Norway spruce stem form variability in Gheorgheni forests, Romania

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Abstract. Taper models are used to determine diameters at different heights on the stem. Multiple taper equations are available for the Norway spruce, both at local or country level. A local model is required for a precise determination of the wood volume. To develop a local taper model, measuring a significant number of trees is necessary. This study aimed to determine if new models are required for the Gheorgheni region. In this study, a preliminary analysis was made on 468 trees. The stem variability was analysed using form factors (natural and artificial) and form quotient (natural and artificial). Our results showed no significant differences regarding form factors and quotients between determined values and ones available in the literature. At national level, a general taper model for Norway spruce is used. The stem form determined on measured diameters differs from the model used as reference only for diameters higher than 40 cm. In the case of diameters below 20 cm, our measurements are fitted perfectly by the general stem profile existing in the literature.
Key Words: *Picea abies*, form factor, form quotient, taper, Eastern Carpathians.

Introduction. Norway spruce is one of the most important coniferous species with an extended area from the Alps to the Balkans and the Carpathians, extending to the Scandinavian Peninsula and northern Russia (Caudullo et al 2016). Spruce has a high growth rate and produces quality wood in various ecological conditions. According to the Romanian National Forest Inventory (NFI 2018), Norway spruce is the most spread coniferous species (approximatively 24% of the total volume of standing trees). In the Carpathians region, Norway spruce is the main coniferous species. Accurate estimation of stem volume and wood products has always been interesting for forest managers (Diéguez-Aranda et al 2006). The tree's stem form and taper models represent a challenge in determining the wood volume of standing trees. Taper functions estimate diameters at any point along the stem and can be used to estimate the total volume of stem or individual logs of any length at different heights (Kozak 2004). The taper models represent one of the necessary components in modern forest management planning (Özçelik & Crecente-Campo 2016). They can be used to predict the relationship between tree growth and carbon stocks (Liu et al 2020). To determine tree volume, the taper models can be used to determine the transversal area at different height levels (g_i) rather than the diameter at different heights along the stem (d_i) (Adamec et al 2019).

In Romania, the first research on the stem form and taper models of Norway spruce dates back to the 1950s (Popescu-Zeletin et al 1957). Significant studies were conducted by Ichim (1954) and Leahu (1997 and 2007). The most complex researches on different species of economic interest were made by Giurgiu et al (1972) and later by Giurgiu (1979) and Giurgiu & Draghiciu (2004). Recent studies conducted on Norway spruce in Romania highlighted the stem form particularities according to the site, management practices and even genetic specifications (Vasilescu et al 2017a; Vasilescu et al 2017b; Bouriaud et al 2019; Amarioarei et al 2020; Strimbu et al 2021).

The tree stem, implicitly taper of the tree, is affected by the stand density, stand age, production class, management practices (thinning treatments) and even genetic factors (Liu et al 2020). Stem taper varies from tree to tree and taper model calibrated at the population level may produce diameter predictions with high precision for trees within that population (Yang et al 2009). Based on these facts, the determination of taper models at regional level (e.g. forest districts) is necessary. As valuable tools in forestry, appropriate taper equations that work well across different species or genotypes are difficult to obtain (Özçelik & Brooks 2012). To get precise models, many trees need to be measured, which involves a significant effort (felling the trees, snag cutting, diameter measurements along the stem for hundreds of trees). An initial step in this process is determining if there are significant differences between existing models and a model calibrated for a specific region. This study aimed to determine if the form and taper of Norway spruce stems from the Gheorgheni region differ from general models existing in the literature.

Material and Method. The study area is located in the Gheorgheni region, Harghita county, Eastern Carpathians (between 46º50`N, 25º20`E and 46º40`N, 25º40`E) in the forests administrated by the Regime Forest, District Gheorgheni. In the study area, the main species is Norway spruce (*Picea abies* L.) and in smaller proportion: fir, beech, birch and aspen. The biometric variables collected were two perpendicular diameters at different heights along the tree stem and total height. For trees under 20 m height, diameter measurements were made every half meter (e.g. 0.5, 1, 1.5 m and so on) and for trees over 20 m, height measurements were made every meter (e.g. 1, 2, 3 m and so on). Additionally, for all measured trees, two diameters were measured at the height of 0.3 m (stump) and 1.3 m (diameter at breast height). All measurements were made on fallen trees. For height measurements, a tape was used, and for diameter measurements, a forestry caliper, both with 0.1 cm accuracy. The taper data were collected from 480 trees in 20 research plots. The measurements were verified and validated by checking decreasing rate along the stem. The final database includes 17,140 diameters from 468 trees (Table 1).

