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# Changes in the assimilation apparatus and the conducting of root of woody plants in various environmental conditions

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**Abstract.** The features of the development of tissues of the assimilation apparatus and the conducting roots of Scots pine (*Pinus sylvestris* L.), larch (*Larix sukaczewii* Dyl.), birch (*Betula pendula* Roth) and poplar (*Populus balsamifera* L.), growing in extreme forest conditions, are investigated. Adaptive species-specific changes in the anatomical and morphological organization of woody plants were revealed. The average values of growth of wood, bark, integumentary tissues and mesophyll were established. It is established that wood increments change depending on extreme forest growing conditions.

## 1. Introduction

Plants in natural habitat conditions are influenced by a complex of environmental factors. The effects of individual environmental factors on plants at different levels of the structural and functional organization are actively studied [1, 2].

Assimilating organs and the root system of woody plants are significant structures in their balanced functioning, ensure successful growth and development of plants. Changes in the anatomical and morphological structures of the assimilation organs and conducting roots lead to changes in the overall structural and functional organization, changes in the work of the assimilation organs, to the absorption and redistribution of water and dissolved minerals, to the synthesis of organic substances and the accumulation of nutrients and, consequently, to a decrease productivity and state of woody plants in general [3].

Morphological changes of woody plants caused by growth in extreme forest conditions are associated with impaired physiological and biochemical processes. The appearance and development of signs of damage to the assimilation apparatus (chlorosis and necrosis) is associated with changes in the morphometric characteristics of the tissues of the leaves and needles. Assessment of the characteristics of adaptation and resistance of woody plants to the action of extreme factors is an important aspect of expert assessment in identifying the causes of damage to plants and predicting their resistance [3].



## 2. Materials and methods

Assessment of the relative vital state (RVS) of stands was established. Testing areas were laid in forest stands according to the generally accepted methods [4-7]. On each trial plot, a continuous count of trees was made (at least 200 pieces), the diameter and height of all trees were determined. The definition of the RVS of stands allows to give a comprehensive assessment of their state under the influence of various environmental factors. RVS plantation was determined on the following scale: healthy plantation, weakened, greatly weakened and completely destroyed.

On each trial plot, samples were taken in accordance with the following scheme: assimilation apparatus 100 pcs. from the middle part of the crown, a root conductive system of 50 pcs. at a depth of 10-30 cm.

The preparation of temporary and permanent preparations was carried out according to the generally accepted procedures [8]. The preparations were studied using an Amplival microscope (Carl Zeiss Jena, Germany) with a different magnification of the objective. The slices were photographed with a digital camera Olympus Camedia C 4000 (Olympus LTD, Japan) at a 192-fold magnification.

The statistical processing of the actual material was carried out by the standard methods [9] using the MS Excel 2000 software package.

The research was conducted between 1996 and 2018.

### *Brief description of habitats*

The Ufa Plateau (UP) (Russia, Republic of Bashkortostan, geographic coordinates 55°55' north latitude 55°20' east longitude), formed about 250 million years ago, is composed of Sakmaro-Artinian limestones and partly lime-prominent dolomites [10, 11]. These rocks are often siliceous, and in some areas strongly phosphorized, up to the formation of phosphorites. Above these rocks, in most cases, a thin eluvio-deluvium is developed from cartilaginous clays and heavy loamy [12]. The hydrothermal coefficient varies within the limits of 1.2-1.4 [12]. The extreme forest resource factor of the water-protective forests of the plant is long-term soil permafrost. It was discovered by the hydrologist A.G. Lykoshin in the early 50-ies of the twentieth century in the survey works at Pavlovsky [11]. The phenomenon of soil permafrost is described in sufficient detail in the phytocenotic, soil, ecological and forestry relations [12].

