Introduction of pedunculate oak in the conditions of the northern border of the range

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Abstract. The problem of increasing the biological diversity of taiga forests has recently been particularly relevant. One solution is the widespread introduction into the culture of dendroflora species growing on the border of their range. For the southern taiga vegetation region, English oak (Quercus robur) can become promising in this respect. The dendrological garden of the Vologda GMHA acted as an object for research. During the evaluation of dendrometric indicators, the presence of significant annual increases in height was established. There is a slight frosting of annual shoots. The winter hardiness score corresponds to I-II. Photosynthetic pigments in the assimilation apparatus of the plant are normal. The presence of generative development indicates naturalization. Seeds of the 1st quality class will ensure the production of seed material.

1. Introduction

Representatives of the nemoral dendroflora are often found in the forests of the southern taiga forest region. Often trees acquire the life form of a shrub and are part of the undergrowth of pine and spruce stands. Interest in extrazonal flora is steadily growing, both from the industrial and scientific communities. The study of broad-leaved species in boreal forests has become especially important in recent years, when active work is underway to increase their productivity and biological diversity.

One of the promising species for advancing to northern conditions is the pedunculate oak, the range of which is changing, including as a result of spontaneous introduction. Currently, in most literary sources [1-4], the northern border of the common oak distribution runs along the line of the Karelian Isthmus (Otradnoye station) - the eastern shore of Lake Ladoga - Tikhvin (south of the Svir River) - the Vologda region (Cherepovets) - Kirov region - Cis-Urals - Perm and Sverdlovsk regions.

The purpose of the research is to study the growth and fruiting of English oak in the conditions of the northern border of the range. The plantings of this species in the dendrological garden of the Vologda State Museum of Art and Culture act as an object of research.

The dendrological garden is located in the Vologda region, on the territory of which there is experience in growing oak both at production facilities [5-6] and in landscaping [4;6]. But all the above studies are devoted to adults, often with an unknown origin of planting material.

In the framework of this study, plant specimens of the second generation of introduced species are used. Seeds for sowing were taken in cultural plantings on the territory of the Vologda region.
The dendrological garden is located in the southern taiga zone, which is characterized by an average annual air temperature of 2.2 °C, and the duration of the frost-free period is 116 days, the period with an average daily temperature above 5 °C is 159 days. The depth of soil freezing is 67 cm. The average temperature of the warmest month (July) is 17.5°C, the coldest (January) is minus 10.7°C. The amount of precipitation for the year is 566 mm. The soils are sod-medium podzolic, light loamy. For plantings of English oak, regular agrotechnical care is carried out in the form of mowing the grass, and during the first 5 years of growth, the tree trunks were loosened.

2. Materials and methods
To establish dendrometric indicators, the diameter and height were measured. The diameter was determined using a Kromatech digital caliper in two mutually perpendicular directions at a height of 1.3 m from the root neck. Height was measured using a pole and a measuring tape.

Winter hardiness was determined according to the GBS RAS scale. The content of sugars and starch by laboratory experiments. Why were wood samples taken from annual shoots in the autumn-winter period and cuts were made. Starch was determined by staining, sugar content according to the Molisch method.

When studying photosynthetic pigments of leaves, samples were taken from the middle part of the crown in the middle of the day, when the content of pigments is maximum (from 11-14 hours). The collected material was crushed, weighed on an Ohaus SPS402F electronic balance, and an alcohol extract was prepared. The content of pigments was determined using a KFK-2 photocolorimeter. Chlorophyll a was determined in the spectral range of 665 nm, chlorophyll b - 649 nm, carotenoids - 440.5 nm.

Acorns were harvested in September, after full maturation, which was determined by the presence of the corresponding color. Germination was carried out in boxes with sand, immediately after collection, according to the method given in GOST-13056.6-97, GOST-13056.8-97 [7-8].

Statistical indicators were determined using computer programs Statistica 7.0 and CurveExpert.

