Variation with age of height-diameter models in *Pinus radiata* D. Don in Galicia

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Abstract

One way to define the structure of the stand is the achievement of models that link diameter and height (as individual variables). In even-aged stands these models depend on the age of the trees. So, the values of the parameters fitted in the models must be modified as time goes on. A common method to know the evolution of the parameters in high productivity species is the measurement of the variables (diameter and height) every five years. In this work, 15 linear functions with two and three parameters are tested to be used as height–diameter curves. The annual evolution of the parameters of the height-diameter model showing the best shape and accuracy is analysed in two artificial stands of *Pinus radiata* in Lugo (Spain). There is not a remarkable variation of the parameters with the age of the stand in the considered range of ages.

Key words: height curve, stand structure.

1. Introduction

In the usual practice of forest inventory, the aim is to know the timber volume in each of the plots installed in the stand. Timber volume in a plot is the sum of the volumes of the trees within it. If a suitable individual tree volume equation for the species and region is available, the required predictor variables can be measured for each tree and the estimated volumes individually computed for all trees. It is very frequent the use of volume equations such as $v = f(d, h)$ with breast height diameter (d) and total height (h) as predictor variables. In many forest inventory situations, it is inefficient to measure all predictor variables for every tree in each plot because of the different measurement costs involved. The breast height diameter can be obtained at little expense in almost any timber type. Height measurements are considerably more expensive to collect and in tall dense stands the accurate measure of heights can be very difficult. As a result, plot volumes are generally obtained by measuring all trees on the plot for breast height diameter and subsampling for heights. Since both tree height and tree diameter are correlated with age, height appears to be correlated with diameter (HUSCH *et al.*, 2003). In even-aged stands height and diameter are closely correlated, but this relationship varies with stand age. Data from the height sample trees can be used to establish a height/diameter regression relationship $h = h(d)$. Such link between h and d are usually expressed by mathematical functions being obtained using regression analysis fitting or bivariant distributions of heights and diameters (GADOW *et al.*, 2001).

According to CASTEDO DORADO (2003), more than 30 functions have been developed as height-diameter curves. Some of these functions are included in table 2. The fitting can be based on pairs of data (d, h) of individual trees or based on data of mean heights for every diameter class (PRODAN *et al*., 1997). After the regression coefficients have been estimated from the height sample tree data, the equation can be substituted by height in the volume equation $v = f[d, h(d)]$ (CLUTTER *et al.*, 1983; DÍAZ-MAROTO HIDALGO *et al*., 2003). These models allow assigning mean heights to some diameters, individual height predictions and volume estimations (CASTEDO DORADO, 2003).

The knowledge of breast height diameters and heights is very important in forest management, not only in stock estimation but also in modelling height and diameter growth (CAÑADAS *et al*., 1999). To describe properly the biological process of height growth of the tree, the *h-d* models must accomplish the next conditions (CASTEDO DORADO, 2003):

- non-linear models because the relationship between h and d is curvilinear. However, non-linearity is not always detectable because the sample is too small or because of the random variability of tree heights within a given diameter class (CAÑADAS *et al*., 1999; LAAR and AKÇA, 1997).
- some equations forces the height curve through the point $d = 0$ and $h = 1.3$ m while other models forces through the coordinate origin, being desirable the first option
- monotone increasing for all values of d where the model is defined (curve with positive slope)
- upper asymptote with the estimated height converging to a constant as d tends to infinite (slope tending to be horizontal for high diameters).
- inflexion point in the case of uneven-aged stands.

There are also generalised equations, which also include stand variables in the model, empirically developed for some species and regions, where the above conditions are not accomplished (GADOW *et al*., 2001; PRODAN *et al*., 1997).

The models do not yield accurate predictions of height for diameters beyond or in the tails of the diameter distribution because of the usual lack of data in those regions. Therefore, it is suitable to underline the diameter range where the model is valid (CAÑADAS *et al*., 1999; CASTEDO DORADO, 2003; RONDEUX, 1993).

Height-diameter models are usually fitted for pure even-aged stands, where the curves depend mainly on species, age, site index and crown class (CAÑADAS *et al*., 1999; PARDÉ and BOUCHON, 1988; RONDEUX, 1993). The shape of the curve changes with the age of the stand: the slope of the curves tends to reduce in the late stages of the rotation, the curvature tends to reduce and the curve raises, *i. e*., the trees of a specific diameter class increase their mean height with the age (PARDÉ and BOUCHON, 1988; PRODAN *et al*., 1997). In stable uneven-aged stands the height-diameter curve does not change with age (PARDÉ and BOUCHON, 1988).

