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Influence of morphometric parameters of relief on macro- and microstructure of wood *Pinus silvestris* L. in the North of the Russian plain

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Abstract: Pine grows in a variety of environmental conditions which form several of technical properties of wood. The purpose of this study is an analysis of the morphology and the structure (i.e., the annual ring width, the latewood content, the tracheid wall thickness of the early- and latewood) of pine wood growing in areas with different relief and soil condition. The annual ring width and the latewood content don't have a pronounced dependence on the relief. The tracheid wall thickness of early wood has a high degree of correlation with aspect, photosynthetically active radiation (PAR) and diurnal anisotropic heating – DAH (r = –0.81 to –0.88). The tracheid wall thickness latewood is highly correlated with topographic wetness index and profile curvature (r = 0.88). The relief parameters PAR and DAH, which characterize the distribution of insolation, have a high degree of correlation with the tracheid wall thickness of early wood. In the conditions of the middle taiga subzone the flat relief influences the microstructure of pine wood due to redistribution of heat and moisture.

Keywords: pine; relief; morphology and structure of wood; Arkhangelsk region

On the plains, the distribution of Scote pine has a mosaic character, reflecting the geomorphological, petrographic and soil diversity of landscapes. Pine is xerophyte. Features of the assimilation apparatus and the root system allow it to grow on very different soils: on Sands and sphagnum bogs with a multi-meter thickness of peat. On rich soils, pine is crowding out by spruce. At the moment, in the middle taiga subzone pine accounts for no more than 25% of the forested area. (Rysin, Savel'eva 2008).

Middle taiga subzone is typical for the European North of Russia. It accounts for 48% of forested land (33.4 million ha). Dark coniferous formations dominate, monotony and depletion of the species structure of the undergrowth are expressed. Undulating lacustrine-glacial plains with alternating ranges dominate. (Forests of the USSR 1966; Tsvetkov 2000).

Acid reactions of soil, groundwater, marsh waters, as well as the presence of free organic acids

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in soils are typical for taiga landscapes. Almost all processes occur with the participation of hydrogen ion. The deficit of many elements (primarily N, P, Ca, K, Na) is typical for the average landscape. Excess are Fe, Al, H (Tsvetkov 2000).

The limiting factor of growth of woody plants in the middle taiga are a lot of mean rainfall (395 to 570 mm) and low average annual temperature (–1.1 to 0.9°C) (Budyko 1968). This leads to strong moisture of the soil. The humidity factor is 1.33. Evaporating capacity is less than the amount of precipitation (Lvov, Ipatov 1976). In these climatic conditions, the main factors affecting the productivity of taiga ecosystems are lithological and geomorphological conditions. These include the composition of soil-forming rocks and the fertility of the soil associated with them, as well as the nature of the terrain, affecting the degree of moisture (Swain, Hillis 1959; Whittaker 1975; Bazilevich et al. 1986; Goryachkin et al. 2010; Gopp 2012; Neverov et al. 2017).

A number of works have been carried out to identify the importance of relief on the productivity of taiga landscapes (Sandlersky 2006; Sharaya, Sharyi 2011; Alekseev, Nikiforov 2014; Rahmatullina et al. 2017; Chernikhovsky 2017), as well as soil fertility (Gavva, Ryabinina 2010).

With the development of computer and aerospace technologies, digital terrain modeling has allowed quantitative modeling and analysis of the earth's surface topography, as well as the relationship between relief and other natural and anthropogenic components of geosystems (Hengl, Reyter 2009). The complexity of the tasks of scientific and practical research, the need to reduce the level of their subjectivity determined the transition from traditional morphometric methods to digital terrain modeling (Florinsky 2010). The aim of research is to study the influence of morphometric parameters of relief on the quality characteristics of pine wood (i.e., the latewood content, the annual ring width, the tracheid wall thickness of the early- and latewood).

MATERIAL AND METHODS

Study area. The research area is located in the middle taiga subzone in the Ust'yansky district of the Arkhangelsk region (Russia) (Fig. 1). The subject of the research are pine wood (*Pinus sylvestris* L.) selected from the permanent sample plots laid out in 2014–2016 in the typical forest types (bilberry pine, sphagnum pine, cowberry pine).

