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ORIGINAL PAPER

Hydrological properties of bark of selected forest tree species. Part I: the coefficient of development of the interception surface of bark

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Abstract

Key message **The coefficient of development of the interception surface of bark allows for objective assessment of the degree of bark surface differentiation between different species.**

Abstract Inter-species differentiation of bark morphology and its variability progressing with tree age suggest that the hydrological properties of the bark of particular species depend on the degree of development of the outer bark surface of trees. The aim of the present research was to develop a method of calculating the actual bark surface with the use of the coefficient of development of the interception surface of bark, describing the degree of development of the outer bark surface of trees. The primary aim was to show inter-species differentiation of the coefficient of development of the interception surface of bark at breast height, as well as its variability within a single species, progressing with tree age. The present study shows the results obtained for 77 bark samples collected at the breast height of the following tree species: *Pinus sylvestris* L., *Larix decidua* Mill., *Abies alba* Mill., *Picea abies* L., *Quercus robur* L., *Fagus sylvatica* L., *Acer pseudoplatanus* L. and *Betula pendula* Ehrh. In all of the examined species, the coefficient of development of the interception surface of bark shows a distinct relation to the breast-height diameter. The highest values of coefficient of development of the interception surface of bark among the thickest trees are reached by: *L. decidua*—2.56, *Pinus sylvestris*—2.28 and *B. pendula*—2.44, whereas the lowest values are reached by the bark of European beech *F. sylvatica*—1.07. The coefficient of development of the interception surface of bark describes the morphological differentiation of the outer bark surface of trees in an objective way. Owing to its mathematical form, the coefficient of development of the interception surface of bark may be useful in the modelling of hydrological processes occurring in forest ecosystems.

Keywords Forest hydrology · Plant interception · Bark of forest trees · Bark surface · Coefficient of development of the interception surface of bark

Introduction

The bark of forest trees has a number of various functions. From the point of view of the formation of water balance in forest ecosystems, what is focused on is the role of bark in rainfall retention (Herwitz 1985; Levia and Herwitz 2005; Levia and Wubbena 2006; Valovà and Bieleszovà 2008) as well as the influence of the differences in bark roughness and water capacity in different tree species on the size of stemflow production (Návar 1993; Aboal et al. 1999; Levia et al. 2010; Van Stan and Levia 2010). Bark constitutes the environment for the life of numerous organisms, such as bryophytes and lichens, whose species composition and distribution over the bark surface largely depend on differences in the texture and acidity of the bark of different forest tree species (Bates and Brown 1981; Stephenson 1989; Kuusinen 1996; Everhart et al. 2009; Öztürk and Güvenç 2010; Öztürk and Oran 2011). In the literature, it is

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stated that bark may be used in the biomonitoring of air pollution (Schulz et al. 1999) and that it is important in the protection of the vascular cambium during the occurrence of heat stress caused by forest fires. Among important factors that are frequently decisive in the survival of a tree during a fire are bark thickness (Harmon 1984; Hengst and Dawson 1994; Pinard and Huffman 1997; Barlow et al. 2003) and its volume density (Bauer et al. 2010).

The interception of rainfall by forest trees is a complex process, dependent on many factors, such as rainfall intensity, duration, and raindrop size (Calder 1996, 1999; Suliński et al. 2001). The interception ability is closely connected with the total surface of the overground parts of a plant, which is largely determined by the plant species, its height, weight, and morphological features (Cebulska and Osuch 1998; Keim et al. 2006). Research on plant interception, understood as a process of rainfall detention by the whole surface of a plant (Suliński et al. 2001), do not allow for distinguishing the extent to which the amount of intercepted water is affected by the surface of leaves, branches or the stem. Research focused only on the rainwater interception by leaves may understate the actual water capacity of the tree crowns, and consequently lead to an underestimation of the role of bark in rainwater retention (Klaassen et al. 1998). Given the heterogeneity of the various parts of the plant, its surfaces with different retention properties must be considered separately. Therefore, there is a need to divide the plant into the surface of leaves, shoots and bark, whose water retention properties vary depending on the age (Osuch 1998; Osuch et al. 2005a, b).

