Histological changes in the structure of one-year sprouts of *Pinus sylvestris* L. as a reflection of the structural adaptation of the species during its introduction

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Abstract. Comparative anatomical studies of one-year sprouts *Pinus sylvestris* L. made it possible to obtain data on the features of vegetative organ formation, histological changes and the persistence of structural features by the influence of environmental factors. It is noted that the parameters of histological structure and cytological indexes of one-year sprouts are strongly influenced by the hydrothermal coefficient (HTC) of growing conditions. The structure of the one-year sprouts of *Pinus sylvestris* L., growing in sufficient humidification (HTC=1.6) conditions, is characterized by the greatest thickness of cortex, phloem and xylem, the largest radius of pith, the maximum diameter of resin canals, while having the smallest size of external protective tissues. Histological studies of the geographical cultures of *Pinus sylvestris* L. of the central forest-steppe revealed, that being in the same growth conditions, the anatomical structure of one-year sprouts significantly changes. Histological and cytological indexes of the anatomical structure of the one-year sprouts of *Pinus sylvestris* L. populations from the dry steppe increase by 33%, from the broad-leaved forest zone decrease to 30%. Thus, structural adaptation of the assimilation apparatus to new growing conditions occurs, which determines in general the productivity and stability of the woodlands of *Pinus sylvestris* L.

1. Introduction

Morphological-anatomical structure of vegetative organs carries the information about the evolutionary and ecological norm of the adaptation response of species [1]. This was noted in the works of many authors who studied the impact of climate change as well as anthropogenic impact on the environment [2-4]. Influence of the environment in which the woody plant grows is strongly reflected in the morphological, anatomical and physiological-biochemical parameters of vegetative organs. Once in a certain environment, plants begin to adapt intensively [5-7].

The main role in adaptability is assigned to vegetative organs, which have high plasticity when climatic conditions change. The adaptation of plants to environmental conditions is one of the main properties, providing the opportunity to survive, continue to exist and reproduce [2].

Adaptability is manifested at various structural levels: from the biochemistry of cells to the structure and functioning of an individual plant as well as communities and ecological systems in general [4, 8].

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The increase of the anthropogenic impact on environmental conditions in the pine stand entails the largest number of changes in the anatomical indicators of the needles, which ensures the resistance of the plantation to negative factors [7].

Adaptation of plants is of great importance when introducing species, in particular, when transferring seeds from some soil-climatic conditions to others that differ from their original habitats. The study of the natural gene pool of the species with specific ecotypes and the creation of its introductive gene pool makes it possible to identify bioclimatic features that ensure active adaptation of plants to certain environmental conditions [3, 9].

In the works of some author, it was noted that *Pinus sylvestris* L. is a very plastic species that has wide ecological amplitude of soil and climatic factors. This indicates that it is possible to adapt to different growing conditions and occupy the relevant natural niches due to the high rates of ecological reaction of the species, that is, adaptability [3, 9]. However, the authors did not note why such ability arises in the plant.

Studying the physiological and anatomical features of the structure of vegetative organs of *Pinus sylvestris* L. in geographical cultures, these authors [3, 4] note that *Pinus sylvestris* L. responds to changes in environmental conditions with more or less significant adaptive reactions. They only occur under certain conditions and the influence of natural selection. However, what mechanism regulates this natural selection in geographical cultures, the authors do not note. Only a change in morphological-physiological and anatomical features of vegetative organs was revealed, which reflects the polymorphic structure of the species, which is quite common in the previous history of its development [3].

Thus, histological changes in the structure of vegetative organs (one-year sprouts) of *Pinus sylvestris* L. can serve as a marker of environmental conditions, which is of global importance for solving environmental problems on a global scale. To this end, the anatomic-morphological features of the structure of one-year sprouts of *Pinus sylvestris* L. in geographical cultures introduced from different locative conditions, as well as in natural habitats were studied. A comparative analysis of histological signs and structural indicators of one-year sprouts in order to establish the influence of genetic and environmental factors on the adaptation abilities of the species was carried out.