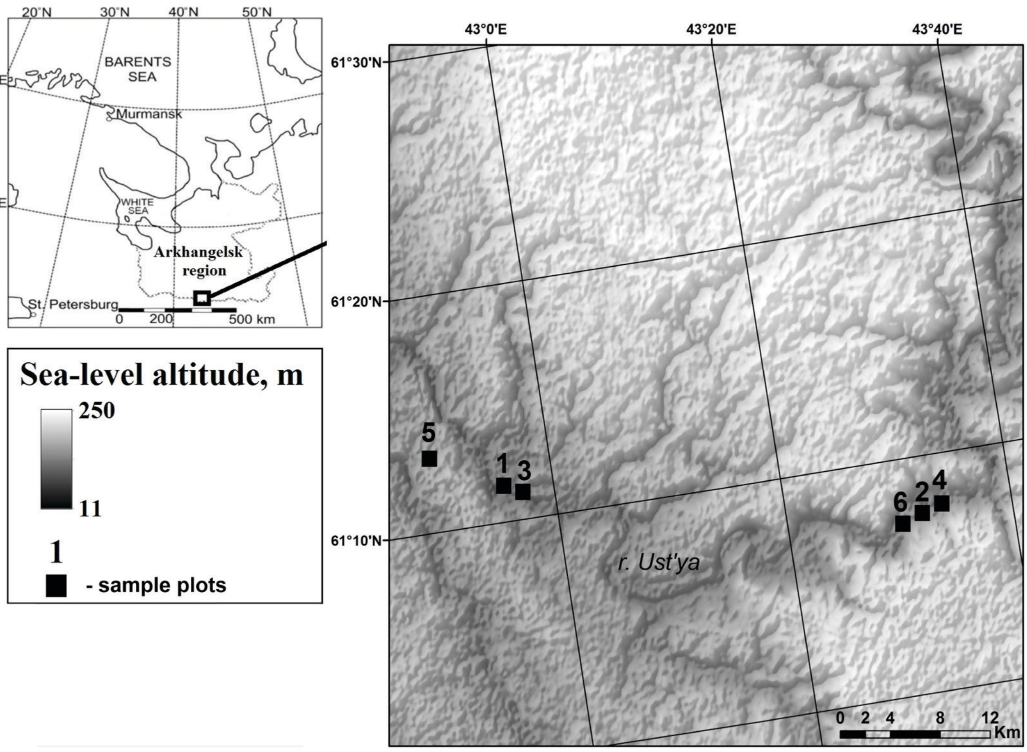

Fig. 1. Outline map of location of sample plots

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Table 1. Morphometric characteristics of the relief of sample plots

Sample plot	Altitude (m a.s.l.)	Slope (°)	Aspect	Topographic wetness index	LS factor	Photosynthetically active radiation	Diurnal anisotropic heating	Profile curvature
1	72	1.24	NE	12.6	0.44	329.7	–0.0181	0.00034
3	70	1.65	NE	12.5	0.75	330.2	–0.0163	0.00030
5	86	0.97	NE	11.5	0.01	330.6	–0.0136	–0.00051
2	86	1.43	SE	12.1	0.50	334.5	0.0117	0.00045
4	85	1.40	SE	12.1	0.52	333.9	0.0058	0.00011
6	81	1.39	SW	12.0	0.62	334.8	0.0240	–0.00024

Core samples were taken using an increment borer (Haglöf, Sweden) on normal trees without visible damage, perpendicularly to the tree trunk at a height of 1.3 m from the ground surface. In total, 30 cores were selected from each of the seven plots, following a south to north transect. The following macrostructure parameters were determined by these cores: the latewood content and the ring width were calculated in Lintab 6 (Rinntech, Germany) and the software TSAP-Win (Version 4.80, 2012) (Rinn 2003). The tracheid wall thickness of early- and latewood was measured in the microstructure of wood. For this purpose, wood samples of about one age of 0.5–1 cm were cut from 10 cores from each of the sample plots. Then they were placed in 96% ethanol for 3 months. After that, transversal sections were made on the microtome MS 2 with a thickness of 14 to 18 microns. Colouring of the sections was performed with a solution of safranin for 2–3 minutes (Furst 1979). The sections were used to measure 20 cells of early- and latewood in each visible annual layer (Yatsenko-Khmelevsky 1954) using a light microscope "Axioscope A1" with an increment dosing device (Zeiss, Germany). For each visible annual ring 20 cells of early- and latewood was measured. In total, 6 plots were laid. Sample plots 1, 3, 5 and 2, 4, 6 are located approximately in the same conditions of relief. The slope angle in the research area varies from 0.97° to 1.65°, the elevation values varies from 70.6 to 86.2 m. The predominant aspect is of the North-Eastern and South-Eastern slopes (Table 1).

The soil in the blueberry pine is podzolic medium loam, underlain by medium loam. The soil in cowberry pine is podzolic sandy loam, underlain by light loam. The soil in sphagnum pine is marsh peat soils. To carry out the research, a digital elevation model of the Arkhangelsk region was created on the basis of the free global digital elevation model ASTER GDEM (Version 2, 2011) (Mineev et al. 2015).