The industrial zone of the city of Sterlitamak (SIZ) (Russia, Republic of Bashkortostan, geographic coordinates 55°37' north latitude 55°57' east longitude), the relief is characterized by vast, low terraced hollow-ridged plains. Most of the area is represented by steppe landscapes, now plowed, and only small areas are occupied by broad-leaved forests. The soil cover is represented by typical and leached black earth, sometimes with dark gray and gray forest soils. The hydrothermal coefficient varies between 0.8 and 1.0 [13, 14]. The extreme growth conditions are: aerogenic pollution of a mixed type (a number of industrial enterprises).

Dumps of the Kumertau brown coal mine (KBCMD) (Kumertau) (Russia, Republic of Bashkortostan, geographic coordinates 52°45' north latitude 55°47' east longitude). The indigenous rocks are represented by Permian and Tertiary clays, conglomerates, sandstones, limestones, ancient alluvial sands and gravel. The man-made soils and young soils of the Kumertau dumps are poor in nitrogen, mobile phosphorus and are characterized by a relatively high number of absorbed bases. The plain relief is gently sloping - hilly in the south and east. Hydrothermal coefficient is about 1.0 [15, 16]. The age of the dumps is 68 years, the extreme conditions are: lack of organic materials, overburden, increased insolation.

The dumps of the Sibai branch of the Uchalinsky mining and processing plant (SB UMP) in Sibai (Russia, Republic of Bashkortostan, geographic coordinates 52°42' north latitude 58°39' east longitude) are located in the subarea of the southern forest-steppe of the Urals. Forests are represented by birch pins over depressions of the relief and on the shadow slopes of the hills. Broad-leaved breeds are absent. The relief is flat and steep. Dumps are located in the area of the Bashkir mining complex. Hydrothermal coefficient varies 0.8 – 1.0 [16, 17]. The age of dumps near 100 years, extreme conditions are: a lack of organic substances, large blocky overburden rocks, increased insolation.

The dumps of the Uchaly Mining and Processing Combine (UMPC) (Russia, Republic of Bashkortostan, geographic coordinates 54°19' north latitude 59°23' east longitude) are located on the southeastern border of the subzone of pre-forest-steppe pine-birch forests. Pine and pine-birch forests predominate. The relief is low-mountainous. Dumps are located on the territory of the Beloretsk industrial hub. Hydrothermal coefficient varies 1.2-1.8 [18, 19]. The age of the dumps more than 100 years, the extreme conditions are: lack of organic materials, overburden, increased insolation. Dumps of copper-quarried deposits of UMPC and SB UMP are composed of large-sized rock poorly weathered quartzites, porphyrites, pyrite and clay. Soils on these heaps have no morphological expression of genetic horizons and are characterized by a low content of humus, a slightly alkaline reaction of the medium and a high content (especially soils of the SB UMP) of absorbed bases. Soils are poor in nitrogen and, in most cases, phosphorus [19].

### 3. Results and discussion

The species-specific and general reactions of woody plants to the effects of the extreme environmental factors are the basis of resistance and determine the adaptive potential of the forest-forming species [20-28].

#### 3.1. Assessment of the relative vital state (RVS) of stands

The general condition of birch stands of ecotopes studied in comparison with other investigated tree species is characterized as the best. Plantings in the UP are classified as "healthy" (PVS is 96.7%). The remaining birch forests are characterized as "weakened". PVS is: 66.8% (SIZ), 69.8% (dumps of SB UMP), 73.1% (dumps of UMPC) and 75.7% (dumps of KBCMD).

PVS of poplar plantations in the SIZ is 75%. Plantation is classified as "weakened".

Characterizing the vital status of pine forests at the UP (78.6%), as well as on the KBCMD dumps (67.2%), SB UMP (66.4%) and UMPC (77.8%), it can be concluded that they are all related to category "weakened", while pine plantations in the SPC are classified as "severely weakened" - their OZHS is 47.6%.

Vital status of larch plantings decreases in a number of biotopes of the plant (about 100% "healthy") > SIZ (74% "weakened") > KBCMD dumps (55% "strongly weakened"). The weakening of the state of stands is due to the combined effect of natural and technogenic factors, and the role of the latter in the presented series is constantly increasing.

