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Impact of forest growth conditions on the wood density: the case of Amur Region

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Abstract

The problem of determining the dependence of the chainsaw on the density of wood, substantiation of effective options for the number of chainsaws in the assortment and whiplash method of logging is quite relevant. In the Far East of Russia, in particular, in the Amur region, the forest growth conditions are different from the western ones, and therefore, the properties of the wood differ from the generally accepted ones. The article describes forest growth conditions that influence the properties of the wood in areas of the Amur region. Using the method of density determination, the density of larch, pine and birch were studied for first time in the areas of the region. The dependence of the density on humidity, age, species, season of the year and the area of growth was found out. The results of the research showed that under humidity of 70%, the density of larch was 1088.99 kg/m^3, it was 919.8 kg/m^3 for pine and it was for birch 915.9 kg/m^3.

Key words

forest growth conditions of the Amur region, Amur region, wood density, Dahurian larch, Scots pine, Asian white birch, wood moisture content

Introduction

In modern conditions of economics, the manufacturing of ecologically safe products, such as products made of wood, is an important theme for entrepreneurs and investors (Wang et al. 2000). While harvesting and processing wood, it is necessary to take into account the following factors: the thickness of trees in the forests in use and the number of trees per unit area; the lay of the land on which the trees in use grow and are subjected to harvesting, soil conditions (type and properties of soil, ground bearing capacity, and so on) and seasons of the year (Kostenko 2012).

The Amur region refers to heavily forested territories, its forest cover is 64%; the forests on the whole territory are mountainous, more than a half grows on the perpetually frozen ground, others are on the soils with a long-term seasonal frozen ground (Romanova and Sorvina 2017; Yaborov 2005). Annual layers affect the chemical composition of cells, and they, in turn, affect the composition of the soil and climate in the area of larch growth (Earle 2011). The density of larch at 12% moisture content is 665 kg/m^3, pine 505 kg/m^3 and

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birch 640 kg/m^3 (Yaborov 2005). The relative density of pine wood in different forest conditions depends on its anatomical characteristics and is 0.340…0.580 g/cm^3 (Ugolev 2002). There is a dependence of the density of wood and the width of the annual ring on the age of wood (Fries and Ericsson 2006). The influence of stand density on the growth of trees and qualitative characteristics of wood in plantation pine species in China has been studied (Kang et al. 2004).

The total stock of wood is assessed to be 1.9 bln. m^3 (mature and overmature forest is 50.4%), including 1.5 bln. m^3 of coniferous species. The total rated wood-cutting is 17.7%, including 9.6 mln. m^3 of really available forest development. The total area of forests of the region is 28.3 mln. ha with the wood volume of almost 2 bln. m^3 or 17% from the area of forest of the Far East. The forest area is 64.4%, the supply per head is 19.2 ha of forests and 1.9 thousand m^3 of the wood (Yaborov 2005). The forest cover or the ratio of forest land to total land area is found by the ratio of the forest cover area to the total land area and expressed as a percentage. The value of the forest cover in separate areas of the Russian Federation is different and depends on physiographical, climatic and soil conditions. The dynamics of the forest cover is under influence of anthropogenic activities and natural calamities that lead to the forest destruction. Thus, the aim of the research is to study the influence of forest growth conditions on the density of the wood in the logging areas of the Amur region.

Material and methods

For experimental studies, the species of the wood were taken from those regions where the assessment of the forest cover was higher. By this criterion, the following areas were chosen: Zeysky, Skovorodinsky, Magdagachinsky, Selemdzhinsky and Shimanovsky. With average forest cover, Svobodnensky and Bureysky areas were chosen. The average forest cover in these areas was 46–47% (Yaborov 2005). To provide the continuous use of timber in the region, the proportion of mature, overmature and maturing forests must be at the level of 10–15% (Yaborov 2005). In the experimental studies, those species of trees were involved that have a high percentage of timber stand in the region. Among the coniferous species, there is Dahurian larch, the Scots pine and among the broad-leaved trees, there is the Asian.