In good sites the slope is higher than in poor sites (PARDÉ and BOUCHON, 1988). The curve is also influenced by the stand density (number of trees per hectare). In large forests, if the stand density is not uniform the fitting of a unique curve for the whole stand is actually the grouped fitting of several different curves. A unique curve, with high variability on the regression model, can be not valid for the complete stand (CAÑADAS *et al*., 1999; PRODAN *et al*., 1997).

The parameters of the curves depend on age but also depend on other stand variables related with age as mean height, top height, mean diameter, basal area or stand density, as it was pointed out before. The evolution of the height-diameter curves with stand variables or even with the site index can be modelled using generalised *h-d* curves (CAÑADAS *et al*., 1999; CASTEDO DORADO, 2003; PRODAN *et al*., 1997). According to LÓPEZ SÁNCHEZ *et al*. (2003), it is necessary to introduce mean or top height as predictor variables in the *h-d* equations for *Pinus radiata* to obtain acceptable predictions.

For growth modelling, it might be advantageous to pool the height measurements of successive re-measurements and to relate the parameters of the function being used to age. When the nature of these relationships is known, age is introduced as an additional predictor variable, according to SADIQ *et al.* (1983), POLLANSCHÜTZ (1974) and LAAR (1986), cited in LAAR and AKÇA (1997).

The age and the rest of stand variables can be explicit predictor variables in the model, as diameter is, but they can also be used to estimate by regression equations the parameters of the *h-d* model.

2. Material and methods

The sampled area is the forest of Traspenalba (47º70'N and 6º26´W, 550 m elevation), which is located in Lugo, in the eastern mountains of Galicia (Spain).

The study has been performed in two *Pinus radiata* plantations that have been thinned and pruned along the rotation. The stands have NW orientation and present the next accompanying vegetation: *Calluna vulgaris*, *Ulex europaeus*, *Erica arborea*, *Pteridium aquilinum*, *Rubus* sp. and some individuals of *Quercus robur* and *Pinus pinaster* (VARELA VÁZQUEZ, 2001). The main characteristics of the stands are shown in table 1.

To obtain the annual diameter distribution in each stand, every year along ten years the breast height diameter was measured in several plots, covering annually 4239 m^2 on average in stand I and 3141 m^2 in stand II. The minimum diameter considered was 7.5 cm. The number, location and size of the measured plots were not the same all years.

The fitting of the *h-d* curves was carried out using 753 heights measured along ten years in stand I (33 % of the trees in the plots were measured on average) and 424 heights in stand II (30 % of the trees in the plots). It means that nearly 60 heights per stand and year have been registered. It is assumed that this amount of data is enough for fitting purposes because 20-30 heights should be measured at least in each stand to obtain sufficiently accurate estimates (LAAR and AKÇA, 1997; RONDEUX, 1993). In spite of this measurement effort, it was not always possible to register 3-5 heights in each diameter class, as RONDEUX (1993) recommends.

Normality of the height and diameter distribution was examined using the test of Kolmogorov-Smirnov with the significance correction due to Lilliefors for distributions of less than 30 trees and the Shapiro-Wilk test for distributions less than 50 trees.

The site index of each stand was estimated using the Assmann top height definition and the yield tables for *Pinus radiata* in Galicia (SÁNCHEZ RODRÍGUEZ, 2001). In the estimation of the Assmann height, it was considered the correction by PARDÉ and

BOUCHON (1988) to avoid bias in small plots (under 5000 m^2): to take one tree less in the selection of the 100 biggest trees per hectare to obtain their mean height. What is more, in some cases the height of the dominant trees was not directly measured and it was estimated with the obtained *h-d* curves (CAÑADAS *et al*., 1999).

Both stands are very close but they exhibit different features. In stand I the slopes are moderate, stand density is intermediate and site index is 21 (the second best in a scale from 13 to 25). However, the stand II is slightly younger, exhibits soft slopes, low densities and site index is 25, the best one for the species in Galicia.

Table 1. Characteristics of the stands.