#### Assimilation apparatus

It should be noted that a characteristic feature of the anatomical organization of leaves is their high variability depending on the lighting, water availability and temperature regimes, as well as the intensity of the supply of man-made environment [2].

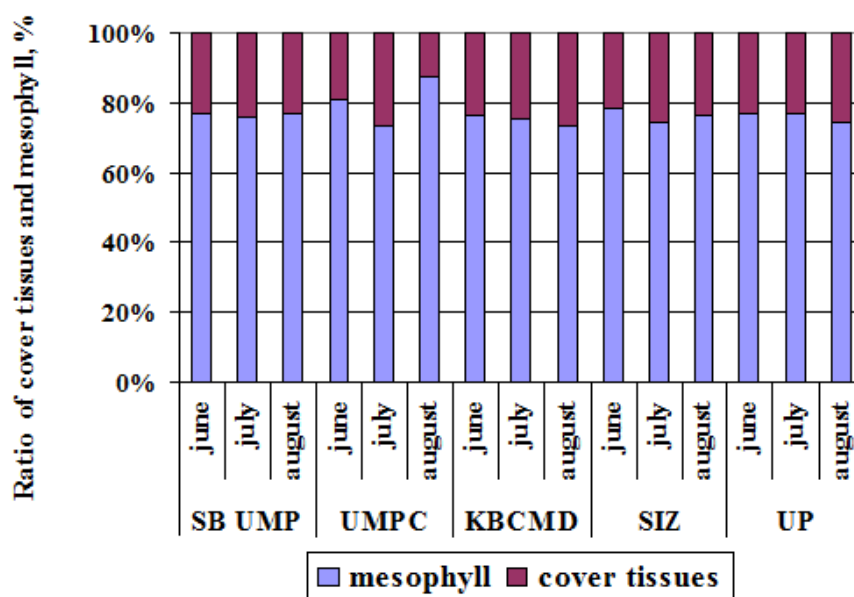
It has been established that the thickness of individual layers increases in birch in extreme growth conditions during the growing season. Thickening of the leaf blade is observed on the heaps: SB UMP, UMPC, KBCMD and on UP. In the poplar thickening of the leaf blade is observed on the heaps: SB UMP, UMPC, KBCMD and in the SIZ (Figures 1-4).

Significant differences in the structure of the pine assimilation apparatus were revealed. It is shown that the characteristic feature in the anatomical organization of pine needles is the regularity of thickening of the first, second and third year needles layers during the whole vegetation period in all test plots - on the SF dumps of the SB UMP, UMPC and KBCMD, in the SIZ and UP. Earlier, we found that an increase in the thickness of individual layers of needles occurs when extreme environmental factors such as UP, excess salt content in the plant substrate and chronic aerotechnogenic polymetallic pollution of the environment occur on plants [24, 25].

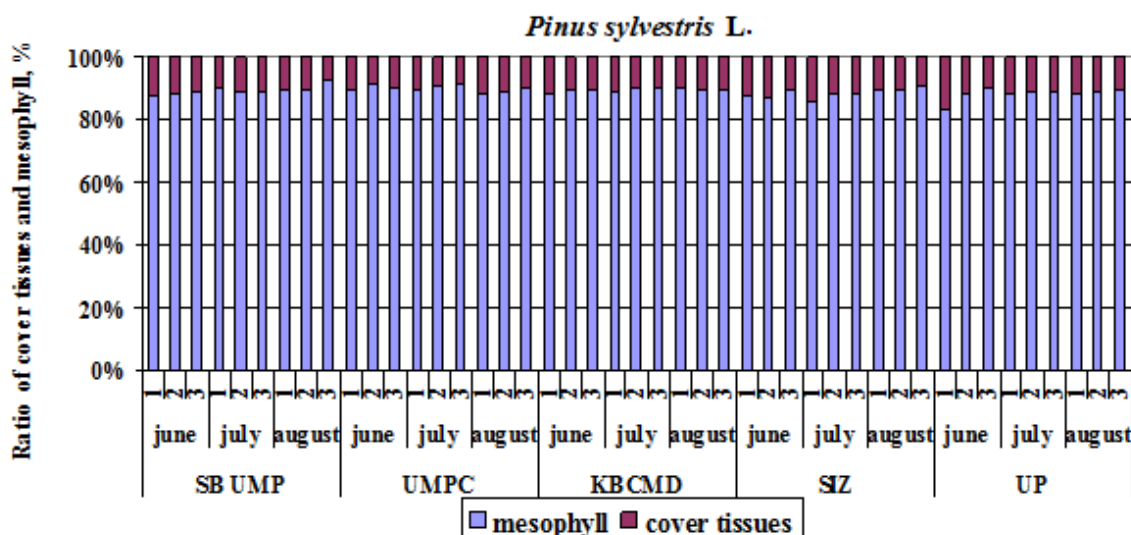
It should be noted that waxy plaque appears on the surface of the epidermis of the needles as a protective element, which is also considered as an adaptive response of plants to deterioration of the growth conditions. The formation of needles with a small thickness of layers and reduction of its biomass of needles is aimed at realizing adaptation to extreme growth conditions by enhancing its xeromorphy.