Dahurian larch (*Larix gmelini* (Rupr.) Rupr.) is a unique tree that grows in almost all forms of the land form and it grows in the mountains till 2–2.5 thous. meters. Pure forest stand is formed only in the conditions unfavourable for other species: swamps, frozen grounds and steep hills. In all other types of soil, it grows together with pine, spruce and birch. The tree of the first size grows till 35 meters of height and 1.5 meters in diameter. The body of the tree is straight, tapered and usually it is longbutt. The bark is light-grey; while young, it is thin pellety, while old it is thick, reddish and fissured. It lives up to 500 years old and more. The tree crown is cone-shaped or pyramidal and crumby. The needle foliage is light green, soft and short; 20–60 needles in the bunch drop annually. The network of roots is deep in freshly drained soils and over the ground in swamped and frozen ones. The average value of the density of the larch wood under standard humidity (12%) is 665 kg/m^3; at dry conditions, it is 635 kg/m^3 and the average basic density is 540 kg/m^3. The density of the larch wood strongly depends on the type and place of growth. The larch lumber that has the highest density wood grows in Altai (12 = 725 kg/m^3), in Ural and Cis-Ural areas (12 = 675 kg/m^3). The least density wood is typical for the European larch (12 = 506 kg/m^3) (Yaborov 2005; Earle 2011; Besschetnov et al. 2018).

The Scots pine (*Pinus silvestris* L.). This species is one of the most wide-spread species that grows in the Amur region. It takes 487.5 thous. ha, and it grows in Tygdinsky, Tyndinsky and Zeysky forest areas. It grows in different types of land area: from flood beds of rivers till mountain peaks. Technical characteristics of the pine: density is 513 kg/m^3, density in the fresh wood is 625 kg/m^3, specific gravity is 0.51; ultimate static bending strength of wood is 71.8 Mpa, compressive strength along the grain of wood is 34.8 Mpa, ultimate tensile strength along the grain of wood is 84.1 Mpa (data taken at humidity of 12%; 1 MPa = 1 n/mm^2) (Wang et al. 2000; Fries and Ericsson 2006; Kozlov et al. 2009; Peltola et al. 2009). Asian white birch *(Betula platyphylla* Sukacz*)* grows in all soils, survives in excessive soil water and grows well in dry soils of mountain slopes. In poor soils, it forms almost pure stands, in most cases of secondary origin. In relatively rich soils, there are mixed forests of spruce, pine, oak, aspen, and so on. In good soils, it reaches up to 27 m in height and up to 60 cm in diameter. It lives to 150 years old, sometimes up to 250 years old. The trunk is straight with a wide, spreading and loose crown. The shoots bark is smooth dark, the bark of branches and of the top of the trunk is white (birch bark). At the bottom of the trunk, the bark gets dark, almost black and fissured when the tree gets older. The leaves are light green, the root system is shallow. Properties of birch wood: the density is 0.63 g/cm^3, the mechanical hardness is 40–48 MPa, flexural strength is 80–90 MPa, the compressive strength is 45–55 MPa, impact strength is 70–80 J/m^2 and the wear by abrasion is 0.5–0.6 mm (Givnish 2002; Yaborov 2005; Moser et al. 2015; Dyachuk 2018).

The forest-growing conditions of wood include the climate of the region with sunlight, average air temperature, precipitation, air humidity, wind speed and soil composition. The temperature and light conditions and water availability necessary for the development of plants and limiting their geographical distribution depend on the climate. The coldest areas of the Amur region are Tyndinsky, Skovorodinsky (north-west of the region) and Selemdzhinsky (east of the region). The warmest place in the region is the south-west adjacent to the Amur river. This area includes Blagoveshchensk and Poyarkovo. In the cold seasons, the weather is clear; the Amur region takes one of the first places in Russia by the number of sunshine hours in the winter (Yaborov 2005). In spring, in the Amur region, dry winds are often observed. Often dry winds are accompanied by dust or sand storms. Summer is moderately hot, in the north, it is warm with high clouds and significant rainfall. The rainiest months of the year for the whole region are July and August: 40–50% of annual precipitation falls during these two months. Amur autumn is the shortest season of the year. The period with average daily temperatures below +15°C, but above zero, lasts an average of 40–45 days. In the first half of October, in the north of the region, the average daily temperature drops to sub-zero; in the south, it occurs at the end of October, and this means the beginning of winter.