2. Materials and methods

The object of the research was *Pinus sylvestris* L., which grows in the geographical cultures of Voronezh forestry (Bryansk, Voronezh and Volgograd origins) and in the natural forests of Bryansk (Karachevsky forestry), Voronezh (Khrenovsky forestry) and Volgograd (Archedinsky forestry) regions. Conditions of research objects growth are characterized by different natural-climatic indicators (table 1).

The material for the study was collected in the summer period 2008 and 2014. According to the materials of the taxation description, areas with old-age plantations of *Pinus sylvestris* L. were selected in natural coniferous forests. Test sections of 0.25 hectares were laid at each area. The geographical cultures of *Pinus sylvestris* L. are 45-60 years old. The area of accounting sections for these plantings is 0.05 hectares. In all selected sections, a continuous group of trees was carried out with distribution by thickness stages. When measuring the diameters of the trunk at the height of the chest, a measuring fork was used, and an altimeter was used to measure the heights. For anatomical studies, three model trees with common characteristics of this area and having average height and diameter indicators were taken from each section. Samples of apical one-year sprouts which were fixed in 96° ethanol in a mixture with glycerol were taken from these trees.

Microstructural analysis methods were used to investigate the anatomical structure of the sprouts. Cross sections of one-year sprouts were made with the help of a luge microtome. The obtained sections were placed on a microscope glass with a drop of glycerin and examined with a Biolam monocular microscope (Lomo, USSR) at the eight- and twenty-fold lens magnification. An ocular micrometer was used for the measurements. When studying the microstructure of the sprouts, measurements of the pith radius, xylem thickness, phloem thickness, cortex thickness, diameter of resin canals and periderm thickness were made. The thickness of *Pinus sylvestris* L. sprout tissues was measured in the order of their location, ranging from the periphery to the radius of the pith. Cell width was measured for each of...
these tissues at the greatest magnification of the microscope. Cell sizes were measured transversely and longitudinally. In total, 25 measurements of sprouts from each object were made.

**Table 1.** Characteristics of natural and climatic conditions of objects research growth.

| Indicator                        | Bryansk region (Karachevsky) | Voronezh region (Khrenevsky) | Volgograd region (Archedinsky) |
|----------------------------------|------------------------------|-----------------------------|--------------------------------|
| Natural-climatic zone            | Broad-leaved forest zone     | Southern forest-steppe zone | Dry steppe zone                 |
| Average annual temperature, °C   | +4.5                         | +6.9                        | +6.9                           |
| Rainfall per year, mm            | 750                          | 486                         | 200                            |
| Hydrothermal coefficient (HTC)   | 1.6 (sufficient humidification) | 0.9 (insufficient humidification) | 0.5 (weak)                     |
| Growing season, days             | 185                          | 200                         | 206                            |

Statistical processing of measurement data was carried out, including calculation of the main statistical characteristics: arithmetic mean M; mean quadratic deviation σ; arithmetic mean error m; coefficient of variation V,%; test accuracy index P,%. Statistical indicators are used to determine accuracy of experimental data. The average values used without the accuracy index (P, %) may be unreliable due to the small sample, or due to the high variability of the trait. Different features on the same slice have different levels of variability, which is reflected in the coefficients of variation and accuracy indexes. The calculation was made using the computer programs Excel and StatSoft STATISTICA 6.0. We calculated the arithmetic mean and arithmetic mean errors. Statistical verification of criteria (t₁, t₂, t₃) for the influence of natural and climatic conditions was performed. The difference between compared mean values was evaluated by Student's test, which is t ≤ 0.05.

**3. Results and discussion**

The many and varied impacts of environmental conditions are reflected in the change in the structural parameters of the one-year sprouts of *Pinus sylvestris* L., as confirmed in the present work. Histological and cytological studies of one-year sprouts are presented in tables 2 and 3.