Geomorphometric parameters were calculated in SAGA GIS (Version 6.4.0, 2018). Raster maps of slope and aspect were built. Then a vector layer of sample areas was applied on these maps, and for each area the values of the relief parameters were extracted. To assess the impact of relief on pine wood, 3 main attributes (slope, aspect, profile curvature) and 4 calculated (topographic wetness index, LS factor, photosynthetically active radiation, diurnal anisotropic heating) were selected. Slope is a fundamental geomorphometric parameter, which is naturally associated with surface runoff, drainage, erosion, power profile of the soil, the amount of solar energy, it determines the microclimatic features of the site (in particular temperature, evapotranspiration and humidity of the upper soil layers) (Zevenbergen, Thorne 1987). Aspect is the clockwise angle between the North direction and the slope projection on the horizontal plane, it determines the main direction of the current lines (the movement of water or other material down the slopes), the orientation of the site in relation to the flow of sunlight, the amount of solar radiation received by the earth's surface, it affects the local climate (Zevenbergen, Thorne 1987). Topographic wetness index (TWI) is an indicator of soil hydromorphism, which is largely determined by the terrain features of the territory, it allows to assess the prerequisites for the development of wetlands and the development of waterlogging processes (Hengl, Reuter 2009). LS factor is the topographic index, called the factor length and steepness of slopes, or index of potential plane of erosion (Moore et al. 1991). Photosynthetically active radiation (PAR) is part of the biocenosis of solar radiation in the range from 400 to 700 nm, used by plants for photosynthesis (Tooming, Gulyaev 1967). Diurnal anisotropic heating (DAH) is a dimensionless index showing which slopes will have more heat and which slopes will have less heat, taking into account the

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asymmetry of the daily energy balance (Böhner, Antonić 2009). Profile curvature (PROFC) is the curvature of the line formed by the intersection of the earth's surface and the vertical plane, it determines whether the slope is convex or concave, and characterizes the flow rate and other accumulation processes (Moore et al. 1991). These indicators were calculated by Eqs. 1–7:

$$\text{SLOPE} = \arctan\left(\sqrt{G^2 + H^2}\right) \quad (1)$$

where:
G – angle of slope from east to west,
H – angle of slope from south to north.

$$\text{ASPECT} = 180° - \arctan\left(\frac{H}{G}\right) + 90° \times \left(\frac{G}{|G|}\right) \quad (2)$$

$$\text{TWI} = \ln\left(\frac{A}{\tan(\beta)}\right) \quad (3)$$

where:
A – specific catchment area,
β – local angle of slope.

$$\text{LS} = \left(\frac{As}{22.13}\right)^m \times \left(\frac{sin\beta}{0.0896}\right)^n \quad (4)$$

As – specific catchment area,
m = 0.4–0.6,
n = 1.2–1.3.

$$\text{PAR} = 0.42 \times S + 0.60 \times D \quad (5)$$

S – total daily direct insolation,
D – total daily diffuse insolation.

$$\text{DAH} = \cos(\alpha_{max} - \alpha) \times \arctan(\beta) \quad (6)$$

α_{max} – exposure of the slope at which the maximum excess heat is observed,
α – slope exposure.

$$\text{PROFC} = \frac{\left(\frac{\partial z}{\partial y}\right)^2 \frac{\partial^2 z}{\partial x^2} + 2\frac{\partial z}{\partial x}\frac{\partial z}{\partial y}\frac{\partial^2 z}{\partial x \partial y} + \left(\frac{\partial z}{\partial x}\right)^2 \frac{\partial^2 z}{\partial y^2}}{\left(\left(\frac{\partial z}{\partial x}\right)^2 + \left(\frac{\partial z}{\partial y}\right)^2\right)\sqrt{\left(\left(\left(\frac{\partial z}{\partial x}\right)^2 + \left(\frac{\partial z}{\partial y}\right)^2\right)\right)^3}} \quad (7)$$

$\frac{\partial z}{\partial y}$ – partial derivative of the earth's surface function from North to South,
$\frac{\partial z}{\partial x}$ – partial derivative of the earth's surface function from West to East.

The taxation characteristics of the studied stands are also approximately the same (Table 2).