Table 1

The mean biometric tree characteristic (dbh – diameter at breast height; ht – total height; V – tree volume) by research plots

Research plot	*No. measured trees*	*dbh±sd (cm)*	*ht±sd (m)*	*V±sd (m^3)*
GH114A	11	40.03±14.03	35.73±5.34	2.31±1.72
GH118B	28	20.86±4.14	20.41±2.09	0.36±0.16
GH119A	138	42.60±12.75	33.16±5.64	2.23±1.36
GH12A	16	15.17±8.14	18.22±6.74	0.21±0.29
GH134A	15	33.32±4.59	26.52±2.56	1.04±0.36
GH146A	16	42.86±13.59	31.97±6.11	2.10±1.55
GH179B	71	18.52±4.65	20.23±3.3	0.29±0.18
GH207A	15	21.75±4.42	18.32±1.91	0.35±0.14
GH236A	9	33.09±12.34	23.17±5.45	1.06±0.78
GH237B	12	28.95±10.75	20.58±5.25	0.75±0.52
GH26B	10	37.72±10.19	26.16±2.94	1.37±0.75
GH2B	14	40.38±9.71	34.08±3.46	1.90±0.91
GH301A	15	47.52±7.89	29.57±2.58	2.19±0.71
GH31B	11	22.20±5.53	26.99±3.51	0.48±0.23
GH35C	15	43.80±6.42	29.92±2.82	1.92±0.64
GH39A	15	47.34±8.37	38.60±3.1	3.00±1.08
GH40A	14	30.46±5.89	25.09±1.64	0.90±0.36
GH62A	15	56.60±12.55	38.34±2.6	3.94±1.86
GH7C	13	22.70±4.86	23.91±3.47	0.48±0.27
GH94B	15	34.71±5.18	26.56±2.1	1.11±0.31
Total	468	34.14±14.76	27.89±7.62	1.47±1.37

To characterise the stem form, the following indicators were calculated (Giurgiu & Decei 1997; Van Laar & Akça 2007):

$$k_{0.5} = \frac{d_{0.5}}{d_{0.1}}$$

Where:
$k_{0.5}$ – natural form quotient for the relative height of 0.5;
$d_{0.5}$ – diameter at the relative height of 0.5;
$d_{0.1}$ – diameter at the relative height of 0.1.

$$k = \frac{d_{0.5}}{dbh}$$

Where:
k – artificial form quotient for the relative height of 0.5;
$d_{0.5}$ – diameter at the relative height of 0.5;
dbh – diameter at breast height.

$$f_{0.1} = \frac{v}{g_{0.1} \cdot h}$$

Where:
$f_{0.1}$ – natural form factor;
v – tree volume;
$g_{0.1}$ – basal area at the relative height of 0.1, function of $d_{0.1}$;
h – tree height.

$$f = \frac{v}{g \cdot h}$$

Where:
f – artificial form factor;
v – tree volume;
g – basal area at height of 1.3 m, function of dbh;
h – tree height.

Data analysis. The data set was managed as a database in Excel format and exported in text files to be processed in R Studio. The calculations and figures were generated using the R language (R Team 2020).

Results and Discussion. The measurements of diameter along the stem were made in both younger and mature trees. The smallest mean diameter by stands was 15.17±8.14 cm, while the largest mean diameter was 56.60±12.55 cm. The distribution of trees number by diameter category follows a relatively normal distribution with right asymmetry (Figure 1A). The smallest mean height by stand was 18.22±6.74 m in the same plot where the smallest mean diameter was recorded. The maximum stand height was 38.60±3.10 m. The distribution of tree number by height category follows a normal distribution without a visible asymmetry (Figure 1C). The relationship between diameter at breast height and the total height of measured trees highlights a uniform distribution of trees, with fewer specimens with a diameter higher than 70 cm (Figure 1B).

The taper of a tree can be evaluated apart from regression equations by a series of indicators. The most common is the form factor calculated as a ratio between tree volume and a cylinder volume with the same basal area and height as the tree. The form factor can be calculated using the basal area at an absolute height of 1.3 m (based on dbh) or using the basal area at the relative height of 0.1 (based on $d_{0.1}$). The mean natural form factor $f_{0.1}$ in the study area is 0.504, smaller than the value of 0.544, obtained by Giurgiu & Decei (1997), considered as a reference for the Norway spruce in Romania. For spruce from the north part of Eastern Carpathians, Ichim (2008) obtained a natural form factor of 0.440.