The bark of forest trees is a structure which undergoes constant changes due to the dying of some tissues and the growth of new ones (Grochowski 1990). The water capacity of bark depends on the properties of the bark tissue, such as its thickness and texture, which change with the tree age and thickness (Hengst and Dawson 1994; Pinard and Huffman 1997; Pypker et al. 2011). The bark of different species is very diversified with respect to its thickness and texture—from extremely rough to completely smooth (Jackson 1979; West 2009). For example, the surface of bark of Scots pine *Pinus sylvestris* L. and beech *Fagus sylvatica* L., of the same thickness and height, will differ due to their different structure. Pine bark has numerous cracks and fissures, while beech bark is relatively smooth over the entire length of the stem. Thus, the active area of the bark taking part in the interception of rainwater will differ greatly between these two species. Differences in the degree of development of the bark surface between these species may suggest that the potential interception capacities of the pine bark surface will be larger than the potential interception capacities of the beech bark surface.

Morphological differentiation of bark occurs also within a single species. For example, Pawłowski (1956) described three types of outer bark of Norway spruce *Picea abies* L.: *numularis* with round flakes, *squamata* with slightly elongated flakes and *corticata* with quite thick flakes. Similarly, Eremin (1977) classified the three types of outer bark in spruce as four categories by including anatomical characteristics. Etverk (1972) attempted to analyse the succession of features of outer bark in spruce by distinguishing the following forms: *rimescocarta*, *globocarta* and an intermediate form. According to research by Hoffmann (1958), the features of bark in Norway spruce are also related to the conditions of tree growth. The richer and more abundant the habitat, the thicker the bark formed by this species.

The differentiation of the bark surface is relatively hard to parametrize and there is little information on the methods of its measurement. An attempt to determine the allometry of bark thickness was made by Harmon (1984) as well as by Adams and Jackson (1995). MacFarlane and Luo (2009) described the bark structure of 15 tree species using the bark-fissure index (BFI) while Van Stan et al. (2010) constructed a device which measures the bark microrelief.

Owing to inter-species differentiation in the bark morphology and its variability progressing with tree age, research on interception and water capacity of bark should take into consideration its actual surface. Therefore, the object of this study is the actual surface of the bark of the stem of selected forest tree species, including its morphological properties. The aim of the study was (1) to develop and propose a method of calculating the actual surface of the bark A_d by means of the coefficient of development of the interception surface C_{sd}. describing the degree of development of the outer bark layer in trees; and (2) to demonstrate the interspecies differences in the shaping of the coefficient of development of the interception surface C_{sd} at breast height and its variability within a single species, progressing with the age of trees.

The coefficient of development of the interception surface C_{sd} can be defined as the ratio of the actual surface A_d of a bark sample to the surface of a section of the cylinder corresponding to the smooth surface of the examined sample. Assuming that the surface of the bark of the stem was perfectly smooth, the coefficient of development of the interception surface C_{sd} would have the minimum value of 1.0. The greater the coefficient of development of the interception surface C_{sd}, the more developed the actual surface of the stem bark A_d and the greater the theoretical possibility of retaining the rainwater which is in direct contact with the bark and which flows down the stem.

The inspiration for the present study was experiments on the water capacity of the bark of different tree species; their results are presented in Part II of this study.

Materials and methods

The research area

Bark samples were collected in the Trzebunia Forest Subdistrict (49°46′28″N, 19°51′51″E), which is part of the Myślenice Forest District, located in the southern Beskid Makowski in central Poland. The samples were obtained from the bark of the trees growing on the mixed mountain forest habitat, on an eastern slope within the altitudes from 650 to 700 m.

The scope of the research

The study included eight species of forest trees: Scots pine *(P. sylvestris* L.), European larch *(Larix decidua* Mill.), silver fir *(Abies alba* Mill.), Norway spruce *(P. abies* L.), common oak *(Quercus robur* L.), European beech *(F. sylvatica* L.), sycamore maple *(Acer pseudoplatanus* L.), and silver birch *(Betula pendula* Ehrh.). The bark samples were obtained during the summer of 2011, after the beginning of the growing season of the trees, which made it possible to sample the study material without mechanical damage to bark. The samples were collected using a saw, a knife and a chisel from the stems of living trees at breast height (1.3 m) by cutting, on the tree side facing the top of the slope, possibly rectangular pieces of bark with the size dependent on the thickness of the tree. Because the bark samples were obtained from trees growing under the same site conditions, the elaboration of the results was based on the assumption that tree thickness is the measure of their age. To demonstrate variation of the bark surface between the different species as well as the coefficient of development of the interception surface C_{sd} together with age, from 6 to 11 bark samples were collected for each species from trees with thickness ranging from 5 to 60 cm.