3. Results and Discussion
Pedunculate oak is grown from seeds in the sowing department of the nursery of the dendrological garden. At the age of 5 years they were planted in a row planting, the distance between plants in which is 3 m. At the moment, the trees are 16 years old. They have entered the stage of generative development. Their dendrometric parameters are shown in table 1.

| Indicator        | Average | Measurement limits | Standard deviation | The coefficient of variation, % |
|------------------|---------|--------------------|--------------------|--------------------------------|
| Diameter cm      | 8±0.25  | 4-12               | 2.24               | 28.0                           |
| Height, m        | 4.9±0.11| 2.9-9.7            | 1.04               | 21.2                           |
| Height gain, cm  | 41±1.24 | 32-48              | 4.63               | 11.3                           |

The average diameter of tree trunks is 8 cm (maximum 12 cm) and height 4.9 m (maximum 9.7 m). The annual increase in height is in the range of 32-48 cm, on average - 41 cm. Such increases are typical for oak during the active growth phase, which, as a rule, is observed up to 30 years. The coefficient of variability of dendrometric indicators is insignificant, the highest variation is in diameter and height, which indicates the uniformity of the stand. The presence of annual growth, which has high values, indicates that the natural conditions of the southern subzone of the taiga meet the requirements for oak growth. On figure 1 shows a graph of the dependence of plant height on their age.
In the studied plantings, a positive dependence of the height of trees on their age is observed, characterized by a correlation coefficient of 0.0997. This value is interpreted as very high, which allows you to perform a regression analysis and determine the form of the relationship between the indicators. The linear regression equation looks like this: 
\[ y = 39.961x - 99.531. \]

One of the reasons limiting the spread of oak in northern conditions is the unfavorable factors of the winter period. To a greater extent, winter hardiness depends on the content of cryptoprotectors in wood. For this purpose, the content of starch and sugars during the dormant period of plants was determined by staining. The results obtained indicate a high content of starch (blue-black color was obtained when the section was stained with Lugol's solution) and sugar (sugar content is 0.54%). There is a slight freezing of annual shoots, even in cold winters no more than 40%. Winter hardiness score according to the GBS RAS scale I-II. A characteristic damage for oak is frost cracks on the trunks, but they were not found in the plantings of the dendrological garden [9].

Under stressful conditions, which are the natural characteristics of the northern border of the range, the features of the passage of photosynthesis are important. The pigment composition is considered one of the most informative indicators characterizing the state of the photosynthetic apparatus of any plant organism. As is known, this process is very sensitive to changes in external factors. The content of photosynthesis pigments in pedunculate oak leaves is shown in table 2.

| Meaning            | Content, mg/g fresh weight | Ratio          |
|--------------------|-----------------------------|----------------|
|                    | chlorophyll a | chlorophyll b | carotenoids | sum of chlorophylls | chlorophyll a | chlorophyll a+b | carotenoids |
| The average        | 5.6±0.3       | 2.4±0.3       | 2.5±0.4     | 8.6±0.5             | 3±0.6         | 4.2±0.6       |
| Minimum            | 3.7           | 0.5           | 1.2         | 5.0                 | 1.3           | 1.3           |
| Maximum            | 6.7           | 3.9           | 5.1         | 9.6                 | 7.5           | 7.3           |

The efficiency of photosynthesis depends to a greater extent on the content of chlorophylls a and b, their ratio indicates the degree of formation of the assimilation apparatus. The normal ratio of
chlorophyll a to chlorophyll b is between 2.2 and 3.0. In the conditions of the dendrological garden, these values correspond to the upper limit of the norm. Also, the results obtained indicate the exactness of light.

Carotenoids perform a protective function in the plant body. The ratio of chlorophylls and carotenoids significantly responds to changes in stress conditions. The optimal ratio of these pigments is 2.0. In our case, it is about 2 times higher, which indicates adaptation to unfavorable conditions. In general, the results obtained characterize the course of the photosynthesis process as normal.

The entry of woody plants into the fruiting stage indicates their naturalization. On the territory of the dendrological garden, the pedunculate oak bears fruit and forms full-fledged seeds. Flowering is observed in late May-early June. The trees produce male and female flowers. The female flowers are inflorescences on short stalks located in the axils of the upper leaves. The inflorescence may have from 3 to 12 flowers. Male flowers in the form of earrings. Their length is 2-3 cm. Fruits ripen in September - acorns with one seed inside. A sign of maturation is the acquisition of a gray or brown color with green longitudinal stripes. Quantitative and qualitative indicators of pedunculate oak seeds are given in table. 3

Table 3. Quantitative and qualitative indicators of pedunculate oak seeds.

| Indicator   | Average | Measurement limits | Mode | Standard deviation | The coefficient of variation, % |
|-------------|---------|--------------------|------|--------------------|---------------------------------|
| Length, mm  | 27.7±0.44 | 17-33              | 25   | 3.09               | 11.1                            |
| Thickness, mm| 16.8±0.20 | 13-20              | 17   | 1.39               | 8.3                             |
| Width, mm   | 16.9±0.20 | 13-20              | 17   | 1.39               | 8.2                             |
| Volume, mm³ | 8009.6±263.07 | 2873-13200         | 7225 | 1860.20            | 23.2                            |
| Weight 1000 pieces, g | 4553.97±552.93 | 2429.7-6589.2     | -    | 1563.92            | 34.3                            |