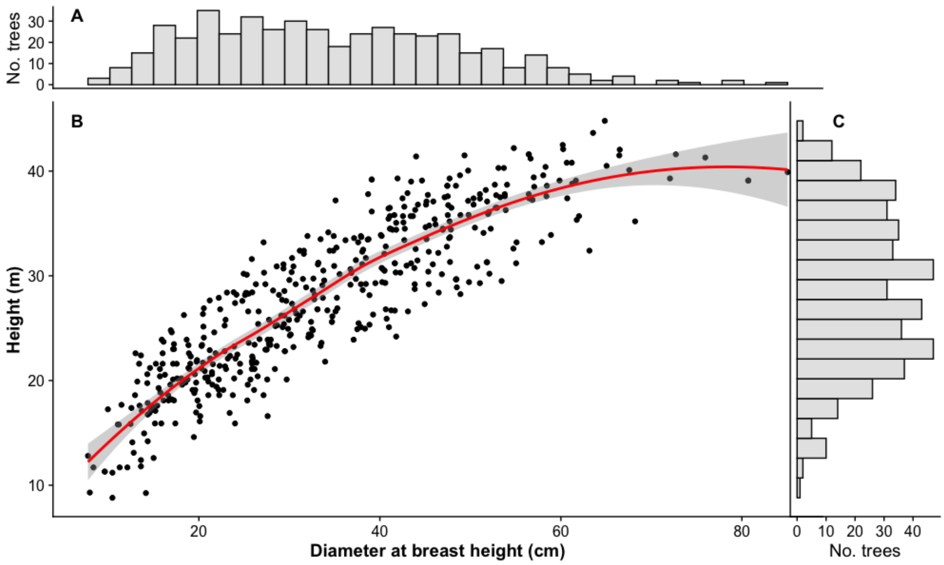

Figure 1. Relationship between diameter at breast height (dbh) and total height (ht) (B); The distribution of tree number by diameter category (A); The distribution of tree number by height category (C).

Plots' mean artificial form factor varies from 0.390 in GH62A to 0.499 in GH207A. The smallest artificial form factor was recorded in a stand with a mean dbh value of 56.6 cm, and the larger artificial form factor was recorded in a plot with a mean dbh value of 21.8 cm. From these two extreme values of the artificial form factor, it can be highlighted that the form factor decreases with increasing dbh. The smallest differences between natural and artificial form factors are recorded for plots with smaller diameters, and the large differences are recorded for higher diameters (Figure 2).

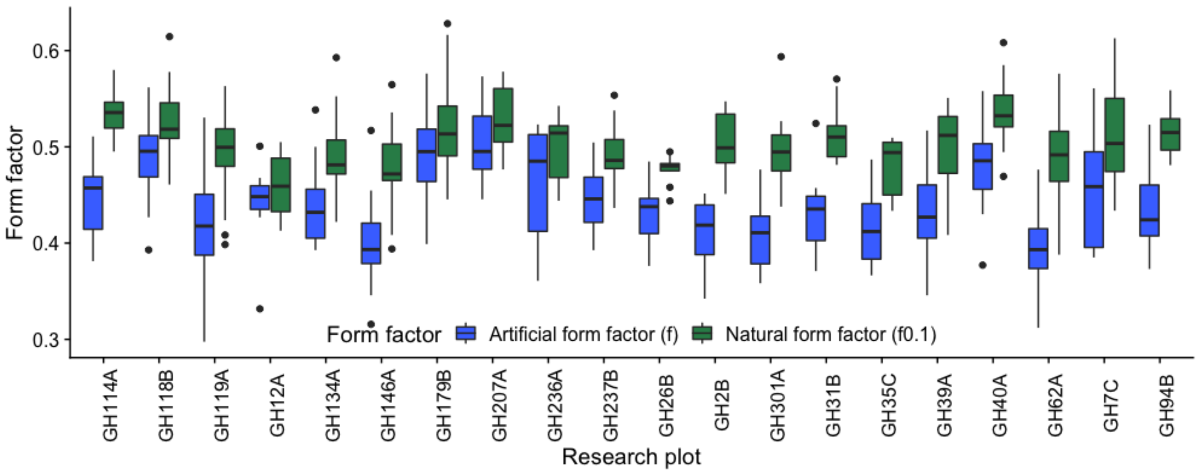

Figure 2. Mean values of natural form factor ($f_{0.1}$) and artificial form factor (f) by stands.