The actual bark surface

The actual surface of the bark in each sample was assumed to be the surface with all irregularities, cracks and cavities. According to the present authors, the actual surface can be calculated according to the formula:

$$A_d = A \cdot C_{sd} \quad (1)$$

where A_d is the actual surface of the bark sample (cm^2); A is the model surface of a bark sample (cm^2), corresponding to the surface of the cylinder slice; C_{sd} is the coefficient of development of the interception surface, describing the level of development of the outer bark layer of the trees.

Determination of the parameters needed to calculate the actual bark surface A_d required the use of a number of measurement and calculation procedures, details of which are shown below.

The model surface

The model surface for all tested samples of bark was calculated according to the formula:

$$A = l_a \cdot b_a \quad (2)$$

where A is the model surface (cm^2); l_a is the average length of the side of the bark sample (cm), parallel to the core of a tree stem; b_a is the average value of the sample width (curvature) (cm).

The length of the side parallel to the stem core l_a was calculated from the arithmetic mean of several lengths l_i measured with calipers. Measurements of lengths l_i were taken at regular intervals (0.5–1.0 cm), and their number was dependent on the width of the sample.

When calculating the average width (curvature) of the bark samples b_a, the researchers had to apply the geometrical relationships related to the circle. For this purpose, it was assumed that the cross section of the examined tree stems was round. This assumption allowed the calculation of the average radius of the tree cross section R, based on standard measurements of the tree diameter at breast height (DBH), carried out in two directions perpendicular to each other. The study sought to choose the trees in which the values of the two diameters did not differ from each other by more than 2 cm.

To calculate the length of the curvature b_a, individual bark samples were cut with a 0.6 mm thick saw into stripes with the width *s,* dependent on the length of the sample (Fig. 1). For each bark sample, the constant width *s* was adopted, located in the range from 0.5 to 1.0 cm. The division of the bark samples into strips was performed after the completion of a series of experiments of simulated rainfall, when the samples were in a state of maximum filling with water.

The cross sections of the strips of each bark sample were scanned at a scale of 1:1, in the resolution between 600 and 1,200 dpi. The choice of image resolution was dependent on the degree of differentiation of the surface of the bark. It should be noted that although the cross sectional line is dimensionless, after cutting the bark with a saw with 0.6 mm thickness, the two sides of the cross section were different from each other. Therefore, the surfaces of the cross sections were scanned in two versions: first all of the upper sections and then all bottom sections of the strips which made up the sample (Fig. 1). Before scanning the cross sections, it was necessary to check whether the

