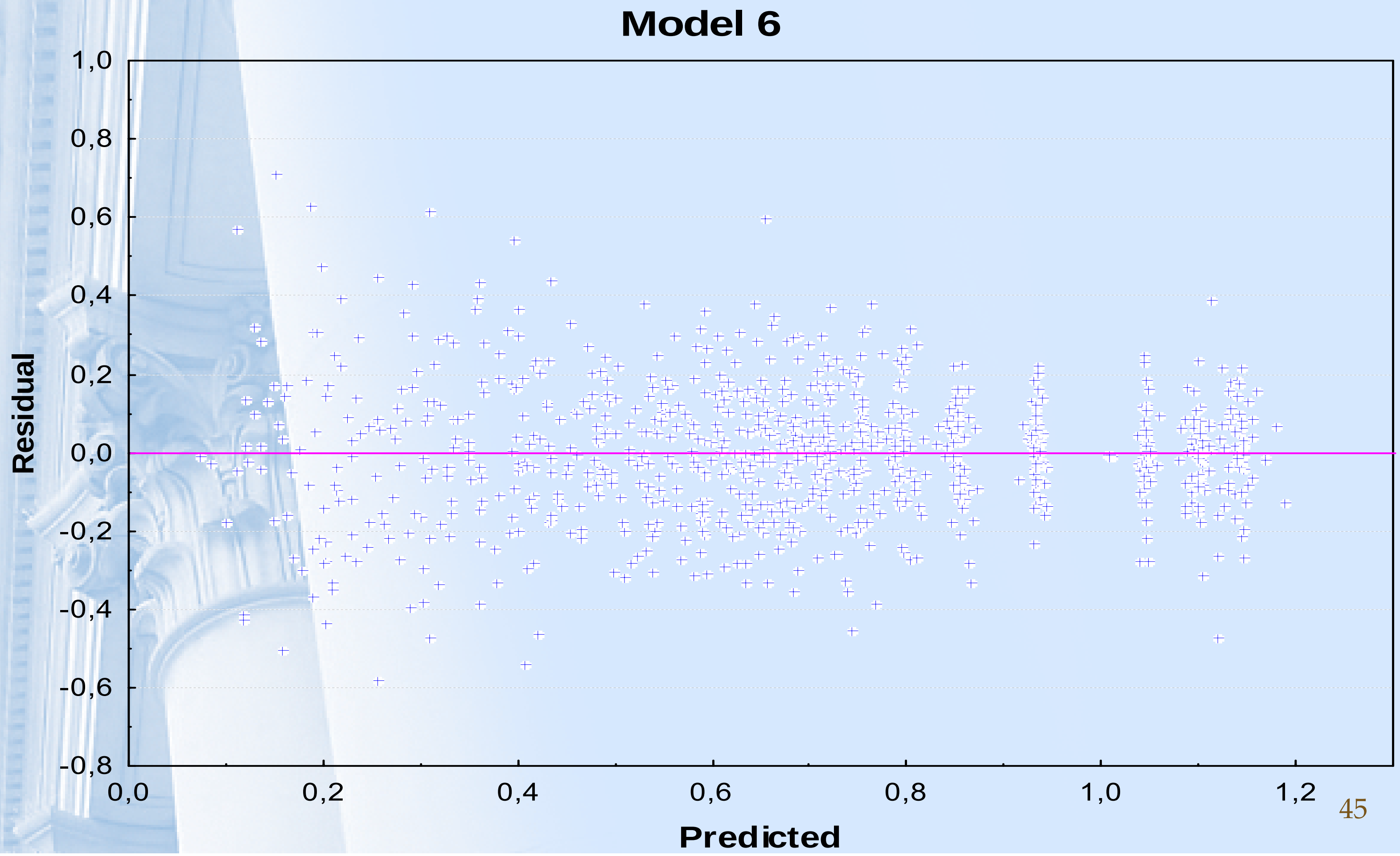


variation of Sapwood area by (age x crown ratio)