The form quotient is calculated as a ratio between diameter at the relative height of 0.5 and either dbh or $d_{0.1}$. The mean natural form quotient for the study area is 0.679, a value smaller than the figure generally accepted for Norway spruce in Romania (0.737), proposed by Giurgiu & Decei (1997). Ichim (2008) obtained a mean value for the natural form quotient of 0.661, similar to the value obtained in this study. In contrast with the form factor, there is a smaller variability between natural and artificial form quotients (Figure 3). Regarding the natural form quotient, the lowest mean value was 0.592 and the higher was 0.709. The plot’s lowest mean value for the artificial form quotient was

0.656 and the largest was 0.729. Differences between dbh and $d_{0.1}$ justify these variations.

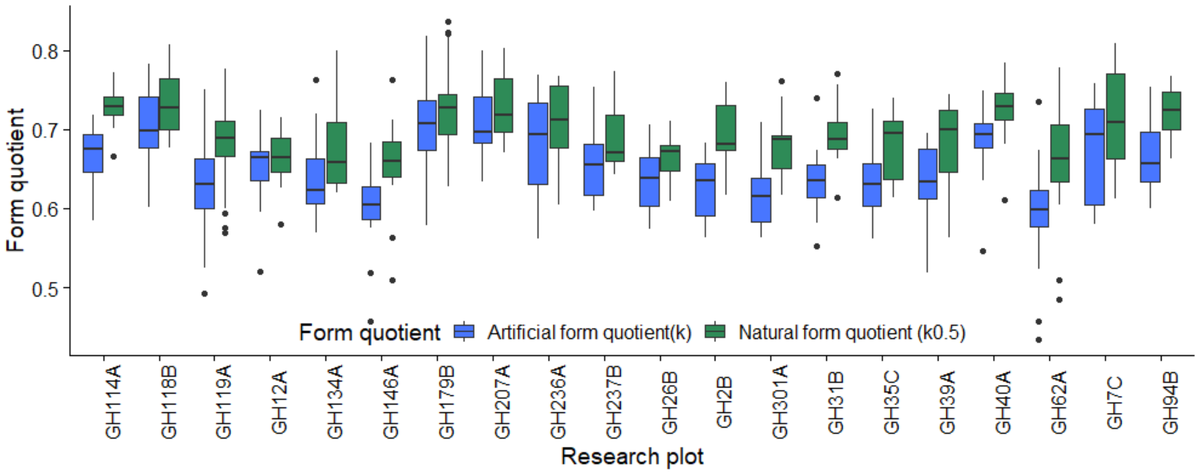

Figure 3. Mean values for natural form quotient ($k_{0.5}$) and artificial form quotient (k) by research plots.

Taper models are essential tools for predicting diameter at different heights along the stem (Kozak 2004; Liu et al 2020). Local site particularities could induce differences, and general calibrated models cannot be used with precision. The tapper models calibrated on measurements made on local sites reveal higher accuracy for determining the wood volume for trees within the same population (Socha 2002). To determine differences between the taper function proposed by (Giurgiu & Draghiciu 2004) and the tree taper from forests administrated by the Regime Forest District Gheorgheni, their relationship between relative diameter and relative height was analysed (Figure 4).