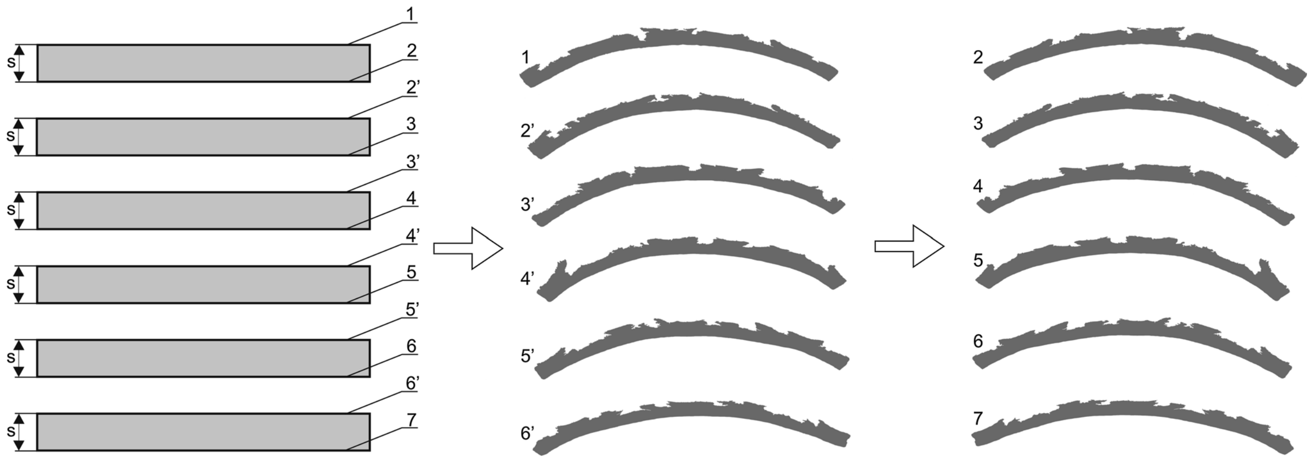

Fig. 1 An example of the division of a bark sample into strips with corresponding cross sections, where s is the strip width in the range from 0.5 to 1.0 cm; *1, 2′–6′* are the upper cross sectional scans of each strip; *2–7* are lower cross sectional scans of the strips

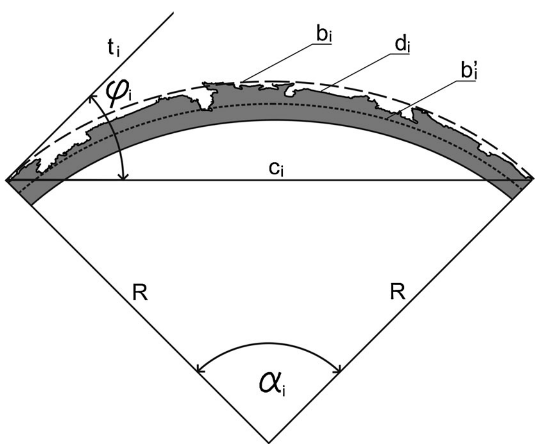

Fig. 2 A diagram showing the parameters measured and calculated for each cross section of a bark strip, where R is the radius of the tree, c_i is the chord of a section of a bark arc, t_i is the tangent passing through the extreme point of the arc, φ_i is a girth angle, α_i is the central angle of a bark section, d_i is the length of the cross sectional contour line, b_i is the length of the arc cross section, calculated according to geometrical relations, b_i' is the length of the curvature of the cross section, calculated in a subjective manner

curvature of the individual strips of bark corresponded to the radius R of the tree from which it was collected. This was done by means of previously prepared templates. In the event, when non-compliance with the radius of the tree was noted, the templates allow for giving the strips the shape of the original curvature.

Measurements of all parameters needed for further calculations were made in the SigmaScan Pro.5 software on the basis of scanned images.

To calculate the curvature b_a of a given bark sample, for each cross section the bark section chord c_i was measured (Fig. 2), which, together with the radius of the tree R, was used to calculate the length of the curve b_i of particular cross sections. Using the formula for the chord length c_i, which is

$$c_i = 2 \cdot R \cdot \sin \varphi i \tag{3}$$

the value of the girth angle $\varphi_i(°)$ was calculated between the chord c_i, and the tangent t_i passing through the extreme point of the arc on the surface of the bark (Fig. 2). On the basis of the girth angle φ_i, for each cross section, the central angle $\alpha_i(°)$ of the arc segment was calculated using the formula:

$$\alpha_i = 2 \cdot \varphi_i \tag{4}$$

Knowledge of the central angle α_i of a section of the circle allowed for the calculation of the length of the arc b_i (cm) of individual strips of bark, using the formula:

$$b_i = (\alpha_i / 180°) \cdot \pi \cdot R \tag{5}$$

On the basis of the calculated values b_i of individual sections, the length of the curvature of a sample b_a was calculated as the arithmetic mean of all values b_i.