The second ten-day period of September is the average date of the first autumn frosts. Once every 3–4 years, early frosts in early September destroy the crops. This causes a huge damage to the agriculture of the region. The first snow in the north of the region falls in September; in the south, it falls in the first half of October, but sometimes, the first snowflakes can be seen in the second ten days of September even in the south. The conditions for soil formation in the Amur region are characterized by a number of features: 1) cold, snow-free winter contributes to deep freezing of the soil; 2) cold, dry, prolonged spring slows down the thawing of the soil and the development of plants; 3) warm and rainy summer (in July and August, half of the annual rainfall falls) leads to waterlogging.

Meadow black soils develop on brown clays of river and lake origin, under meadow and meadow-marsh grassy vegetation. They are characterized by high fertility, the humus horizon is 20 to 40 cm and sometimes 50 cm. The humus content in the top is 4 to 8%. By colour, structure and fertility, they resemble the black soil of the European part of Russia. Therefore, the first researchers of the nature of the Amur region and immigrants called them ‘Amur black soils’ (Yaborov 2005). In the areas where the forest cover is the highest, brown-taiga and mountain-brown-taiga soils prevail. These soils are most favourable for the growth of larch and pine. Thus, the richer the soil is, the more nutrients the wood gets, it becomes looser, the annual rings become wider, and accordingly, its density and weight get less. However, logging companies seek to treat the wood, which in a small volume will be heavier. Therefore, the worse the soil of wood growth is, the more profitable it is for loggers.

The density of wood is characterized by the ratio of its mass to volume. In laboratory conditions, the density of wood is determined by the samples of rectangular cross-section of 20 × 20 mm in size and height (along the length of the fibres) of 30 mm (all-Union State Standard 16483.1-84). The mass is determined by weighing on an electronic scale with an error of up to 0.01 g, the linear dimensions by a calliper of accuracy class 2, an error of up to 0.01 mm (GOST (all-Union State Standard) 2005). The volume is calculated as a product of the results of measurements of width, thickness, and height, and expressed in fractions of cubic meter (m^3). In addition, the volume can be measured by the device – a volume meter by the sample displaced liquid (mercury) not wetting the wood. The sample may have an irregular geometric shape.

The density of wood depends on the humidity, and to compare, the density values are always made by single humidity. The density, as well as all the other indicators of physical and mechanical properties of wood, should be reduced to a standard humidity of 12% (ρ 12%).

For calculations, the density of wood is sometimes used in a completely dry state: in this case, the weight and volume of wood are measured after the sample is dried to a moisture content of zero.

For some purposes, it is convenient to use a value called the conditional density of wood ρ_{cond}. This indicator is calculated as the ratio of the sample mass in a completely dry state to the sample volume at the hygroscopicity limit ($W_{h.l.}$ = 30%). The relative density of wood does not depend on moisture. Determine the conditional density as follows: the sample is kept in water until it acquires a constant size and determine its volume V_{max}. The sample is then dried to a dry state and the mass m_0 is determined by weighing. The formula is used to calculate the conditional density:

$$\rho_{cond} = m_0/V_{max}$$

where:

m_0 – the mass of the wood sample in a completely dry state, kg;

V_{max} – the volume of the sample at humidity above the hygroscopicity limit, m^3.

The conditional density is determined as follows: the sample is kept in water until it acquires a constant size and then its volume V_{max} is found. The sample is then dried to a dry state and the m_0 mass is determined by weighing. By dividing the mass by the volume of the sample, the conditional density is calculated. With increasing moisture content, the wood density increases. Within the annual layer the density of wood is different: the density of late wood is 2–3 times greater than the early one. Therefore, the better developed the late wood is, the higher its density becomes. Heavier wood is more durable. Density is the amount of wood substance in unit volume. The amount of wood substance is directly dependent on the size of the anatomical elements that perform a mechanical function in a living tree. By the density at humidity of 12%, the wood species can be divided into three groups: species with small (540 kg/m^3 or less), medium (550–740 kg/m^3) and high (750 kg/m^3 and above) density.