During anatomical studies, it can be observed that the thickness of the cortex has the greatest parameters among the tissues of the one-year sprout. The periderm which has an important protective function has the smallest values of parameters. There is a phloem or secondary cork under the cortex. The underlying xylem is almost 2 times thicker than the phloem (table 2).

The microstructure of the one-year sprouts of *Pinus sylvestris* L. growing in various natural and climatic conditions is very different. From the table 2 it can be seen that parameters of histological structure of one-year sprouts are strongly influenced by natural-climatic indicators, especially hydrothermal coefficient (HTC) of growth conditions. It is noted that the structure of one-year sprouts of *Pinus sylvestris* L. growing in conditions of sufficient humidification (HTC=1.6) is characterized by the highest indicators of the cortex thickness, the phloem thickness, the xylem thickness, the radius of the pith and the diameter of the resin canals. At the same time, the smallest size of external protective tissues is observed on this object. On the contrary, with weak humidification (HTC=0.5), the tissue indexes of the one-year sprout have the lowest values. That is, there is a decrease in the thickness of the conducting and storage tissues when moved to arid conditions. The ground tissues thickness, on the contrary, increases, which is an important sign of the adaptability of the species. Adaptation to xerophytic conditions is manifested in a significant increase in the external protective tissues thickness. The periderm thickness in the zone of broad-leaved forests is 83.4 μm, and it increases to 96.3 μm (table 2) in the direction to the dry steppe zone. Thus, a thicker periderm is formed when moving to extreme arid conditions in order to protect against adverse environmental factors. Since the thickness of other sprout tissues during transition to the dry steppe decreases, therefore, the size of the sprout itself decreases too.
Table 2. Histological structure of *Pinus sylvestris* L. sprout.

| Histological indicators | Natural coniferous forests (2008) | Geographical cultures (central forest-steppe) (2014) |
|--------------------------|-----------------------------------|---------------------------------------------------|
|                          | Bryansk, Karachevsky | Voronezh, Khrenovsky | Volgograd, Archedinsky | Bryansk, Karachevsky | Voronezh, Khrenovsky | Volgograd, Archedinsky |
| Periderm thickness, μm   | 83.4±3.8             | 87.6±3.2            | 96.3±3.2            | 86.1±3.6            | 86.9±3.3            | 87.2±3.6            |
| V, %                     | 18.4                 | 20.8                | 19.2                | 23.1                | 18.9                | 19.5                |
| t1=1.8                  | t2=1.8               | t3=1.3              | t1=2.2              | t2=1.3              | t3=2.3              |
| Cortex thickness, μm     | 748.5±24.5           | 515.2±22.5          | 503.2±23.5          | 602.1±26.2          | 520.2±22.2          | 518.0±24.7          |
| V, %                     | 16.9                 | 22.9                | 24.4                | 17.2                | 20.1                | 18.9                |
| t1=6.5                  | t2=0.6, t3=6.8       | t1=7.0              | t2=1.1, t3=4.1     |
| Resin canals diameter, μm | 180.2±6.8           | 150.2±7.3           | 141.2±5.8           | 158.0±6.8           | 149.2±6.6           | 143.2±6.4           |
| V, %                     | 18.9                 | 23.2                | 18.4                | 22                  | 24                  | 21.4                |
| t1=2.6                  | t2=1.6, t3=4.8       | t1=2.7              | t2=1.1, t3=4.1     |
| Phloem thickness (secondary cork), μm | 170.2±2.8 | 128.4±5.2 | 111.8±4.6 | 139.8±3.8 | 122.4±4.8 | 119.8±4.6 |
| V, %                     | 9.2                  | 15.6                | 18.9                | 8.3                 | 21.3                | 20.2                |
| t1=6.1                  | t2=1.6, t3=9.8       | t1=7.9              | t2=1.7, t3=10.9    |
| Xylem thickness, μm      | 433.8±19.9           | 387.0±12.7          | 265.8±11.0          | 400.6±17.9          | 388.0±13.2          | 341.5±9.5           |
| V, %                     | 22.3                 | 17.4                | 21.3                | 23                  | 16.4                | 20.3                |
| t1=2.1                  | t2=6.2, t3=6.8       | t1=1.9              | t2=7.1, t3=7.2     |
| Pith radius, μm          | 345.6±11.7           | 208.6±8.9           | 149.1±5.7           | 240.2±13.6          | 210.8±7.8           | 198.5±5.9           |
| V, %                     | 17.2                 | 18.9                | 19.1                | 20.3                | 22.1                | 20.8                |
| t1=8.4                  | t2=4.2, t3=13.9      | t1=10.4             | t2=5.0, t3=15.8    |