The presented procedure for calculating the length of the average curvature b_a of particular bark samples was aimed to create a uniform and objective basis for these calculations for all examined samples. Figure 2 shows another way of determining the average length of the curvature of a bark sample b_a'. The method consisted in measuring the length of curves b_i' for individual strips as a line following, in a subjective manner, possibly the deepest depressions in the cross section of a given strip. The average length of curvature of a bark sample b_a' was calculated as the arithmetic mean of the value b_i' calculated for all cross sections of a given bark sample. When using this method, formula 2 for the model surface takes the form:

$$A' = l_a \cdot b'_a \quad (6)$$

where A' is the model surface of a sample (cm^2); l_a is the average length of a side of a bark sample, parallel to the core of the tree stem (cm); b'_a is the average width of a sample, calculated with the subjective method (cm). Analogously, formula 1 for the calculation of the actual surface, described in the previous section, takes the form:

$$A'_d = A' \cdot C'_{sd} \quad (7)$$

where A'_d is the actual surface of a bark sample (cm^2); A' is the model surface defined by formula 6 (cm^2); C'_{sd} is the coefficient of development of the interception surface of bark, calculated as described further below.

The coefficient of development of the interception surface

The next stage, leading to the determination of the coefficient of development of the interception surface C_{sd} and C'_{sd}, consists in measuring the length of the contour lines d_i of particular cross sections of a given bark sample (Fig. 2). The length of the contour line d_i allows for the calculation of the degree of its distortion with respect to the length of the curvature b_i or b'_i of a given cross section. As a measure of this irregularity, one can regard the coefficient of development of the contour line of the cross section C_{ski} or C'_{ski}, calculated according to the formulas:

$$C_{ski} = \frac{d_i}{b_i} \quad (8)$$

or

$$C'_{ski} = \frac{d'_i}{b'_i} \quad (9)$$

where d_i is the length of the contour line of a given cross section of the bark (cm); b_i and b'_i are the lengths of the curvatures calculated according to the methods described above (cm).

Assuming that a bark sample was divided into the representative number of strips following the adopted rules, according to the authors the average value of the coefficient of development of the contour line of the cross section C_{sk} or C'_{sk} calculated for all cross sections sufficiently illustrates the differentiation of this feature for the entire surface of a given bark sample. Therefore, it is the coefficient of development of the interception surface C_{sd} or C'_{sd} that was regarded as the measure that describes the degree of differentiation of the outer bark layer of trees; it is determined by means of formulas:

$$C_{sd} = \frac{\sum_{i=1}^{n} C_{ski}}{n} \quad (10)$$

or

$$C'_{sd} = \frac{\sum_{i=1}^{n} C'_{ski}}{n} \quad (11)$$

where n is the number of cross sections of a given bark sample.

The values of the coefficients of development of the interception surface C_{sd} or C'_{sd} obtained in this way were used to calculate the actual surface A_d and A'_d of bark samples according to formulas 1 and 7.

Results and discussion

Measurements covered the total of 77 bark samples obtained from the stems of 8 species of living coniferous and deciduous trees at the height of DBH. The researchers collected: 10 samples of the bark of Scots pine (*P. sylvestris*), 11 samples of the bark of European larch (*L. decidua*), 10 samples of the bark of silver fir (*Abies alba*), 11 samples of the bark of Norway spruce (*P. abies*), 6 samples of the bark of sycamore maple (*A. pseudoplatanus*), 8 samples of the bark of silver birch (*B. pendula*), 10 samples of the bark of common oak (*Q. robur*), and 10 samples of the bark of European beech (*F. sylvatica*).

The lengths of the average curvatures b_a and b'_a of particular bark samples, calculated using the methods described in the research methodology, differ from one another. Among the consequences of these differences are also differences in the values of the parameters calculated with their application, such as the model surface A and A', the coefficient of development of the interception surface C_{sd} or C'_{sd} and the actual surface A_d and A'_d. Examples of these differences for selected bark samples are shown in Table 1.