According to the All Union State Standard 6483.1-84, experimental studies were conducted on the density of wood of different species growing in the Amur region at normalized humidity. Samples were made in the form of a rectangular prism with a base of 20 × 20 mm and a length along the fibres of 30 mm. If the annual layers were more than 4 mm wide, the cross-sectional dimensions were increased so that the sample included at least 5 layers. The method of random selection, using an independent randomizer, for example, using a random number generator (a simple application for a smartphone) was used to determine the variability of the investigated features with the greatest accuracy. The minimum number of samples in a series for one location is 16. As a sample from the log, a core board was cut at least 60 mm thick, with the condition that the geometric centre of the ridge pass through the cut out board. According to the experimental data, diagrams of the wood density dependence on various forest growth factors were made. The studies were conducted in different seasons: winter and summer (GOST (all-Union State Standard) 2005; Romanova and Sorvina 2017; Dyachuk 2018). In the process of experimental studies, samples were taken from the butt part of the wood. The number of trees, selected for sampling in each area was 50, the number of samples of 10 for each species of wood from each district of the region, the trees corresponded to the 5th class of age. The age of the tree was determined by the annual rings when harvesting it directly on the cutting area. The age of these trees ranged from 65 to 110 years. The total number of samples from each sampling region was about 200.

Results and discussion

Having studied the dependence of density on moisture (through the example of larch, pine and birch growing in Tynda area), it was concluded that the higher the moisture content of the wood was, the greater its density became. So, at t humidity of 20%, the density of larch was 777.85 kg/m^3, of pine it was 688.12 kg/m^3 and of birch it was 519.11; at humidity of 70%, the density of larch was 1088.99 kg/m^3, of pine it was 919.8 kg/m^3 and of birch it was 915.9 kg/m^3; when the humidity was 120%, the density of larch was 1404.97 kg/m^3, of pine 1186.69 kg/m^3 and of birch 1181.66 (Ugolev 2002). Thus, the wood species influences its density. Larch wood had the most density, birch had the least among the studied.

Pine is the species that has an average density, though its density is slightly greater than that of birch.

Having studied the dependence of the density of wood on age and species (through the example of Tyndinsky area), it was found out that the older the tree was, the greater its density was. The density of larch that has grown to 110 years old is 1089 kg/m^3 at average humidity, which is 210 times more than the density of larch that is 65 years old. The corresponding dependence was obtained in other areas of the region (Kostenko 2012; Romanova and Sorvina 2017; Dyachuk 2018).

Having studied the dependence of the density of wood on the area of growth, it was found out that the further to the north the area is located, the more density the wood has. Using the trend line, the linear dependence equations were made. For larch, the equation is $y = -72.44x + 1156.9$, the coefficient of determination is 0.972. For birch the equation is $y = -84.375x + 1071.5$, the coefficient of determination is 0.9265. For pine the equation is $y = -73.878x + 973.09$, the coefficient of determination is 0.9648. The coefficient of determination is close to one, which indicates a direct relationship between the density of wood and the area of its growth.

Having studied the dependence of the density of wood on the time of year, it was found out that the same species of wood of the same age growing in the same area have greater density in winter than in summer. Larch growing in Tyndinsky area has the density of 1088.99 kg/m^3 in winter and 968.99 kg/m^3 in summer. Thus, the density of wood depends on the species, humidity, age, the climate of the environment, that is, the area of growth, and the time of year.

In a variety of reference books, the density of such species as birch, pine and larch is taken to be 890, 720, 930 kg/m^3, respectively, at humidity of 70% (Ugolev 2002; Tyukavina 2017). In our studies, these values range from 402 to 1088 kg/m^3. In each area, the density of wood has its own values, which allows to choose the logging equipment that is different in capacity and cost. The data on the density of wood scattered from the South to the North. In the South, the density is lower than the conventional data; in the North, it is higher (Fig. 1).