The degree of variation for all indicators of one-year sprouts in the Bryansk region is similar. In dry conditions of the Volgograd region, the amplitude of fluctuations for most indicators is wider. There is a restructuring of vegetative organs by the influence of environmental factors, which is ensuring the viability of the forest in the new conditions.

In the geographical cultures of *Pinus sylvestris* L. growing on the territory of Voronezh forestry, ecotypes from Bryansk, Voronezh and Volgograd regions have similar one-year sprout parameter values to the indicators of the anatomical structure of local specimens. For example, the periderm thickness is aligned to 86.1-87.9 μm. The one-year sprouts of ecotypes from the dry steppe acquire better parameters when transferred to conditions (table 2) with a higher HTC. That is, when introduced into the central forest-steppe zone, vegetative organs are rebuilt, and differences in histological indicators of one-year sprouts are smoothed out. However, the pattern of differences in the parameters of one-year sprouts which are typical for natural coniferous forests remains. Seed offspring from the broad-leaved forest zone when introduced into the central forest-steppe retains the largest values of parameters of the
anatomical structure of one-year sprouts compared to the data of the sprout parameters of other ecotypes. Thus, the genetic influence on the features of growth in the new conditions was established.

An analysis of the histological study of the one-year sprouts of *Pinus sylvestris* L. showed that the parameters of the cortex thickness, the phloem thickness, the xylem thickness, the pith radius and the diameter of the resin canals in the natural forest differ by 2-65%, in geographical cultures these differences decrease to 0.001%, and in the dry steppe they (table 2) reach a minimum.

Figure 1 shows the general pattern of changes in the anatomical structure of one-year sprouts depending on the growing conditions. The curve of histology indicators of one-year sprouts of *Pinus sylvestris* L. growing in broad-leaved forests (Bryansk region) has the highest border, and the curve of histology indicators of one-year sprouts of *Pinus sylvestris* L. from dry steppe conditions (Volgograd region) – the lowest border. In the graph (figure 1), curves of histology indicators of one-year sprouts of *Pinus sylvestris* L. from plantations of the southern forest-steppe (Voronezh region) and in geographical cultures (central forest-steppe of the Voronezh region) of different origins take an intermediate position. Figure 2 shows images of one-year sprouts of *Pinus sylvestris* L. from natural forests.
Environmental conditions have a significant effect on cell size and shape. According to the cytological analysis of one-year sprouts taken from various natural and climatic conditions, a significant decrease of the cells diameter in all tissues towards arid conditions can be observed. The exception is the cells of the periderm, which, on the contrary, increase in size, which indicates an increase in the protective function of the plant. In general, small cell tissues form in arid conditions (table 3). The largest sprout cells are in the periderm. The peridermal cells are flat; their diameters in the tangent section are 38.2 to 53.7 µm. The smallest cells are observed in the phloem - 8.3-12.1 µm (table 3).