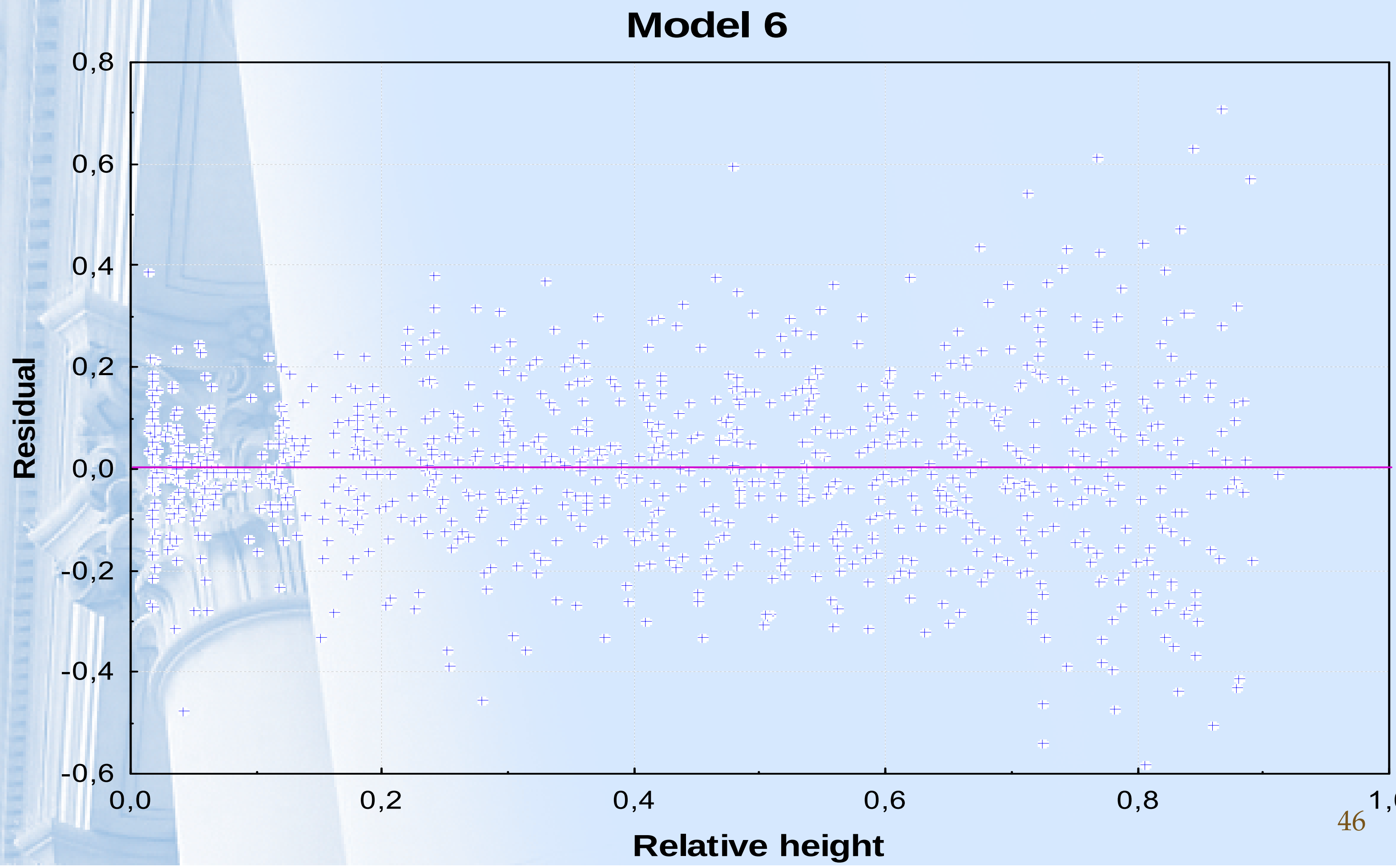


RESULTS

Sapwood taper analysis: residual by predicted