Pedunculate oak seeds are 17-33 mm long (27.7 mm on average) and 13-20 mm thick (16.8 mm on average), such morphological indicators are typical for this species within its natural range. Krechetova (1978) [10] gives the following data: length - 13-36 mm, thickness - 11-12 mm. The most important indicator for assessing the quality of seed raw materials is the weight of 1000 pcs. The growth energy of seedlings depends on this trait, which at the initial stage is provided by the nutrients contained in the seed. Average weight 1000 pcs. seeds of English oak obtained in the conditions of the dendrological garden is 4553.97 g. This value can be considered quite high. A number of scientists [10-12] give data on the mass of 1000 pieces. within 3000-4000 g. In our studies, the results obtained were above average. One possible reason is that the seeds are from the second generation, which usually produces better quality seeds than the mothers.

For all studied indicators, the coefficient of variation was determined, the values of which are not high. The thickness and width have a weak variation of the trait, the length and volume have an average variation. The combination of these features can be considered homogeneous. Somewhat different data were obtained for the weight of 1000 pcs. seeds, which has a strong variability in the value of the trait and it is diverse and heterogeneous.

The dependence of biometric indicators of oak acorns has an average and high degree of dependence. Of particular interest is such an indicator as the volume of seeds, which is used to solve a number of issues in seed production and sorting. Correlation dependence and linear regression equations of the most important indicators are shown in table 4.

The relationship between the values of the length, thickness and width of seeds is estimated as average and is 61%. The ratio of width to volume and thickness to volume can be considered high, it is 72% and 76%, respectively. A very high correlation is observed for the length-to-volume ratio of the acorn (95%). High correlation coefficients make it possible to create a mathematical model that reflects the relationship of indicators in the form of a linear regression.
Table 4. Correlation and linear regression equations.

| Indicators             | Correlation coefficient | Linear regression equation | Approximation confidence factor, $R^2$ |
|------------------------|-------------------------|----------------------------|---------------------------------------|
| Thickness, mm          | 0.61                    | $y = 0.2745x + 9.2365$     | 0.37                                  |
| Lenght, mm             | 0.61                    | $y = 0.238x + 10.308$      | 0.28                                  |
| Width, mm              | 0.61                    | $y = 0.2745x + 9.2365$     | 0.37                                  |
| Volume, mm$^3$         | 0.95                    | $y = 1059.4x - 16104$      | 0.91                                  |
| Thickness, mm          |                         |                            |                                       |
| Volume, mm$^3$         | 0.76                    | $y = 1873.4x - 18305$      | 0.57                                  |
| Width, mm              |                         |                            |                                       |
| Volume, mm$^3$         | 0.72                    | $y = 1783.5x - 16899$      | 0.52                                  |

Seed quality was determined by sowing acorns in boxes with wet sand. Germination energy was recorded on the 7th day, germination on the 14th day. The results are shown in table 5.

Table 5. Quality indicators of English oak seeds.

| Indicator                | Sample number for 100 pcs. seeds |
|-------------------------|-----------------------------------|
|                         | 1      | 2      | 3      | 4      |
| Germination energy, %   | 74     | 76     | 67     | 72     |
| Germination, %          | 85     | 86     | 87     | 85     |
| Benignity, %            | 100    | 100    | 100    | 100    |
| Quality class           | 1      | 1      | 1      | 1      |

The germination energy is in the range of 67-76%, which contributes to the high resistance of crops to adverse conditions and the defeat of various seedling diseases. The seeds of milestone batches have a high germination rate, not less than 85%. The exceptional good quality of acorns indicates the normal passage of pollination, which contributes to the formation of full-fledged seeds. All parties, in the conducted research, correspond to the 1st class of quality.

4. Conclusion
The conditions of the southern subzone of the taiga are favorable for the growth of English oak. The presence of an annual increase in height and diameter was noted. As a result of the research, the fact of freezing of annual shoots in severe winters by no more than 40% was established. The content of cryptoprotectors in wood is high, which indicates a good winter hardiness of the species. The functioning of photosynthesis is efficient, which also meets the requirements of the species for the light period. The presence of generative development and high quality of seed material indicates the naturalization of the species upon introduction and the possibility of its further introduction into culture. Pedunculate oak can be recommended for use in urban landscaping, the formation of green areas of cities, for cultivation in order to collect medicinal raw materials.

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