Variability of some signs of anatomical and morphological features in the structure of the assimilation apparatus in larch is shown. It is characteristically different anatomical structure of the needles of larch, as well as a significant change in the size and shape of the cells of the tissues of the needles. In all trial plots, a clear pattern in the changes in the anatomical features of pine needles in extreme growth conditions was not found. Reducing the thickness of the layers of the needles of larch is a general adaptive response to such extreme factors as soil permafrost and technogenic pollution that directly affect the formation and growth of needles (Figures 1-4).

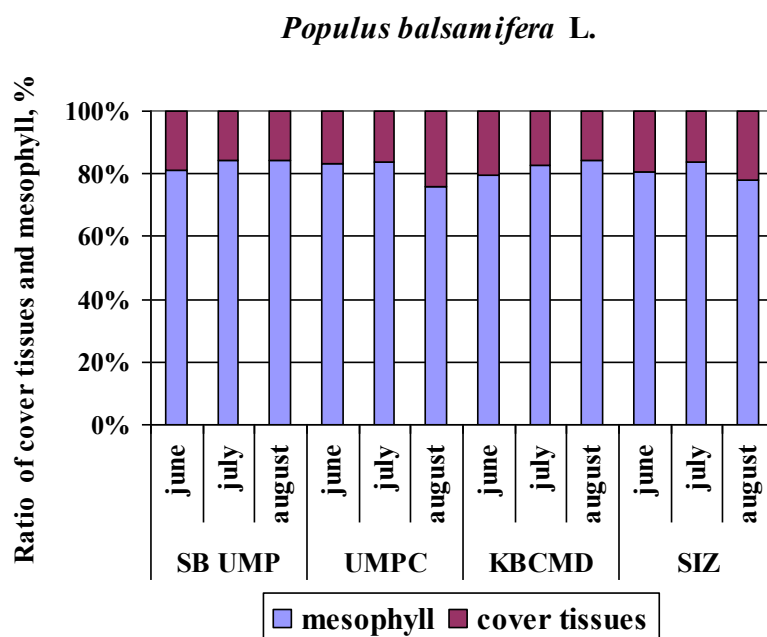
***Betula pendula* Roth**



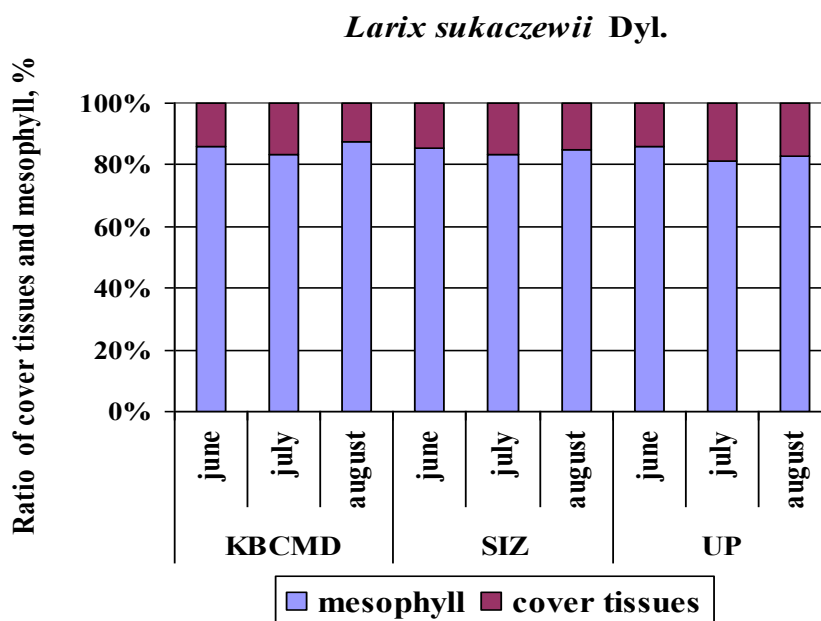
**Figure 1.** Ratio of coverslips and mesophyll (%) of the assimilation apparatus *Betula pendula* Roth, growing in the extreme forest conditions.



**Figure 2.** Ratio of coverslips and mesophyll (%) of the assimilation apparatus *Pinus sylvestris* L., growing in the extreme forest conditions.