There is traceable dependence of the cytological parameters of one-year sprouts of *Pinus sylvestris* L. on the degree of humidification, which leads to a change in histological indicators. Such a picture makes it possible to judge confidently that environmental conditions have a significant impact on the cellular level, and the size of organs is a result of such an influence. Histological and cytological structure indicators of the one-year sprouts of *Pinus sylvestris* L. of Volgograd ecotypes grown on the territory of the central forest-steppe improve by 33% on average. When introducing seeds of *Pinus sylvestris* L. from the broad-leaved forest zone (Bryansk region) into the central forest-steppe, the parameters of one-year sprouts of Bryansk ecotypes decrease to 30% on average.

**Table 3. Cytological indicators of one-year sprouts of *Pinus sylvestris* L.**

| Cell diameter                      | Natural forests (2008) | Geographical cultures (central forest-steppe (2014)) |
|-----------------------------------|------------------------|-----------------------------------------------------|
|                                   | Bryansk, Karachevsky   | Voronezh, Khrenovsky, A2                             | Volgograd, Archedinsky, A1                           |
| Periderm, µm                      | 38.2±1.6               | 43.1±2.5                                            | 53.7±2.1                                             | 41.8±1.5                                             | 42.1±1.4                                             | 43.6±1.3                                             |
| V, %                              | 13.3                   | 15.1                                                | 18.5                                                | 14.1                                                 | 17.6                                                 | 19.5                                                 |
|                                  |                        |                                                     | t₁=1.5a                                             | t₂=3.2, t₃=5.1                                       | t₁=1.3                                               | t₂=3.8, t₃=5.2                                       |
| Cortex, µm                        | 55.3±1.9               | 48.1±1.7                                            | 36.5±1.8                                            | 48.2±1.5                                             | 47.0±1.8                                             | 45.9±2.0                                             |
| V, %                              | 16.7                   | 17.5                                                | 24.3                                                | 13.8                                                 | 15.1                                                 | 18.1                                                 |
|                                  |                        |                                                     | t₁=2.8                                              | t₂=4.8, t₃=7.1                                       | t₁=2.6                                               | t₂=4.6, t₃=6.9                                       |
| Epithelial, resin canal, µm       | 16.9±0.5               | 16.1±0.7                                            | 15.8±0.7                                            | 16.2±0.46                                            | 15.8±0.62                                            | 15.4±0.65                                            |
| V, %                              | 15.1                   | 18.5                                                | 19.1                                                | 14.4                                                 | 18.6                                                 | 19.1                                                 |
|                                  |                        |                                                     | t₁=0.6                                              | t₂=0.5                                              | t₁=1.1                                               |                                                     |
|                                  |                        |                                                     |                                                     | t₂=0.5                                              | t₁=0.5                                               | t₂=0.4, t₃=1.0                                       |
|                                  | Phloem, µm             | 12.1±0.32                                           | 8.4±0.23                                            | 8.3±0.23                                             | 9.6±0.32                                             | 8.9±0.23                                             | 8.5±0.23                                             |
| V, %                              | 17                     | 11.6                                                | 13                                                  | 16                                                   | 13.5                                                 | 14                                                   |
|                                  |                        |                                                     | t₂=8.4                                              | t₂=0.5, t₃=8.6                                       | t₂=9.4                                               | t₂=0.3, t₃=9.6                                       |
|                                  | Xylem, µm              | 17.1±1.0                                            | 13.7±0.6                                            | 12.1±0.2                                             | 14.4±0.9                                             | 13.1±0.5                                             | 12.7±0.1                                             |
| V, %                              | 19.3                   | 16.5                                                | 8.1                                                 | 24.4                                                 | 17.5                                                 | 5.5                                                  |
|                                  |                        |                                                     | t₂=3.0                                              | t₂=2.1, t₃=5.8                                       | t₂=4.0                                               | t₂=2.1, t₃=5.8                                       |
|                                  | Pith, µm               | 52.1±2.5                                            | 41.1±1.2                                            | 35.4±1.6                                            | 42.2±2.8                                             | 41.2±1.5                                             | 40.3±2.1                                             |
| V, %                              | 18.5                   | 17.7                                                | 19.1                                                | 24.5                                                 | 15                                                   | 23.1                                                 |
|                                  |                        |                                                     | t₂=3.1                                              | t₂=2.8, t₃=4.7                                       | t₂=4.0                                               | t₂=3.0, t₃=5.7                                       |

* at = {2.1-2.8-3.7}.

