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SHORT-TERM CHANGES IN HEIGHT–DIAMETER RELATION OF TWO MAPLE SPECIES AND EUROPEAN CORNEL OF UNDERSTORY IN AN OAK FOREST IN HUNGARY ON THE BASIS OF TWO-PARAMETERS MODEL

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Abstract: Forest understory species such as shrub and herbaceous layer, have received little attention in long-term studies. Knowledge of the diameter and the height of trees are fundamental for developing growth and yield models in forest stands. Overstory composition of the Síkfőkút Project site was dominated by sessile oak–Turkey-oak forest (*Quercetum petraeae-cerris* Soó 1963). Similarly to other European countries an oak decline occurred in Hungary oak woodlands at the end of 1970's and about 63% of the oak trees perished in our site. The potential for oak species regeneration was a very low over the period of 1982-2012. Four nonlinear height-diameter functions were fitted and evaluated for Síkfőkút site based on a data set consisting of 2025 individuals for three dominant woody species (*Acer campestre* L., *Acer tataricum* L. and *Cornus mas* L.) and detected any short-term changes in these equations following dieback of oak canopies. These height–diameter equations increase our knowledge of the growth of these species; therefore will enable us to improve management planning in oak forests.

Keywords: oak decline, *Acer campestre*, shrub layer, size, growth model

INTRODUCTION

Knowledge of the diameter and the height of trees are fundamental for developing growth and yield models in forest stands (Lynch and Murphy 1995; Calama and Montero 2004). Many growth and yield systems use height and diameter as the two basic input variables, with all or part of the tree heights predicted from measured diameters (Arney 1985; Huang *et al.* 2000). The relation between the diameter of individuals and its height varies from one stand to another. Within the same forest stand, this relation is not constant over time (Curtis 1967). Numerous generalized and region-wide equations have been developed recently for many tree species (e.g. Temesgen and Gadow 2004; Castedo Dorado *et al.* 2005). Equations for the height and the diameter relation of understory species are not typically in the international papers.

The height–diameter relationship has been calibrated following random-parameter models, using both repeated measurements from permanent plots (Lappi 1997) as well as cross-temporal measurements taken simultaneously in different temporary plots (Jayaraman and Lappi 2001). Linear mixed models were used by Mehtätalo (2004) for Norway spruce (*Picea abies* (L.) Karst.), Jayaraman and Zakrzewski (2001) for sugar maple (*Acer saccharum* Marsh.), and by Lynch *et al.* (2005) for cherrybark oak (*Quercus pagoda* Raf.). A number of height–diameter equations have been developed using only DBH of trees as the predictor variable for estimating total height (e.g. Larsen and Hann 1987; Fang and Bailey 1998; Peng 1999; Robinson and Wykoff 2004). Relation between the diameter of a tree and its height varies among stands (Calama and Montero 2004) and depends on the growing environment and stand conditions (Sharma and Zhang 2004). When actual height measurements are not available and difficult, height–diameter functions can also be used to indirectly predict height growth of individuals (Larsen and Hann 1987).

An increase in the death of oak forests has been observed in many regions of Hungary since 1978 (Igmándy 1987). The species composition of the canopy layer was stable until 1979 and the healthy *Q. petraea* and *Quercus cerris* L. (Turkey oak) also remained constant in the mixed-species forest stand (*Quercetum petraeae-cerris* Soó 1963) of Síkfőkút. Serious oak decline was first reported in 1979–80 and by 2012, 62.4% of the oaks had died; this decline resulted in an opening of the canopy and lead to changes in canopy and in understory dynamics.

The possible response of understory cover, basal area and diversity indices to stand density in our site has shown in the study of Misik *et al*. (2013). Diameter of a woody individuals can be measured quickly, easily, and accurately, but the measurement of height is relatively complex, time consuming, and difficult because of a big size of these individuals in our site. The dynamics increasing of height and diameter of woody species and the structure of new subcanopy layer were showed in the result of Misik *et al.* (2014).

The purposes of this study were (1) to fit and evaluate four height-diameter functions on a short-term data set covering *Acer campestre* L. (field maple), *Acer tataricum* L. (Tatar maple) and *Cornus mas* L. (European cornel) dominant woody species; (2) to identify the most appropriate height-diameter functions for three woody species, and (3) to detect some possible difference between these species on the basis of height-diameter functions during a 4-5 year periods.