	Stand I	Stand II
Plantation date	1971	1974
Surface (ha)	20.26	19.16
Mean slope (%)	17	8
Density (ind./ha) at 30 years age	456	369
Assmann top height (m) at 30 years age	28.7	32.3
Site index	21	25

The fitted models are shown in table 2. All of them are non-linear regression models but they can be transformed and converted to linear models by some transformation of variables. The selected model will be that with the best closeness of the observed measurements to the preedicted values and with the best shape, according to the requirements exposed in the Introduction.

The comparison of the estimates for the different models was based on numerical and graphical analyses of the residuals. Three statistical criteria were examined: bias ($\overline{E}$), mean square error (*MSE*), coefficient of determination (R^2) and adjusted coefficient of determination (R_{adj}^2). Their expressions may be summarized as follows:

$$\overline{E} = \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)}{n}$$

$$MSE = \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n-p}$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2}$$

$$R_{adj}^2 = 1 - (1 - R^2)\frac{N-1}{N-p}$$

where y_i is the measured height in the i^{th} tree

$\hat{y}_i$ is the predicted height in the i^{th} tree

$\bar{y}$ is the average value of the observed heights
n is the total number of observations used to fit the model
p is the number of model parameters.

Table 2. Several linear functions to use in the fitting of height-diameter curves.

N.	Equation	N. of parameters	Source
1	$h = A + Bd + Cd^2$	3	PRODAN *et al*. (1997)
2	$h = 1.3 + Ad + Bd^2$	2	TROREY (1932)
3	$h = A + \frac{B}{d^2}$	2	PRODAN *et al*. (1997)
4	$\ln h = A + B\ln d$	2	STOFFELS and VAN SOEST (1953), cited in CASTEDO DORADO (2003)
5	$h = A + B\ln d$	2	HENDRICKSEN (1950)
6	$\ln h = A + \frac{B}{d}$	2	MACKINNEY *et al*. (1937)
7	$h = 1.3 + Ad^B$	2	HUI and GADOW (1999)
8	$h - 1.3 = \frac{Ad}{B + d}$	2	CAÑADAS *et al*. (1999)
9	$h - 1.3 = \frac{d^2}{(A + Bd)^2}$	2	PRODAN *et al*. (1997), called Näslund formula
10	$h = \frac{d^2}{(A + Bd)^2}$	2	Hossfeld I, cited in CASTEDO DORADO (2003)
11	$h - 1.3 = \frac{d^2}{A + Bd + Cd^2}$	3	PRODAN (1944), cited in DÍAZ-MAROTO *et al.* (2003)
12	$h - 1.3 = A\left(\frac{d}{1 + d}\right)^B$	2	PRODAN *et al*. (1997)
13	$\ln(h - 1.3) = A - \frac{B}{d}$	2	PRODAN *et al*. (1997)
14	$h = A^{B\ln(d) - C\ln^2(d)}$	2	PRODAN *et al*. (1997)
15	$\frac{1}{(h - 1.3)^{0.4}} = A + \frac{B}{d}$	2	PETERSON (1955)

3. Results and discussion

The diameter distribution (table 3) is significantly normal in eleven of the twenty cases (two stands and ten years in each stand) at a 10 % significance level. The deviation from normal distribution in diameter is due to frequencies higher than expected in the smallest diametric classes. As a result, the skewness is usually positive and the kurtosis is negative in most cases. So, the studied distributions are platykurtic.

The mean diameter exhibits an increasing and roughly sustained trend with stand age while other parameters in the distribution description (standard deviation, skewness and kurtosis) do not show a well defined trend with age. The mean diameter increases very significantly with age (R^2 = 0.837** in stand I and R^2 = 0.893** in stand II).

Density decreases significantly with age (R^2 = 0.507* in stand I and R^2 = 0.767** in stand II). The stand density (number of trees per hectare, N) varies considerably within each stand, as indicated by the results of the yearly measured sampling plots.

The height distributions are significantly normal just in eight cases for the same significance level (10 %), probably due to the reduced amount of height data comparing with the available amount of diameter data.

The diameter reduction along the height in stem is 0.6 % - 0.9 %, similar to the values in the yield tables for the same age and site index (SÁNCHEZ RODRÍGUEZ, 2001).

The adjusted R^2 for the models with two parameters was obtained for the linear models with the transformed variables (table 4). The highest values of R^2 were achieved in models 9, 10 and 15. In these three cases R^2 = 0.509 on average for the twenty fittings. The model 10 was rejected because it does not comprise the condition that forces the height curve through the point d = 0 and h = 1.3 m.