*Pinus sylvestris* L. throughout the growth period is influenced by numerous and diverse environmental conditions. Vegetative organs, including one-year sprouts of pine, are the first to respond to changes in the external environment. This influence is the reason of noticeable variability in the anatomical structure of different organs, which predetermines the features of growth, stability and productivity of the plant in certain growing conditions. Differences in the structure of one-year sprouts, which appear during the evolutionary development of the individual (population), can be observed in geographical cultures too. The fact of variability of the structure is very important when transferring...
seeds to more contrasting or different environmental conditions according to certain natural constants. It can be approved that plants adapt to drier habitats structurally and physiologically. These processes are especially characteristic of plant vegetative organs.

The study of the macro- and microscopic structure of *Pinus sylvestris* L. in various growing conditions made it possible to identify the characteristic features of the structure in certain conditions and identify the directions of their adaptation to new conditions, especially when introducing from broad-leaved forests and dry steppe into the central forest-steppe. Thus, our research confirms the results of works previously published by different authors. Changes in the climatic conditions in which woody plants grow strongly affect the morphological and anatomical parameters of the vegetative organs, and, accordingly, the growth of plants [4, 6, 7]. Anatomical and morphological changes in vegetative organs serve as an effective indicator of climate change, which puts this fact on the world level. We recommend a systematic study of histological changes in the structure of one-year sprouts of *Pinus sylvestris* L. to study the patterns of climate change. This will make it possible to more accurately predict the current processes of climate change.

4. Conclusion

The study of histological changes in the one-year sprouts of *Pinus sylvestris* L. made it possible to trace the structural adaptation of the species when it was introduced into new conditions. It is noted that due to the adaptive ability, which is manifested at the morphological-anatomical structural level of vegetative organs, *Pinus sylvestris* L. has wide amplitude of soil-climatic growing conditions. This wide ecological amplitude of the species is caused by the ability to adapt to various conditions and occupy the relevant natural niches due to the high norms of ecological reaction of vegetative organs manifested at the level of histological changes. Our research results confirm this fact.

The norms of environmental adaptation of *Pinus sylvestris* L. when introducing into certain conditions are achieved in the process of evolution and are fixed in the genotype. The wider the amplitude of adaptation capabilities is, the more environmentally plastic species is, and the more successfully it can adapt to various environmental conditions. The change in the morphological-anatomical structure of one-year sprouts of *Pinus sylvestris* L., depending on natural and climatic factors, characterizes wide amplitude of ecological adaptation, which allows the species to grow in contrast conditions.

The results of the studies allowed drawing the following conclusions. The thickness of external protective tissues plays a major role in adapting the species to new growing conditions. The size of external protective tissues of the one-year trunk increases with the introduction of *Pinus sylvestris* L. into more extreme environmental conditions (dry steppe zone). The size of assimilation tissues also varies depending on the growing conditions. In more favorable conditions, the tissue indexes of one-year sprouts are maximum, when introducing into the dry steppe, they decrease. There was a decrease in cell diameter at all levels when *Pinus sylvestris* L. moving from northwest to southeast (small cell tissues form in more unfavorable conditions).

Studies of the structure of the one-year sprouts of *Pinus sylvestris* L., which grows in the geographical cultures of the central forest-steppe, showed that when the species is introduced into new conditions, structural adaptation occurs, it is manifested in a significant change in histological parameters and cytological indicators. The morphological-anatomical structure of one-year sprouts is rebuilt to the indicators of local populations. However, with a more detailed comparison, differences caused by the origin of introduced ecotypes were noted. This indicates the influence of genetic factors responsible for the adaptation of the species to new growing conditions.

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