MATERIALS AND METHODS

Study site

The 27 ha reserve research site is located in the Bükk Mountains of northeast Hungary (47°55' N, 20°46' E) at a distance of 6 km from the city of Eger at an altitude of 320–340 m a.s.l.. The site was established in 1972 by Jakucs (1985) for the long-term study of forest ecosystems. Mean annual temperature is 9.9 °C and mean annual precipitation ranges typically from 500 to 600 mm.

Description of the geographic, climatic, soil conditions and vegetation of the forest was undertaken in detail by Jakucs (1985, 1988). The most common forest association in this region is *Quercetum petraeae-cerris* with a dominant canopy of *Q. petraea* and *Q. cerris*. Both oak species are important dominant native deciduous tree species of the Hungarian natural woodlands. The plot under study is made up of evenly-aged trees, is at least 100 years old temperate deciduous forest and has not been harvested for more than 50 years.

Sampling and statistical analysis

Shoot analysis data of three dominant woody species (*A. campestre*, *A. tataricum* and *C. mas* are on the basis of the biggest mean size parameters in the shrub community) were obtained from a 27 ha study site at regular intervals. Monitoring activities started in 1982 and repeated shrub layer inventories took place in 1993, 1997, 2002, 2007 and 2012. The investigations were performed during the growing seasons.

Collected over the last 3 decades, the 2025 individuals were randomly selected throughout the study site to provide representative information for a variety of densities and heights of dominant woody species. Summary statistics including the mean, minimum, maximum, and standard deviation (SD) for total shoot height and diameter of shoot by woody species are shown in *Table 1*, *2* and *3*.

Table 1. *Acer campestre* shoot summary statistics based on dominant woody species.

Year	No. of sample specimens	Diameter (cm)				Total shoot height (m)			
		Mean	Min.	Max.	SD	Mean	Min.	Max.	SD
1982	195	4.38	1.23	13.32	2.46	4.02	1.00	10.20	2.19
1993	151	6.70	1.40	18.00	3.55	5.17	1.30	15.00	3.05
1997	207	6.79	1.00	21.00	4.21	5.22	1.00	13.00	3.00
2002	160	8.49	0.82	35.00	6.54	6.06	1.10	17.00	3.54
2007	133	10.84	0.95	31.50	6.68	8.01	1.10	19.20	4.47
2012	125	10.63	0.85	37.92	6.02	7.60	1.18	16.50	3.76

Table 2. *Acer tataricum* shoot summary statistics based on dominant woody species.

Year	No. of sample specimens	Diameter (cm)				Total shoot height (m)			
		Mean	Min.	Max.	SD	Mean	Min.	Max.	SD
1982	71	3.43	1.29	9.62	1.66	3.54	1.05	8.46	1.87
1993	45	4.69	1.30	10.10	2.35	3.37	1.30	7.00	1.54
1997	59	4.37	1.00	10.80	2.59	3.83	1.20	10.10	2.02
2002	45	5.28	0.42	14.19	3.68	4.32	1.20	8.10	2.28
2007	28	6.45	1.12	14.45	3.60	4.92	1.63	11.40	2.23
2012	24	7.40	0.59	14.41	3.94	5.50	1.70	8.95	2.29

Table 3. *Cornus mas* shoot summary statistics based on dominant woody species.

Year	No. of sample specimens	Diameter (cm)				Total shoot height (m)			
		Mean	Min.	Max.	SD	Mean	Min.	Max.	SD
1982	155	3.93	1.28	8.92	1.64	3.52	1.05	13.00	1.74
1993	108	5.68	1.60	13.00	2.23	3.81	1.20	9.00	1.21
1997	193	4.97	1.10	13.40	2.58	3.97	1.00	9.60	1.82
2002	117	6.50	0.60	25.00	3.97	4.64	1.10	9.00	1.98
2007	116	7.36	0.80	29.63	5.39	4.63	1.10	8.40	2.04
2012	93	7.59	0.70	15.07	3.08	5.37	1.17	8.80	1.80

Four biparametric nonlinear equations were fitted and evaluated based on a data set consisting from a plot (*Table 4*). Radial and height growth are characterized for specimens of dominant woody species. Height and diameter of all living *Acer* spp. and *C. mas* in the high shrub layer (shrub individuals height ≥ 1.0 m were categorized as high shrubs) were measured with a scaled pole and at 5.0 cm above the ground with a digital caliper and the measurement results were averaged.