Models 9 and 15 have horizontal asymptote. The values of the asymptotes were analysed in both models to check if the mathematical values for the asymptotes have also realistic meaning and physical validity (considering the value of the asymptote as the maximum achievable height for the species *Pinus radiata*). In this study, model 9 shows asymptotes over 50 m in five cases while model 15 shows asymptotes over 50 m just in three cases. Because of that model 15 is finally selected among the tested biparametric models.

Model 11, with three parameters, is discarded because of the poor behaviour of its asymptotes; they are negative in two fittings, two more are very low asymptotes (under 15 m), five asymptotes are high (over 50 m) and three of them very high (over 100 m).

The fitting of the complete parabolic model (model 1 in table 2) shows that the second-order polynomial is not acceptable because in nine of the 20 fittings it is found a decreasing portion of the curve in the range of diameters where the model would be defined. That is, the parabolic model has a maximum located inside the observed range of diameters. The parabolic model with the constant equal to 1.3 (model 2 in table 2) is not either acceptable because in eleven of the 20 fittings the obtained model shows a decreasing portion in the range of diameters where the model would be defined.

With the selected model 15 (table 5), there is no significant relation between age and the parameters of the function. Parameter A shows very small variation and it is not related with age and parameter B is more variable but it is weakly related with age (R^2 = 0.13). It must be underlined that the amount of data in these fittings is just n = 10 years and it is not easy to achieve significant results with so scarce data set, but the analysis of the plotted pairs age-parameter, which is not included in this work, allows to one to assume that there are no trends to remark.

Table 3. Characteristics of the diameter distributions in the stands.

Stand	age	*n*	Diametric range[A] (cm)	Mean diameter (cm)	Standard deviation (cm)	Skewness	Kurtosis	*N* (ind./ha)
I	24	783	9-42	20.5	8.1	0.64	-0.17	1036
	25	154	14-42	26.1	7.0	0.16	-0.73	469
	26	48	20-41	27.2	6.9	0.05	-0.43	472
	27	280	13-46	27.4	8.2	0.26	-0.77	507
	28	153	13-53	27.3	8.9	0.15	-0.48	606
	29	233	16-43	28.2	6.8	0.12	-0.82	461
	30	147	15-48	29.8	7.5	0.25	-0.54	436
	31	143	15-45	31.9	6.9	-0.28	-0.60	381
	32	280	19-52	32.6	7.8	0.17	-0.49	352
	33	83	18-46	31.7	8.0	0.29	-0.73	351
II	21	72	8-55	25.7	9.4	0.67	0.23	576
	22	59	16-44	28.2	7.7	0.34	-0.55	472
	23	128	17-51	28.7	8.4	0.19	-0.44	504
	24	134	15-45	29.2	8.3	0.23	-0.64	536
	25	192	12-51	30.4	8.3	0.01	-0.53	512
	26	124	10-44	29.4	9.2	-0.17	-0.78	496
	27	247	17-51	30.3	8.7	0.16	-0.56	440
	28	143	17-51	33.1	7.9	0.12	-0.86	381
	29	182	18-52	34.8	8.4	0.23	-0.51	364
	30	121	16-57	36.4	9.2	-0.09	-0.84	372

[A]: referred to the subsample of heights.

The bias for the model 15 is included for every stand and year in table 5. On average, the bias is 0.33 m in stand I and 0.32 m in stand II.

The mean square error is 11.66 m^2 in the stand I and 10.34 m^2 in the stand II, on average for the complete series of ten years (table 5). In order to make comparisons with other results, the square root of the mean square error is 15.0 % of the average height in stand I and 12.8 % of the average height in stand II. According to RONDEUX (1993), that percentage is usually under 15 % while NÄSLUND (cited by PRODAN *et al.*, 1997) noted 7-12 % and KRENN (cited by PRODAN *et al.*, 1997) noted 4.5-11.5 %. In this work, the precision of the fitted models is near or over the thresholds proposed by those authors. The explanation of that phenomenon can be found in the high variation in density between plots in each stand and year. As density affects the height-diameter relationships, it is expected a high dispersion of the observed values against the predicted ones.

Table 4. Adjusted R^2 for the $h = h(d)$ models with two parameters.