**Figure 3.** Ratio of coverslips and mesophyll (%) of the assimilation apparatus *Populus balsamifera* L., growing in the extreme forest conditions.



**Figure 4.** Ratio of coverslips and mesophyll (%) of the assimilation apparatus *Larix sukaczewii* Dyl., growing in the extreme forest conditions.

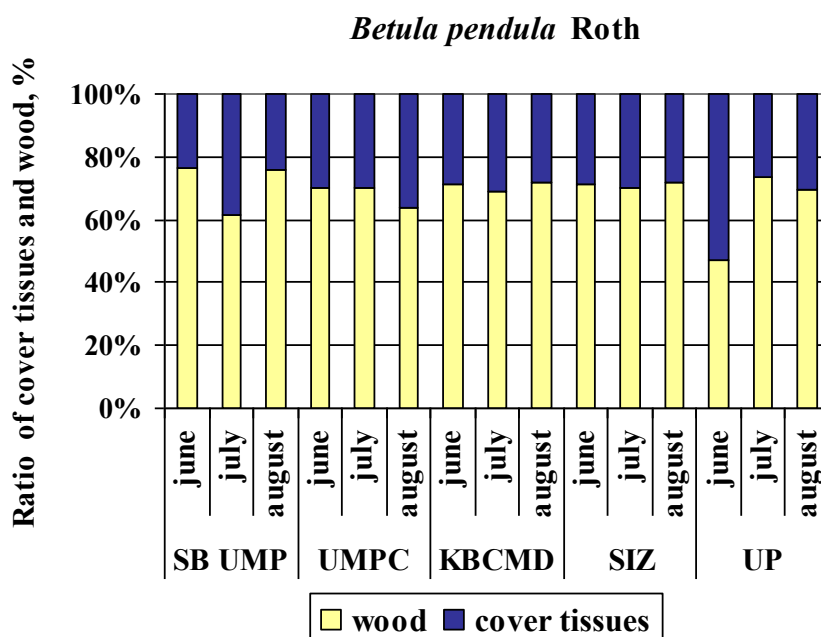
### 3.2. Coverslips

It is shown that in the extreme conditions of growth in birch (Figure 1), the coverslips maximally develop on the dumps of the SB UMP in June (extremely high temperatures and moisture deficit). A similar picture was observed at the beginning of the growing season on the UP, where the coverslips provide protection of the conducting roots from the effects of low temperatures. The conducting system, which carries out the transport of substances, is well developed in the roots of the birch in the SIZ and the KBCMD (Figure 5). Our results support the hypothesis of Mauer O. and Rabatova E. [26].