Table 2. Taxation characteristics of studied stands

Sample plots	GPS	Height (m)	Norm	Stand composition	Age (yr)	Site index
Bilberry pine forest						
1	61°11'45''N 42°56'7''E	17	0.8	7P3F+B	65	IV
2	61°7'31''N 43°31'4''E	19	0.7	8P2F	80	IV
Sphagnum pine forest						
3	61°11'42''N 42°56'14''E	12	0.6	10P	90	Va
4	61°7'32''N 43°31'8''E	10	0.4	10P	100	Va
Cowberry pine forest						
5	61°13'14''N 42°49'34''E	18	0.7	8P2B	80	III
6	61°7'31''N 43°30'40''E	18	0.7	8P2B	70	III

P – pine-tree, F – fir-tree, B – birch-tree

Statistical analyses were performed using the Python software (Version 2.7.12, 2016), package Sci Py (Version 0.18.1, 2016).

RESULTS AND DISCUSSION

The highest latewood content was noted in the cowberry pine (SP5) and the highest annual ring width in the cowberry pine (SP6). The tracheid wall thickness in early- and latewood does not differ in bilberry and cowberry type forest (Table 3). These values are typical for pine wood of the middle subzone (Melekhova 1954; Koperin 1955; Vikhrov, Lobasenok 1963; Wood 1985), as well as for pine growing in Sweden at the same latitude (Karlman et al. 2005).

The smallest values of the annual layer width and cell wall thickness in early- and latewood were observed in sphagnum pine. This is due to the fact that the depth of groundwater in this type of forest ranges 0–0.2 m (Viktorov, Remezova 1988), which is a negative factor of the crane and leads to severe stress and slow growth of the tree.

The annual ring width and the latewood content don't have a pronounced dependence on the relief. The tracheid wall thickness of early wood has a high degree of correlation with aspect, PAR and DAH (r = –0.81, –0.88). The tracheid wall thickness latewood is highly correlated with TWI and PROFC (r = 0.88) (Table 4).

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Table 3. Indicators of macro - and microstructure of pine wood

Sample plot	Mean latewood content (%)	Mean annual ring width (mm)	Tracheid wall thickness (μm)	
			earlywood	latewood
1	25.3 ± 0.73	0.75 ± 0.02	3.22 ± 0.04	8.01 ± 0.05
2	25.5 ± 0.86	1.12 ± 0.05	2.86 ± 0.04	7.45 ± 0.05
3	23.4 ± 0.45	0.54 ± 0.03	3.15 ± 0.06	4.11 ± 0.10
4	22.8 ± 0.76	0.59 ± 0.03	2.79 ± 0.06	3.64 ± 0.09
5	27.4 ± 0.70	1.00 ± 0.03	2.86 ± 0.07	7.51 ± 0.04
6	22.8 ± 0.54	1.50 ± 0.06	2.64 ± 0.07	7.16 ± 0.07

Table 4. Spearman correlation coefficient of morphometric relief indices of sample areas and macro-microstructure of pine wood

Morphometric relief indices	Latewood content	Annual ring width	Tracheid wall thickness	
			earlywood	latewood
Slope	–0.31	–0.37	0.02	0.31
Aspect	–0.54	0.54	**–0.81**	–0.60
TWI	–0.2	–0.65	0.66	**0.88**
LS factor	–0.77	–0.25	–0.26	–0.02
PAR	–0.54	–0.54	**–0.81**	–0.60
DAH	–0.37	0.71	**–0.89**	–0.77
PROFC	–0.6	–0.08	0.69	**0.88**

TWI – topographic wetness index, PAR – photosynthetically active radiation, DAH – diurnal anisotropic heating, PROFC – profile curvature; differences at the significance level α = 0.05 are in bold

Air and soil temperature is a limiting factor in the formation of the annual ring in the taiga zone (Melekhova 1954; Danilov 1986). The temperature of the May–July period affects the ring width and the tracheid wall thickness in earlywood, and the temperature of the air and soil of the August-September period affects the ring width and tracheid wall thickness of latewood (Melekhova 1954; Tardif et al. 2001; Wooda et al. 2016).

The mechanical composition of the soil has a significant effect (Russell 1950). However, the type of forest is determined by soil conditions, first of all, the depth of the groundwater. The groundwater depth is 3–5 m in the cowberry pine forest, the depth is up to 2 m in the blueberry pine forest, the depth is 0–0.2 m in the sphagnum pine (Viktorov, Remezova 1988).

CONCLUSIONS

In the study area, the slope is low (no more than 2 degrees), respectively, the curvature of the surface is poorly expressed in the relief. Therefore, the most important geomorphometric parameters are the aspect and profile curvature, which is the basis for calculating PAR and DAH.

The relief parameters PAR and DAH, which characterize the distribution of insolation, have a high degree of correlation with the traheid wall thickness of early wood. This confirms that the temperature of air and soil are the limiting factor in the growth of woody plants in the taiga zone.

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