Table 4. Nonlinear height-diameter functions selected for comparison.

Function No. and form*		References
[1]	$H = 0.05 + e^{a+b/(D+1)}$	Wykoff *et al.* 1982
[2]	$H = 0.05 + aD / (b + D)$	Bates and Watts 1980; Ratkowsky 1990
[3]	$H = 0.05 + 10^a \times D^b$	Larson 1986
[4]	$H = 0.05 + aD / (D + 1) + bD$	Watts 1983

* H = total tree height (m); D = diameter of shoot height (cm); a, b = parameters to be estimated; e = base of the natural logarithm (= 2.718 28); 0.05 is a constant used to account that diameter is measured at 0.05 m above the ground.

For each year of monitoring we fitted four nonlinear equations with two parameters (*Table 4*) describing the dependence of height on diameter. Height and diameter relationships of trees are generally described using nonlinear mathematical models. We replaced 1.3 with 0.05 m in the different height–diameter models, because we measured diameter of woody species in the understory at 0.05 m. When diameter approaches 0, H approaches 0.05 (e.g. if we use logistic type of function). The asymptotic *t*-statistics for the parameters and the plots of studentized residuals against the predicted height show that many concave and sigmoidal functions can be used to describe the height–diameter relationships. R Core Team (2014) and R package (Grothendieck 2013) were used to model the different nonlinear height-diameter functions. It was determined the most fitting nonlinear equations for each woody species on the basis of residual standard error values.

RESULTS

Tables 5, *6* and *7* show the least squares estimates of the parameters. Coefficient of determination (R^2) values ranged from 0.40 to 0.82, with the average being 0.70 of *A. campestre*, 0.59 of *A. tataricum* and 0.51 of *C. mas* during last three decades, and not reported here. Results in *Table 5*, *6* and *7* show that for the two-parameter models, [2], [3] and [4] the *t*-statistics for the parameters of the functions are not significant at the 0.01 level of *A. campestre* and 0.05 level of the other two species in some studies.

Table 5. Parameter estimations for two-parameter height-diameter functions.

		Estimates for *Acer campestre* in monitoring years					
Function	**Parameter**	1982	1993	1997	2002	2007	2012
[1]	*a*	2.635	2.819	2.752	2.678	3.018	2.846
	b	-6.349	-8.691	-7.856	-6.763	-9.793	-8.346
[2]	*a*	44.650	90.350*	37.067	19.014	35.621	23.305
	b	43.770	111.070*	39.855	15.115	34.661	19.767
[3]	*a*	0.040*	-0.043*	0.041*	0.257	0.166	0.260
	b	0.882	0.913	0.824	0.600	0.728	0.623
[4]	*a*	0.763	0.702*	1.219	3.498	2.627	3.600
	b	0.772	0.675	0.615	0.376	0.524	0.416

Note: *The asymptotic *t*-statistic for the parameter is not significant at the 0.01 level.

The residual standard errors (RSE) of three woody species are summarized in Table 8. The most fitted height-diameter function values for woody species showed in bold. Function of Wykoff *et al.* (1982) generally giving the most suitable results, except of *A. campestre*.

Table 6. Parameter estimations for two-parameter height-diameter functions.

		Estimates for *Acer tataricum* in monitoring years					
Function	**Parameter**	1982	1993	1997	2002	2007	2012
[1]	*a*	2.639	1.986	2.239	2.302	2.280	2.355
	b	-5.959	-4.057	-4.355	-4.420	-4.436	-4.814
[2]	*a*	47.180*	8.969	12.775	12.139	11.500	11.971
	b	42.120*	7.287	9.430	8.048	7.553	7.714*
[3]	*a*	0.056*	0.129*	0.173	0.227	0.257	0.309
	b	0.917	0.604	0.658	0.601	0.557	0.514
[4]	*a*	0.462*	2.040	2.096	2.688	3.113	3.700
	b	0.916	0.364	0.498	0.427	0.365	0.320

Note: *The asymptotic *t*-statistic for the parameter is not significant at the 0.05 level.