Stand	age	*n*	Models[A]											
			3	4	5	6	7	8	9	10	12	13	14	15
I	24	204	0.579	0.667	0.679	0.666	0.665	0.648	0.661	0.663	0.668	0.666	0.603	0,663
	25	81	0.335	0.380	0.380	0.374	0.378	0.335	0.361	0.366	0.374	0.373	0.203	0,365
	26	33	0.635	0.458	0.538	0.517	0.449	0.397	0.453	0.470	0.505	0.507	-0.032	0,464
	27	75	0.197	0.236	0.232	0.231	0.235	0.227	0.231	0.232	0.231	0.231	0.459	0,232
	28	47	0.318	0.399	0.404	0.374	0.398	0.364	0.371	0.372	0.376	0.374	0.322	0,372
	29	77	0.122	0.130	0.128	0.131	0.130	0.131	0.131	0.131	0.131	0.131	0.714	0,131
	30	45	0.464	0.532	0.508	0.546	0.533	0.579	0.565	0.562	0.548	0.548	0.413	0,561
	31	40	0.162	0.202	0.232	0.177	0.199	0.127	0.152	0.157	0.175	0.174	0.308	0,157
	32	123	0.301	0.330	0.313	0.335	0.330	0.334	0.338	0.339	0.336	0.336	0.418	0,338
	33	28	0.512	0.519	0.491	0.556	0.520	0.592	0.578	0.575	0.557	0.558	0.565	0,574
II	21	35	0.477	0.712	0.678	0.726	0.713	0.814	0.780	0.769	0.737	0.734	0.540	0,771
	22	7	0.737	0.977	0.953	0.916	0.978	0.960	0.942	0.937	0.923	0.920	-0.126	0,938
	23	50	0.114	0.137	0.107	0.155	0.139	0.178	0.173	0.170	0.158	0.158	0.056	0,171
	24	17	0.502	0.519	0.566	0.510	0.512	0.397	0.456	0.469	0.504	0.503	0.278	0,466
	25	35	0.586	0.614	0.593	0.677	0.614	0.706	0.700	0.696	0.679	0.680	0.469	0,697
	26	47	0.706	0.811	0.817	0.874	0.807	0.877	0.887	0.887	0.876	0.877	0.408	0,887
	27	86	0.463	0.585	0.542	0.579	0.586	0.603	0.599	0.597	0.582	0.582	0.128	0,597
	28	38	0.588	0.610	0.609	0.627	0.610	0.627	0.628	0.628	0.627	0.627	0.659	0,628
	29	58	0.421	0.411	0.400	0.441	0.412	0.459	0.451	0.449	0.441	0.442	0.668	0,449
	30	51	0.668	0.692	0.695	0.723	0.690	0.696	0.714	0.717	0.723	0.723	0.531	0,717
Mean I		75,3	0.363	0.385	0.391	0.391	0.384	0.373	0.384	0.387	0.390	0.390	0.397	0.386
Mean II		42,4	0.526	0.607	0.596	0.623	0.606	0.632	0.633	0.632	0.625	0.625	0.361	0.632
Mean I+II		58,9	0.444	0.496	0.493	0.507	0.495	0.503	0.509	0.509	0.508	0.507	0.379	0.509

[A] Model codes are described in table 2.

As it is supported by PARDÉ and BOUCHON (1988), the slope of the curves, considered here at d = 30 cm, is higher in the stand with the best site index (slope = 42 % in stand II and slope = 33 % in stand I) but the difference is not significant. The slope does not reduce significantly with age in the stands, probably due to the low range of years considered in the experimentation.

The obtained curves are state curves and they are not stand height growth curves, as those in yield tables. Because of that, it makes no sense the comparison between both types of curves (PRODAN *et al*., 1997).

Table 5. Parameter estimates of the model $\frac{1}{(h-1.3)^{0.4}} = A + \frac{B}{d}$. Significance level is under 0.007 in all coefficients.