It should be noted that despite the differences in the surfaces A and A', and in the coefficient of development of the interception surface C_{sd} or C'_{sd}, the actual surfaces of the samples A_d and A'_d assume similar values. This is due to the fact that a shorter length or curvature b_a or b'_a results in a higher value of the coefficient of development of the interception surface and vice versa: a higher length of the curvature results in a smaller value of the coefficient C_{sd} or C'_{sd}. Consequently, calculation of the actual surface A_d and A'_d using formulas 1 and 7 results in only a small difference

Table 1 Comparison of the parameters of selected bark samples defined by the length of curvatures b_a and b'_a calculated with various methods

Number of sample	a	b_a	b'_a	C_{sd}	C'_{sd}	A	A'	A_d	A'_d
Pine 3	8.87	8.02	7.46	1.53	1.65	71.14	66.17	108.84	109.18
Pine 6	11.99	9.43	8.73	2.27	2.44	113.07	104.67	256.66	255.40
Pine 7	15.31	8.94	9.05	2.21	2.18	136.87	138.56	302.49	302.05
Larch 3	9.50	8.79	8.82	1.88	1.87	83.51	83.79	156.99	156.69
Larch 6	9.81	9.30	9.02	2.05	2.17	91.23	88.49	187.03	192.02
Larch 8	10.76	7.89	7.67	2.22	2.28	84.90	82.53	188.47	188.17
Fir 4	9.35	7.52	7.43	1.01	1.01	70.31	69.47	71.02	70.17
Fir 8	13.46	6.25	6.28	1.29	1.29	84.13	84.53	108.52	109.04
Fir 10	14.51	9.33	9.41	1.45	1.43	135.38	136.54	196.30	195.25
Spruce 3	10.95	5,38	5.60	1.21	1.16	58.91	61.32	71.28	71.13
Spruce 4	8.62	6.63	6.95	1.49	1.42	57.15	59.91	85.15	85.07
Spruce 9	12.36	12.21	12.35	1.72	1.70	150.92	152.65	259.57	259.50
Birch 3	13.95	5.17	5.11	1.56	1.57	72.12	71.28	112.51	111.92
Birch 4	8.95	8.52	8.88	1.70	1.63	76.25	79.48	129.63	129.55
Birch 5	10.60	9.34	9.39	1.74	1.73	99.00	99.53	172.27	172.19
Oak 2	7.87	7.19	7.31	1.31	1.29	56.59	57.53	74.13	74.21
Oak 5	10.99	8.37	8.40	1.60	1.59	91.99	92.32	147.18	146.78
Oak 7	11.17	7.72	7.71	1.53	1.54	86.23	86.12	131.94	132.63
Beech 6	7.09	9.07	8.99	1.10	1.11	64.31	63.74	70.74	70.75
Beech 8	8.48	8.17	8.08	1.01	1.03	69.28	68.52	69.97	70.57
Beech 10	8.12	5.22	5.24	1.07	1.06	42.39	42.55	45.35	45.10
Maple 3	11.28	5.71	5.71	1.08	1.08	64.41	64.41	69.56	69.56
Maple 5	12.36	4.44	4.46	1.36	1.35	54.88	55.13	74.63	74.42

where a *is* the average length of the side of the sample parallel to the stem core (cm), b_a is the average length of curvature of the sample calculated from the geometrical relations (cm), b'_a is the average length of curvature of the sample calculated in a subjective manner (cm), C_{sd} and C'_{sd} are the coefficients of development of the interception surface of bark calculated using formulas 10 and 11, A and A' are the model surfaces of bark samples calculated using formulas 2 and 6 (cm^2), A_d and A'_d are the actual surfaces of bark samples calculated using formulas 1 and 7 (cm^2)

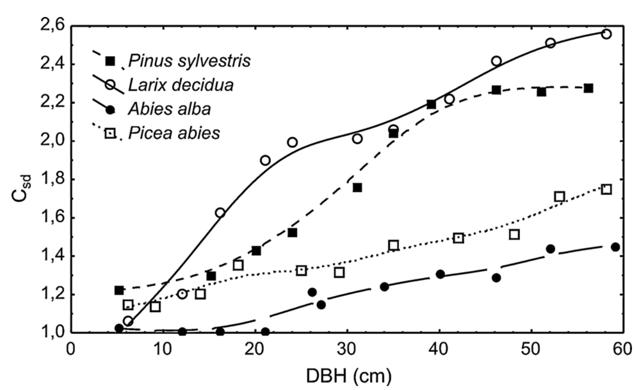

Fig. 3 A diagram showing the course of the coefficient of development of the interception surface of bark C_{sd}, in relation to the diameter at breast height (DBH) of trees of coniferous species