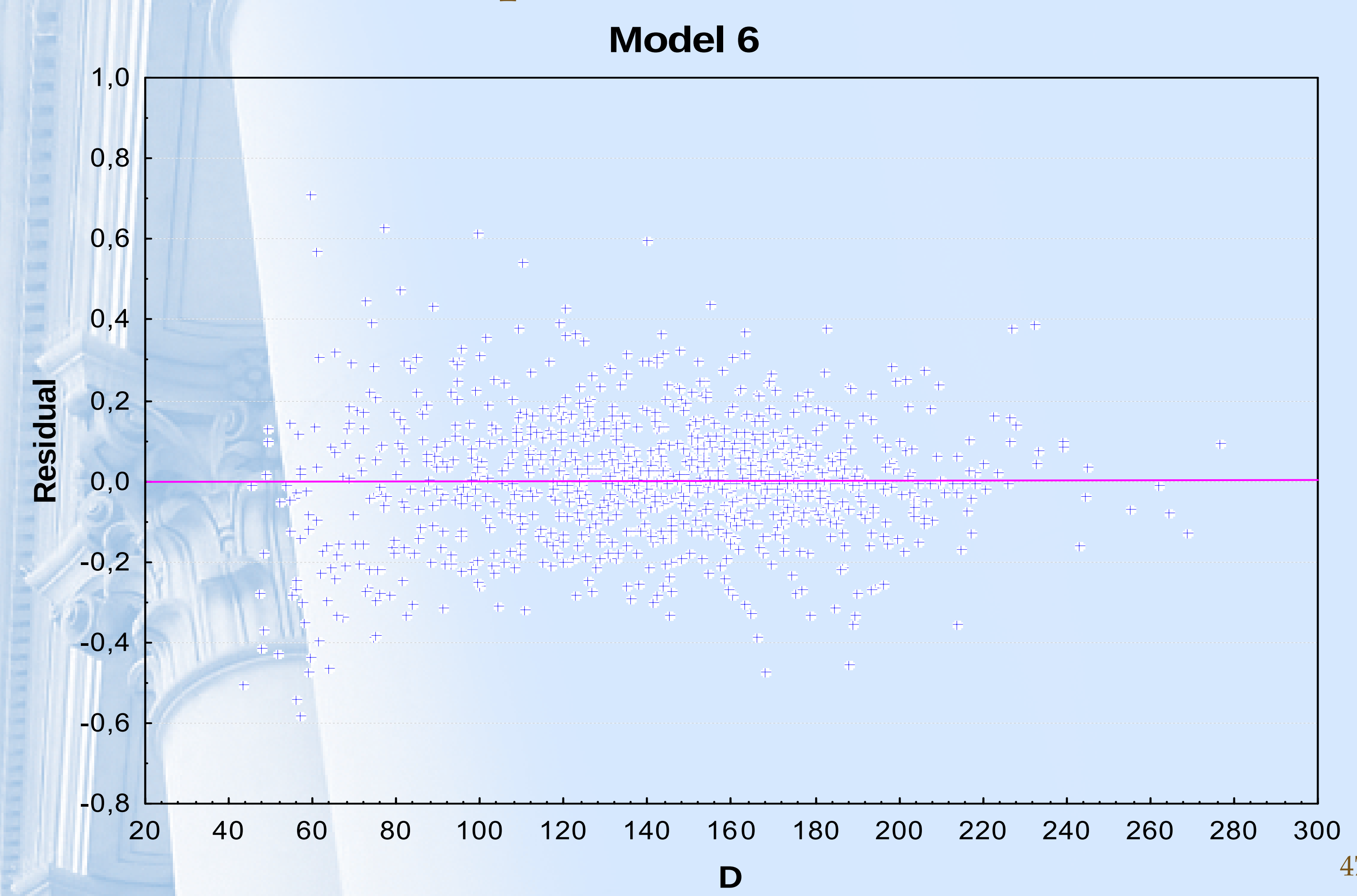


Sapwood taper analysis: Residual by independent variable (h/H)