Stand	age	Confidence interval for the coefficient at 95 % *A*	Confidence interval for the coefficient at 95 % *B*	asymptote (m)	Slope for d = 30 cm	Bias (m)	*MSE*
I	24	0.249 ± 0.010	1.351 ± 0.172	33.6	0.27	0.28	5.79
	25	0.235 ± 0.022	1.870 ± 0.546	38.7	0.36	0.55	13.53
	26	0.181 ± 0.056	3.948 ± 1.472	73.0	0.64	0.20	8.18
	27	0.268 ± 0.018	1.205 ± 0.500	28.2	0.21	0.56	13.69
	28	0.251 ± 0.024	1.635 ± 0.614	33.0	0.29	0.60	17.63
	29	0.261 ± 0.014	0.633 ± 0.358	30.0	0.15	-0.69	7.55
	30	0.221 ± 0.016	1.870 ± 0.494	44.9	0.43	0.34	9.71
	31	0.247 ± 0.030	1.335 ± 0.930	34.3	0.28	0.79	20.97
	32	0.237 ± 0.014	1.609 ± 0.404	37.9	0.34	0.36	11.51
	33	0.226 ± 0.018	1.683 ± 0.550	42.5	0.39	0.27	8.02
II	21	0.229 ± 0.014	1.683 ± 0.312	41.1	0.38	0.30	9.98
	22	0.215 ± 0.024	3.073 ± 0.640	48.0	0.47	0.16	1.33
	23	0.228 ± 0.050	2.408 ± 1.446	41.6	0.41	1.14	33.32
	24	0.238 ± 0.040	1.922 ± 0.994	37.5	0.35	0.43	10.48
	25	0.234 ± 0.016	1.911 ± 0.430	39.1	0.37	0.24	8.01
	26	0.211 ± 0.008	2.111 ± 0.222	50.2	0.50	0.10	5.26
	27	0.211 ± 0.016	2.537 ± 0.450	50.2	0.50	0.39	15.06
	28	0.227 ± 0.014	1.618 ± 0.406	42.0	0.38	0.07	5.19
	29	0.236 ± 0.012	1.384 ± 0.388	38.3	0.32	0.30	7.03
	30	0.209 ± 0.012	2.039 ± 0.360	51.4	0.51	0.08	7.78

The figures 1 and 2 show the graphic presentation of model 15 being fitted every year in each stand. Curves are all fairly close and even the fitted curves for the extreme years of the interval (24 and 33 years in stand I, 21 and 30 in stand II), drawn with the thickest lines, are not in the lower and upper part of the collection of curves and their respective parameters are not significantly different at 95 % level of confidence (table 5). Therefore, the use of an *h-d* model without modifications during, at least, ten years is completely assumable in this species in the second half of the usual rotation. In this type of stands, with high site index, where good height growth must be expected, the *h-d* curves are not easily to distinguish in a range of 10 years. So, in stands with lower growth it is completely reasonable the use of a unique *h-d* model without modifications during, at least, ten years.

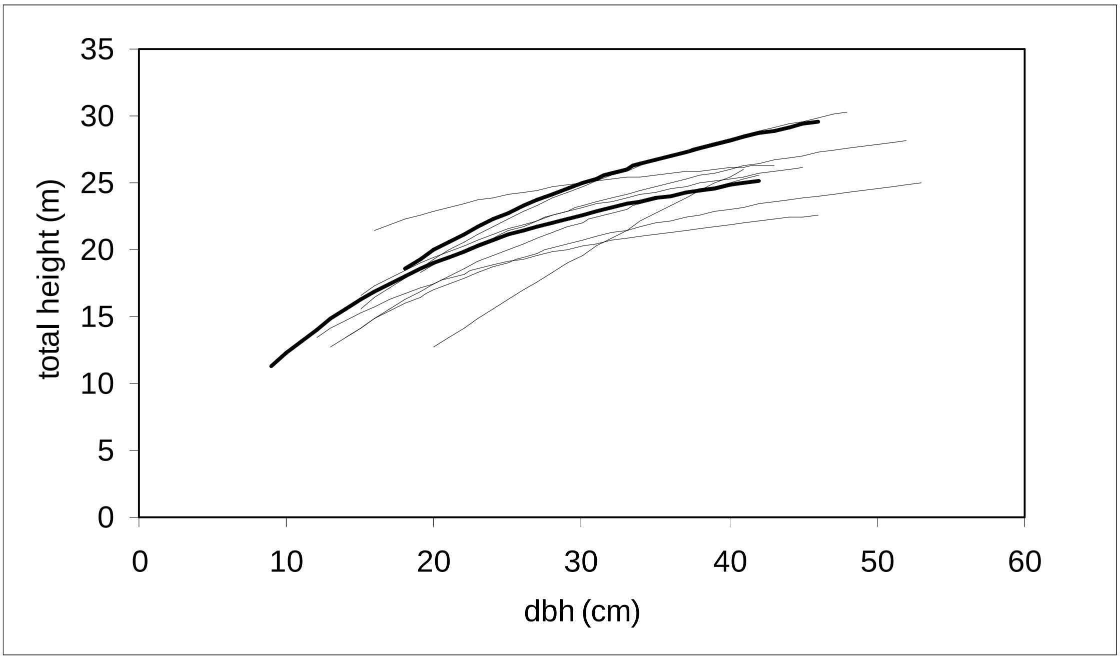

Figure 1. Stand I. Fitted curves with the model 15 at ten successive years. The thickest curves correspond to the extreme ages (24 and 33 years).