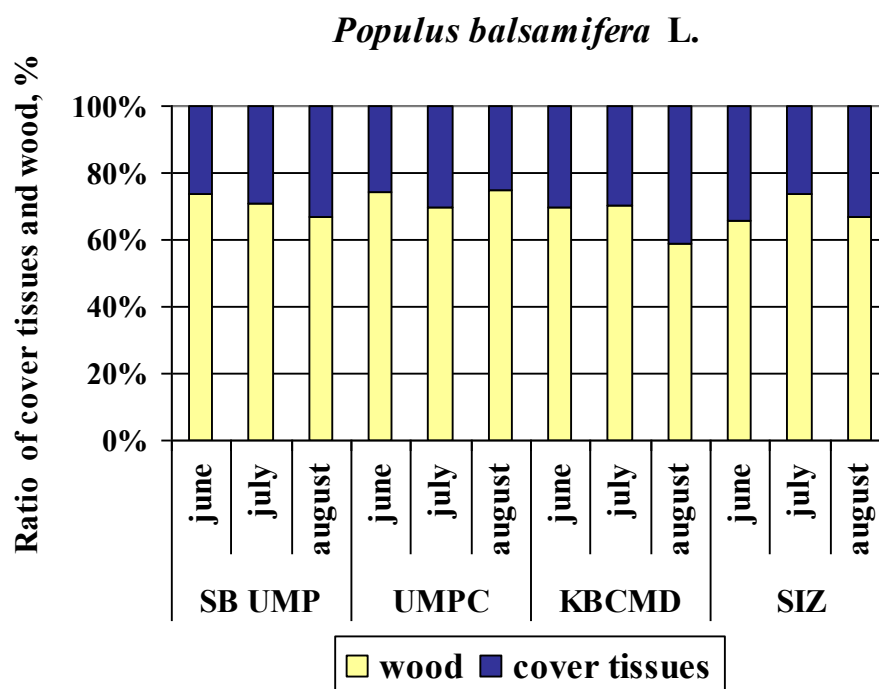
In the poplar growing in the SIZ, covering tissues of the conducting roots are developed. It is significant that at the beginning of the growing season on the KBCMD heaps the thickness of the phloem in the roots of the poplar is minimal, and by the end of the vegetation it reaches its maximum values. The conducting system is developed in the roots of the poplar on the dumps of UMPC and KBCMD (Figure 6).

Cover tissues of the conducting roots are developed in pine plants on the dumps of the SB UMP at the beginning of the vegetative period - at the UP (Figure 7).

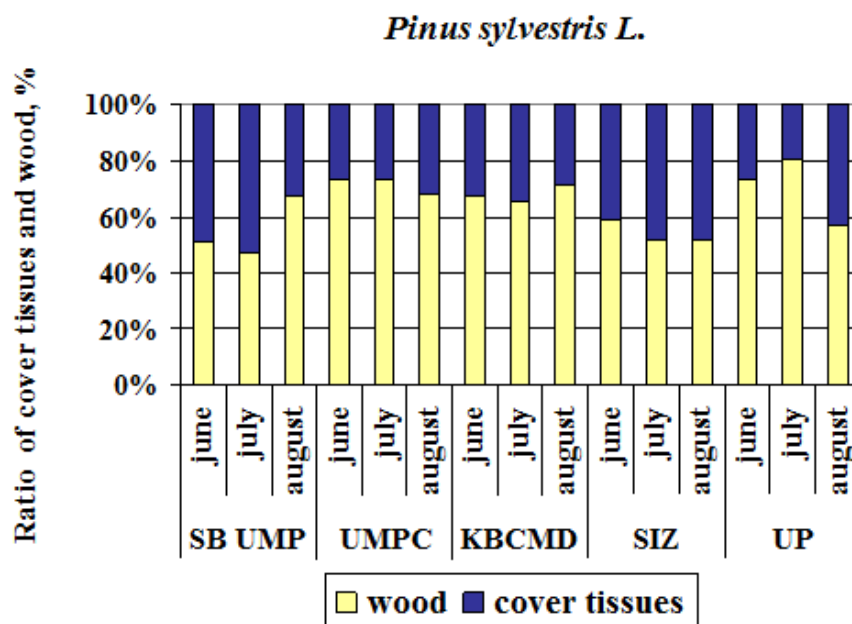
Larch forms powerful cover tissues in conditions of SIZ, and minimal - on UP. At the same time, the conducting larch tissues are well developed in conditions on the UP and on the KBCMD dumps (Figure 8).