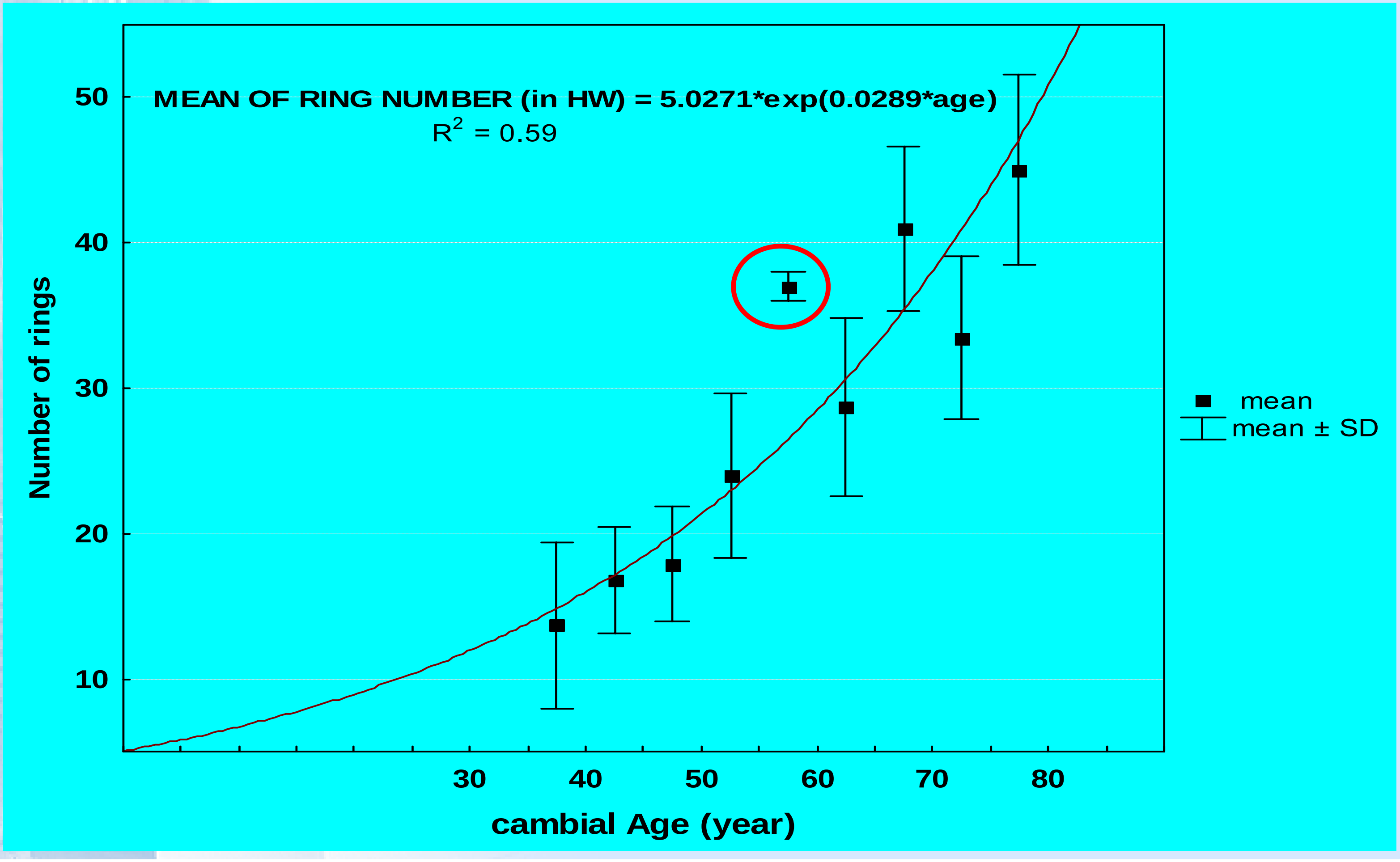
RESULTS

Sapwood taper analysis: Residual by independent variable (D)