According to the experimental data, the dependence equations and the validity coefficient are made: for larch, it is $y = -48.162x + 1087.8$, R2 = 0.9242; for pine, it is $y = -84.375x + 1071.5$, R2 = 0.9242; for birch, it is $y = -73.878x + 973.09$, R2 = 0.9648. The validity coefficient is close to one, which indicates a high convergence of the results (Zaki and Meira 2014; Romanova and Baranov 2016).

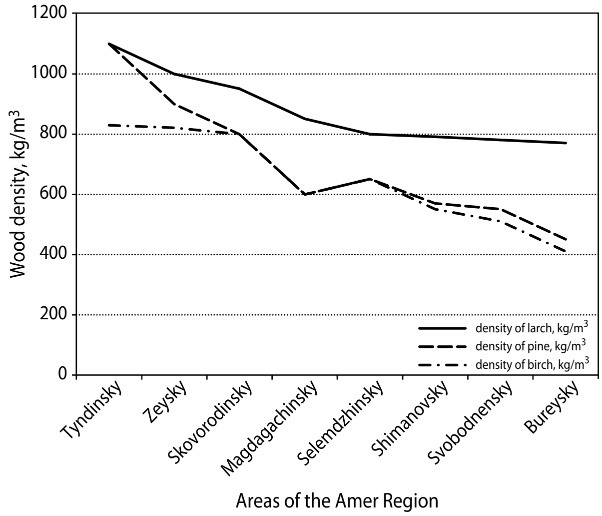

Figure 1. Wood density dependence on the areas of the Amur region

Comparing the data generally accepted and the data under studies, it can be concluded that the average data received during the research are lower by 59, 28 and 249 kg/m^3 in larch, pine and birch, respectively. The data varies from area to area. This is due to the different forest vegetation conditions (temperature, relief, soil, humidity, etc.) and the types of tree species (Daurian birch, Asian white birch), age, as well as different seasons, in which studies were conducted (winter, summer).

Density of wood depends on many factors, including forest growth (Ugolev 2002). Each breed has different density (Kang et al. 2004). Larch has 415…635 kg/m^3 (Fries and Ericsson 2006; Earle 2011), pine has 415…505 kg/m^3 (Fries and Ericsson 2006; Peltola et al. 2009), birch has 520…640 kg/m^3 (Kostenko 2012; Romanova 2017; Dyachuk 2018). In the Northern subzone of the taiga, the conditional density of pinewood is 0.340…0.580 g/cm^3 (Tyukavina et al. 2017).

Experimental studies have found that in each area of wood growth, under different forest conditions, the density of the same wood is different, and it does not meet the generally accepted standards and has a large run from the North to the South. In our study, the densities of the larch range from 745 to 1088 kg/m3, the density of pine from 435 to 1081 kg/m3, the density of birch from 402 to 878 kg/m3. In each district, the density of wood has its own values, which allows us to select the logging equipment of different capacities and cost. The object of research is the forest plantations of the Amur region. The initial data for the statistical analysis are the data of 8 districts of the region and the database consisting of the taxation characteristics of forest plantations. Using the module 'classification and regression trees' in the STATISTICA environment, the cluster analysis of the main forest growth factors affecting the density was carried out (Stanturf and Madsen 2004; Zaki and Meira 2014; Moser et al. 2015).

Conclusion

Studies of the effect of forest growth conditions on the density of wood in the Amur region have shown that the further to the north the area of wood growth is, the greater its density becomes. The density of wood was found out for the first time. The density of larch at humidity 70% is from 530 kg/m^3 in the southern areas to 1089 kg/m^3 in the northern areas, the density of pine is from 435 kg/m^3 to 1002 kg/m^3, the density of birch is from 400 kg/m^3 to 830 kg/m^3. Experimental studies have confirmed the main factors affecting the density of wood: the area of growth, season (winter, summer), species, age and wood moisture. Among the three main logging species of wood, larch has the greatest density, that is. 1088.99 kg/m^3, pine has the density of 1081.28 kg/m^3, and birch 878.23 kg/m^3. Thus, we recommend that to determine the volume (mass) of wood (e.g., for export abroad of the Russian Federation through customs) use not the average density, but the density that corresponds to the area of growth.

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