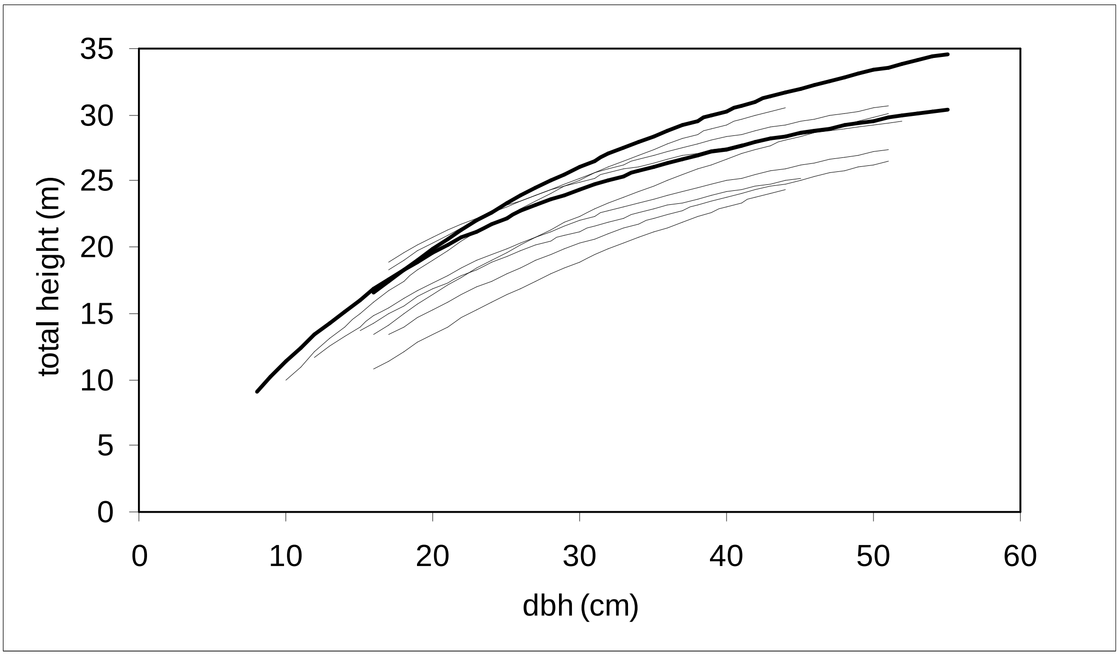

Figure 2. Stand II. Fitted curves with the model 15 at ten successive years. The thickest curves correspond to the extreme ages (21 and 30 years).

Two curves in stand I (figure 1) have somewhat different shape comparing with the rest of the curves in the group. Obtained curve at age 29 yields slow height increasing with diameter while predicted heights for the thinnest trees are slightly high. On the other hand, the curve at age 26 has very high slope and defective height predictions for small diameters. It is worth mentioning that those fittings have a reduced diametric range and low dispersion of the diameter sample. Probably, that is the reason for the anomalous fitting of those groups of data. In stand II (figure 2) the tendency of the ten fittings is more regular.

4. Conclusions

The importance of the use of tree height in forest inventories and the occasional difficulties to obtain this variable by means of single and accurate procedures aims to develop models for the prediction of individual heights with breast height diameter as predictor variable. The local *h-d* models, being fitted for even-aged stands, tend to change with time and successive fittings are necessary to refresh the parameters of the model if the *h-d* curve must be used repeatedly as an effective tool in forest management. Nevertheless, in high productivity stands of *Pinus radiata*, in the second half of the usual rotation, the use of an *h-d* model without modifications during, at least, ten years is fully assumable. Because of that, in stands with lower growth it is completely reasonable the use of a unique *h-d* model without modifications during a decade. With a methodological approach, the *h-d* curve fittings need a wide diametric range of available data to yield accurate height predictions.

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