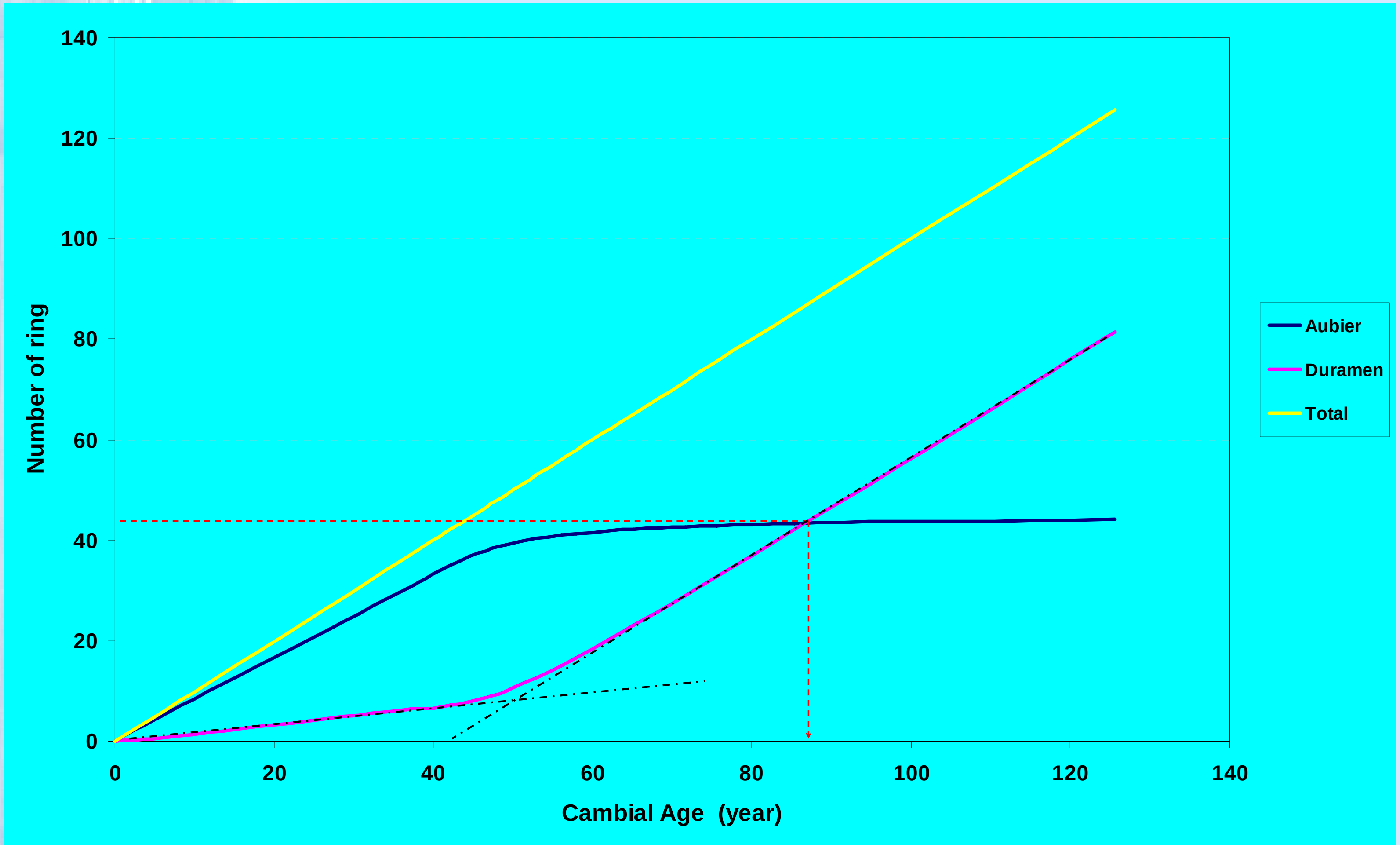
RESULTS

Number of rings contained in HW by cambial age



RESULTS

Theoretical corrected model of « duraminization » process



Analysis of « Duraminization » process of jack pine trees in boreal stands