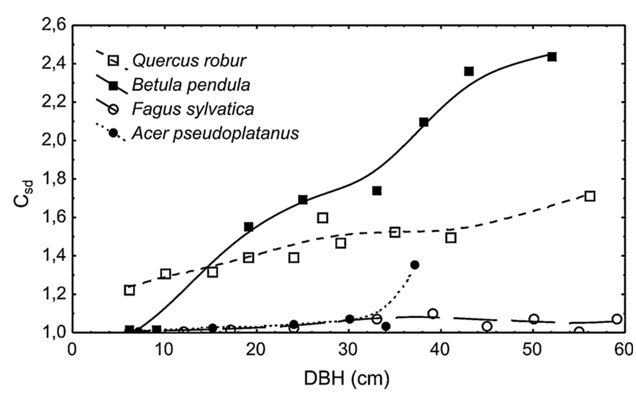

Fig. 4 A diagram showing the course of the coefficient of development of the interception surface of bark C_{sd}, in relation to the diameter at breast height (DBH) of trees of deciduous species

while it is the actual surface that constitutes the ultimate goal of the measurements (Table 1).

According to the authors, the method of calculating the length of curvature b_a using geometric patterns is methodically more correct than the second method in which the measurements are performed in a subjective manner. Therefore, the study results were elaborated using the values obtained from the measurements of the average length of curvature b_a using the first method. The second method may find practical application in the calculation of the surface of the bark of trees with an irregular cross section, in which the diameters measured at breast height in two directions are substantially different from one another.

The results of the present study show differentiation the coefficient of development of the interception surface of bark C_{sd} at the level of DBH not only between particular species, but also its variation within a single species (Figs. 3, 4). A feature that is common for most species is a significant increase in the coefficient C_{sd} with the age (diameter at breast height) of trees, thereby increasing the interception surface of the bark of the tree stem A_d. European beech *(F. sylvatica)* is an exception as its coefficient of development of the interception surface of bark C_{sd} shows little variation in relation to the age of the trees.

Among all species, the largest values of the coefficient C_{sd} characterize the bark of the thickest trees (Figs. 3, 4). Among the coniferous species, the highest values of the coefficient C_{sd} are reached by European larch *L. decidua*: 2.56 (DBH = 58 cm) and by Scots pine *P. sylvestris*: 2.28 (DBH = 56 cm), while among deciduous species—silver birch *B. pendula*: 2.44 (DBH = 52 cm). For coniferous species, the average values of the coefficient C_{sd} are reached by Norway spruce *P. abies*: 1.75 (DBH = 58 cm) while among deciduous species by common oak *Q. robur*: 1.72 (DBH = 56 cm). Relatively low values of the coefficient C_{sd} among coniferous species are reached by silver fir *A. alba*: 1.45 (DBH = 59 cm). The lowest values of the coefficient of development of the interception surface of bark C_{sd} are reached by European beech *F. sylvatica*: 1.07 (DBH = 59 cm). In the case of sycamore maple, the surface of bark in the younger age classes does not show large variation and its structure resembles the bark of European beech (Fig. 4). The coefficient of development of the interception surface of bark C_{sd} in young sycamore trees has values close to 1.00, while in thicker trees it can be seen that the bark surface is highly differentiated, the bark is more protruding and very fragile. The authors managed to capture the moment when the coefficient of development of the interception surface of bark C_{sd} in sycamore maple begins to differentiate. This moment coincides with the period when the trees reach the diameter of about 37 cm at breast height. The present study does not include data on the formation of the coefficient of development of the interception surface of bark C_{sd} in sycamore maple trees which are more than 37 cm thick because of the difficulty in collecting samples of the bark with its structure left intact. However, based on field observations, it can be concluded that the coefficient C_{sd} for old sycamore maple trees certainly assumes high values, similar to larch and pine. Calculation of the surface of the bark for older sycamore trees requires the development of special methods for the sampling of the bark.

Within particular species, the highest variation of the coefficient of development of the interception surface of bark C_{sd} characterizes *B. pendula, L. deciduas*, and *P. sylvestris*, in which the coefficients of variation are, respectively, 31.31, 25.12, and 23.47 % (Table 2). The smallest variation of the coefficient C_{sd} is shown by *F. sylvatica* (3.41 %).