Table 7. Parameter estimations for two-parameter height-diameter functions.

		Estimates for *Cornus mas* in monitoring years					
Function	**Parameter**	1982	1993	1997	2002	2007	2012
[1]	*a*	2.361	1.983	2.225	2.158	2.113	2.181
	b	-5.268	-4.070	-4.623	-3.978	-3.745	-3.863
[2]	*a*	24.380	8.504	13.204	9.290	8.707	9.926
	b	23.110*	6.666	10.870	5.478	4.889	5.858
[3]	*a*	0.040*	0.167	0.130	0.322	0.332	0.301
	b	0.850	0.554	0.684	0.448	0.417	0.497
[4]	*a*	0.813*	2.415	1.842	4.181	4.296	3.524
	b	0.723	0.310	0.495	0.190	0.157	0.306

Note: *The asymptotic *t*-statistic for the parameter is not significant at the 0.05 level.

Function of Watts (1983) has very poor convenience and large RSE values; this function was fitted for *A. campestre* only in two different times. The lower error values were measured in 1982 and in 1993, later these values increased in line with increasing average size of dominant woody species.

Table 8. Comparison of nonlinear height-diameter function: residual standard errors.

Function	Species	Residual standard errors					
		1982	1993	1997	2002	2007	2012
[1]	*Acer campestre*	1.021	1.965	1.347	1.684	2.496	**2.189**
	Acer tataricum	**1.029**	1.134	1.362	**1.003**	**1.359**	**1.510**
	Cornus mas	**1.205**	0.828	1.091	**1.245**	**1.104**	1.251
[2]	*Acer campestre*	**0.972**	1.869	**1.262**	**1.678**	**2.404**	2.207
	Acer tataricum	1.028*	**1.131**	1.348	1.008	1.360	1.513
	Cornus mas	1.202*	**0.827**	1.079	1.256	1.117	**1.247**
[3]	*Acer campestre*	**0.972**	1.866	1.267	1.784	2.423	2.318
	Acer tataricum	1.033	1.133	**1.347**	1.055	1.405	1.546
	Cornus mas	1.204*	0.836	**1.078**	1.354	1.249	1.256
[4]	*Acer campestre*	0.973	**1.862**	1.277	1.906	2.461	2.437
	Acer tataricum	1.036	1.137	1.351	1.096	1.438	1.576
	Cornus mas	1.205*	0.844	1.082	1.399	1.286	1.265

Note: The most fitted height-diameter function values shown in bold.
*The RSE values are not compared because of insignificant *t*-statistics.

The most fitted function for *Acer* species and *C. mas* are shown in *Figure 1, 2* and *3*. Standard error values for the fitted functions, although not reported here, ranged from 0.03 to 116.21, with the average being 7.76 of *A. campestre*, 3.00 of *A. tataricum* and finally 1.16 of *C. mas* during monitoring investigations.

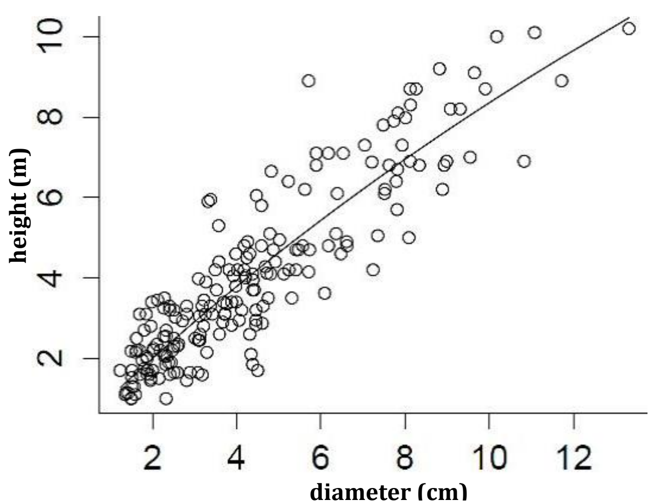

Figure 1. Plot of total tree height against diameter for *Acer campestre* in 1982. The curve was produced by [2] function.