**Figure 5.** Ratio of coverslips and wood (%) of conducting roots *Betula pendula* Roth, growing in extreme forest conditions.

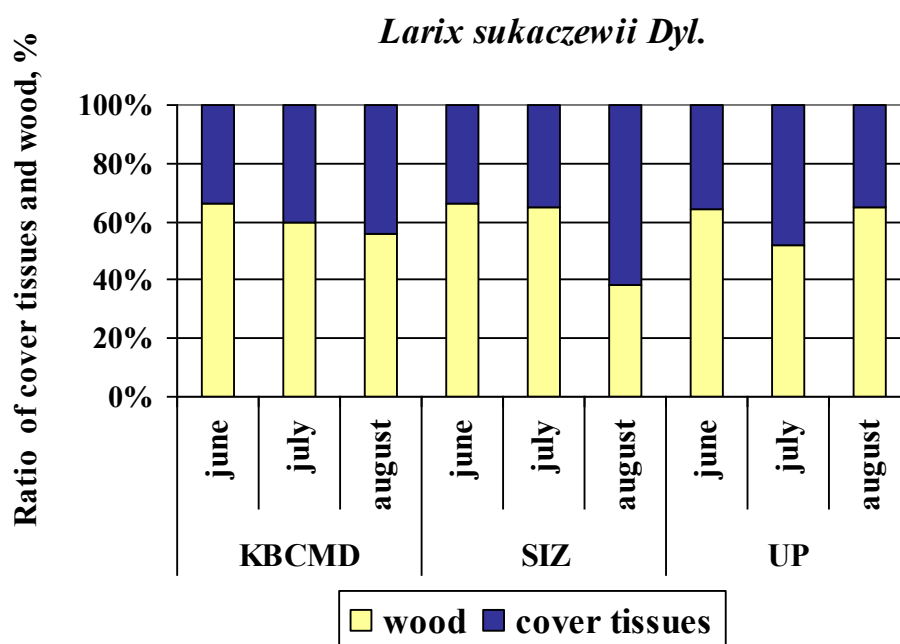


**Figure 6.** Ratio of coverslips and wood (%) of conducting roots *Populus balsamifera* L., growing in extreme forest conditions.



**Figure 7.** Ratio of coverslips and wood (%) of conducting roots *Pinus sylvestris* L., growing in extreme forest conditions.





**Figure 8.** Ratio of coverslips and wood (%) of conducting roots *Larix sukaczewii* Dyl., growing in extreme forest conditions.

#### 4. Conclusion

The changes in the anatomical organization of the assimilation organs and the conducting roots of woody plants are manifested as follows: the thickness of the leaf mesophyll increases in birch; poplar formed powerful leaf cover tissues; in pine, integumentary tissues of needles of the first, second and third year increase; in larch, integumentary tissues of conductive roots increase. At the same time, as a general pattern, it is necessary to note the formation of additional protective layers on the surface of the assimilation organs in the form of a wax coating and a decrease in the density of the mesophyll.

It should be noted that seasonal anatomical and morphological changes in the structure of the assimilation organs and the conducting root system are adaptive in nature and ensure the successful growth of woody plants in extreme vegetative conditions. Assimilation organs in extreme forest conditions during the growing season are characterized by an overall increase in leaf thickness, with the largest increase being due to mesophyll tissues.

During the growing season, the ratio of the values of integumentary tissues and wood of conductive roots increased, which may be associated with a dry period of growth. The development of integumentary tissues of conducting roots is considered as an adaptive response of woody plants to the technogenic transformation of the environment.

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