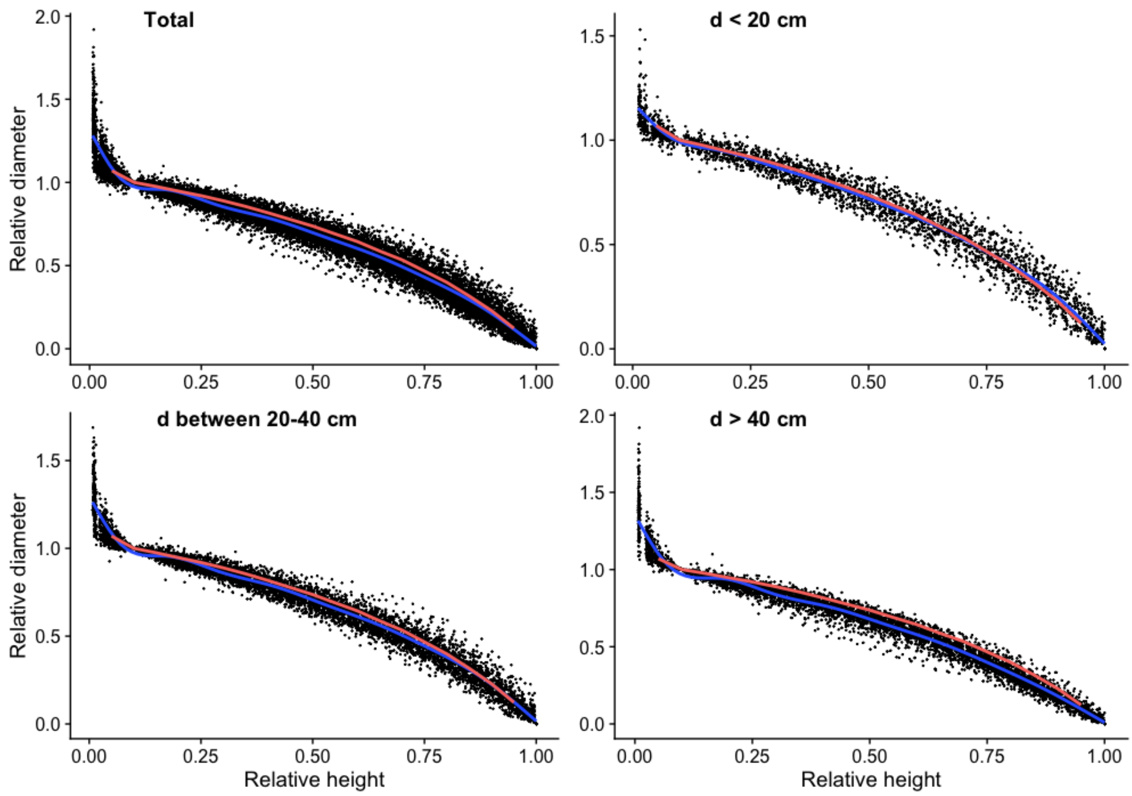

Figure 4. Relationship between relative height (h/H) and relative diameter (d/D) by diameter category (blue - the smooth curve for measured values; red - the taper function proposed by Giurgiu & Draghiciu (2004)).

High dispersion of relative diameter in relation to relative height has been reported in a study on large samples (over 5,400 trees from 200 sites) in Romania (Vasilescu et al 2017a). In general, there is a difference between the smoothen line of measured values and the model proposed by (Giurgiu & Draghiciu 2004) (the general model). The significant differences are around the relative height of 0.5. To determine for which diameters category there are differences between the general model and particular situation in the study area, the sample was divided into three diameter classes. It can be observed that for diameters under 20 cm, the general taper model proposed by (Giurgiu & Draghiciu 2004) fits perfectly the measured data. With increasing dbh, the differences between the general model and the smoothen curve for measured trees are more evident, especially for the relative height of 0.25 and 0.5. The higher differences are present in the case of trees with dbh over 40 cm. The taper model proposed by (Giurgiu & Draghiciu 2004) overestimates the diameters starting from the relative height of 0.2 to 0.8. The stem form of Norway spruce with larger diameters in the study area differs from the model (Giurgiu & Draghiciu 2004). Since the managed forest usually has a diameter larger than 40 cm for forests administrated by Regime Forest District Gheorgheni, the general model for the taper of trees is not accurate.

Based on this study's preliminary results, we can affirm that form factors and quotients of Norway spruce from the Gheorgheni region do not differ significantly from that proposed in the literature. Regarding the taper of trees, differences were found for diameters larger than 40 cm. The data analysis will continue and the regional taper model will be calibrated based on tree measurement.

Conclusions. To develop a local taper model, it is necessary to measure a significant number of trees, which involves a high consumption of resources (both time and financial resources). The study determined if there are new models necessary for the Gheorgheni region to have a higher precision in the wood volume determination. This study's preliminary analysis was made on diameter measurements along the stem from 468 trees. The stem variability was analysed using form factors (natural and artificial) and form quotient (natural and artificial). The results showed small differences regarding the form factor and larger differences for form quotient, compared to values in other regions in Romania. The stem form based on measured diameters differs from the stem profile used as reference only from diameters larger than 40 cm. The data analysis will continue, and the regional taper model will be calibrated based on tree measurement, especially for trees with diameters larger than 40 cm.

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Conflict of interest. The authors declare no conflict of interest.

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