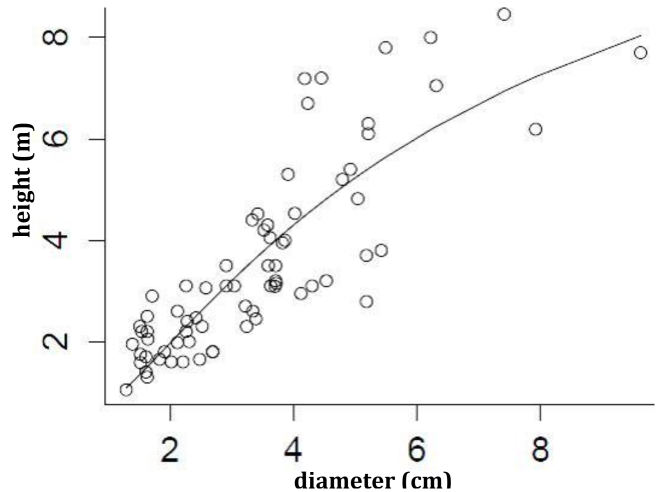

Figure 2. Plot of total tree height against diameter for *Acer tataricum* in 2002. The curve was produced by [1] function.

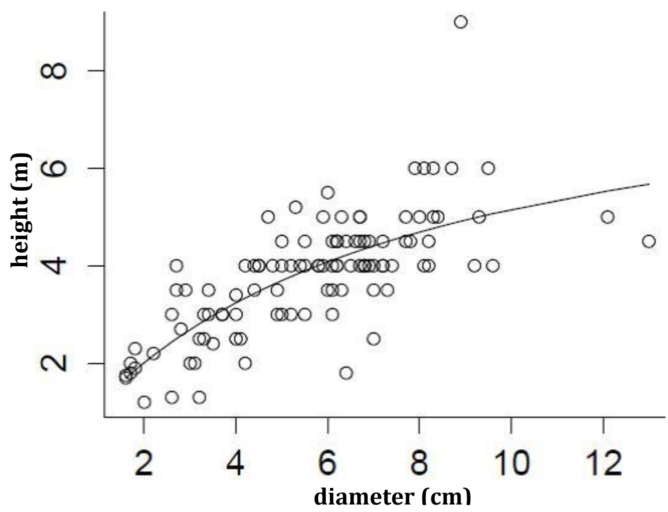

Figure 3. Plot of total tree height against diameter for *Cornus mas* in 1993. The curve was produced by [2] function.

DISCUSSION

The aim of this study was to develop a model capable of predicting the oak death pattern in Síkfőkút oak forest for height–diameter relation of dominant woody species and basic calculation of forest inventories. Woody shoot height is an important variable which is used for estimating stand volume, site quality and for describing understory structure following serious oak decline.

It's known that due to competition, trees with the same diameter are taller in denser forest stands. Density and diameter are not only necessary, but may be sufficient for determining tree height because other factors affecting height are reflected by diameter and density. In the process of developing the proposed model it was found that height increases monotonically with density and that this increase is not bounded by an asymptote (Zeide and Vanderschaaf 2002). Our study is in agreement with this statement of previous finding because *A. campestre* increased in density (from 56 to 204 specimen's ha^{-1}); density of *A. tataricum* and *C. mas* did not changed in importance in the subcanopy layer over the past 3 decades (Misik *et al.* 2014).

Kenefic and Nyland (1999) explored sugar maple height diameter and age diameter relationship in a balanced uneven-aged northern hardwood in USA. They results suggest that regressions show a clear relationship between tree diameter and height in the studied stand. When interpreted in light of the correlation between tree diameter and age, these results suggest a relationship between tree age and height as well. The height parameters vary considerably with diameter; this relationship can be described by statistically valid equation.

Conclusions to be derived from the site are as follows: (1) it was fitted and evaluated four height-diameter functions on a long-term data set covering dominant woody species. (2) The most appropriate height-diameter functions were Wykoff *et al.* (1982) for *A. tataricum* and *C. mas* and Bates and Watts (1980) and Ratkowsky (1990) for *A. campestre*. (3) After the oak decline in the study site was detected remarkably increasing of residual standard errors for these species. This increasing was the lowest by *C. mas* species. These fitted and evaluated equations increase our knowledge of the growth of this species and therefore will enable us to improve management planning in oak forests.

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