Therefore, the species presented in the present study can be divided into three groups:

1. The group of species with the bark surface strongly growing with age of the trees. It includes: *P. sylvestris, L. decidua, B. pendula*, and *A. pseudoplatanus.*
2. The group of species with an average bark surface development with age. It includes: *P. abies, Q. robur*, and *A. alba.*
3. The group of species with the bark surface which develops only slightly with age. It includes *F. sylvatica.*

Analyzing the variability of the coefficient of development of the interception surface of bark $C_{sd,}$ with the age of

Table 2 Descriptive statistics of the coefficient of development of the interception surface of bark C_{sd} for individual species

Sspecies	*n*	Mean	Median	Min	Max	SD	CV (%)	R^2
P. sylvestris	10	1.83	1.90	1.23	2.28	0.43	23.47	0.92
L. decidua	11	1.96	2.02	1.07	2.56	0.49	25.12	0.91
P. abies	11	1.41	1.36	1.14	1.75	0.21	14.78	0.94
A. alba	11	1.20	1.22	1.01	1.45	0.17	14.05	0.90
Q. robur	10	1.45	1.44	1.23	1.72	0.15	10.15	0.84
B. pendula	8	1.74	1.72	1.02	2.44	0.55	31.31	0.96
A. pseudoplatanus[a]	6	–		–	–	–	–	–
F. sylvatica	10	1.05	1.03	1.01	1.10	0.04	3.41	0.30

where *n* is the sample size, *SD* is the standard deviation, *CV* is the coefficient of variation, R^2 is the coefficient of determination describing the dependence of the coefficient C_{sd} on the breast height diameter of trees

[a] Owing to the lack of data on the coefficient of development of the interception surface of bark C_{sd} for thick trees, the calculation of descriptive statistics was not performed

Scots pine, European larch, and silver birch (Figs. 3, 4), it can be seen that there are two inflection points. The authors put forward the hypothesis that one of them may occur after the culmination of the growth of tree height, while the other occurs after the culmination of the growth of tree thickness. However, this hypothesis requires verification during further studies.

The present research results constitute a proposal of calculation of the bark surface of forest tree stems by means of the coefficient of development of the interception surface of bark C_{sd}, describing the level of development of the outer surface layer of the bark. The values of the coefficients C_{sd} in the present study concern only the bark sections obtained at the breast height of trees and they cannot be used for the calculation of the actual surface of the bark of the whole stem. To determine actual surface of the bark of the whole stem, one should calculate the variability of the coefficient of development of the interception surface of bark C_{sd} for each species over the entire length of the tree stem, from its butt end to its top. These measurements may show large variations in the development of the coefficient C_{sd} within a single tree stem, and thus variation in the water capacity of the bark along the stem. This seems to be reasonable due to the variability of the coefficient C_{sd} with the age of trees within a single species (Figs. 3, 4). Similarly to the age of the trees, the coefficient C_{sd} should vary along the tree stems.

Obtaining the average values of coefficients C_{sd} depending on the age and species of trees will be of great cognitive and practical importance in the modeling of water processes occurring in forest ecosystems. Based on the average DBH and height of a stand, as well as the average values of the coefficients C_{sd} for the trees of particular species, it will be easy to determine the entire interception surface of the stem for whole stands. The application of this methodology for the calculation of the actual surface of twigs and branches along with the knowledge of the surface of the assimilation apparatus will allow for determination of the actual interception surface of stands.

Conclusions

The coefficient of development of the interception surface of bark C_{sd} allows for objective assessment of the degree of bark surface differentiation between different species.

The coefficient $C_{sd,}$ is a measure to differentiate bark morphology and indicates that each species has its own properties in the shaping of the surface whose development is dynamic and progresses with the age of trees.

Owing to the mathematical form of recording the degree of differentiation of the bark surface, the coefficient C_{sd} may be useful for modelling the hydrological processes occurring in forest ecosystems. As a measure of surface differentiation, it allows for obtaining certain calculation results when analysing water properties of the bark, thanks to which one can better interpret the interception processes of the bark of various species.

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