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The structure of larch forest stands formed in previously treeless areas as a result of climate change

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Abstract. The article deals with the formation of larch stands on the upper forest boundary in extreme forest conditions under the influence of climate change.

1. Introduction
In modern conditions of development of forest science and nature management, one of the main tasks is to study the response of forest ecosystems to ongoing climate change (warming). When assessing the impact of climate on the growth and development of forest vegetation, the most sensitive objects are high-latitude and high-mountain ecosystems. It is known that the clearest changes in vegetation growth are observed under extreme forest conditions [1-10]. Alpine forest ecosystems are currently little studied and the information obtained about them is very important for monitoring and environmental assessments. The advancement of forest plantations under the influence of climate warming up to the mountain tundra region leads to an increase in forested areas that perform the most important biospheric and ecological functions.

2. Materials and methods
The object of study is located in the Northern Urals in its southern part in the area of the Konzhakovsky mountain range (59°30' - 59°40' N L, 59°00' - 59°20' U L). The peaks here reach a height of 1569 m and have a clear vertical (altitude) zonality.

The mountain forest belt is mostly represented by dark coniferous forests. The predominant species are Siberian spruce, Siberian fir and Siberian cedar, rising to a height of 850–900 m n. y. m. Above the slope (up to 1000 m) there is a subalpine belt, the lower part of which is clump closed forests, above 1000 m - island low forests and low grasses, and in the upper part - individual trees located in groups. On the slopes of Serebryansky Kamen, Siberian larch predominates, forming light forests. Birch plantations (Tylaisky stone) are represented by birch winding. The upper part of the mountains is mountain tundra and loaches.

The studies were carried out on 5 profiles, in plantations with different dominant species. On profiles 1 and 2, larch dominates in the forest stand (slopes of Serebryansky stone), on profile 3 - birch (Tylai stone), and on profiles 4 and 5 - spruce (Ostraya Kosva). Map - the layout of high-rise profiles is shown in figure 1.

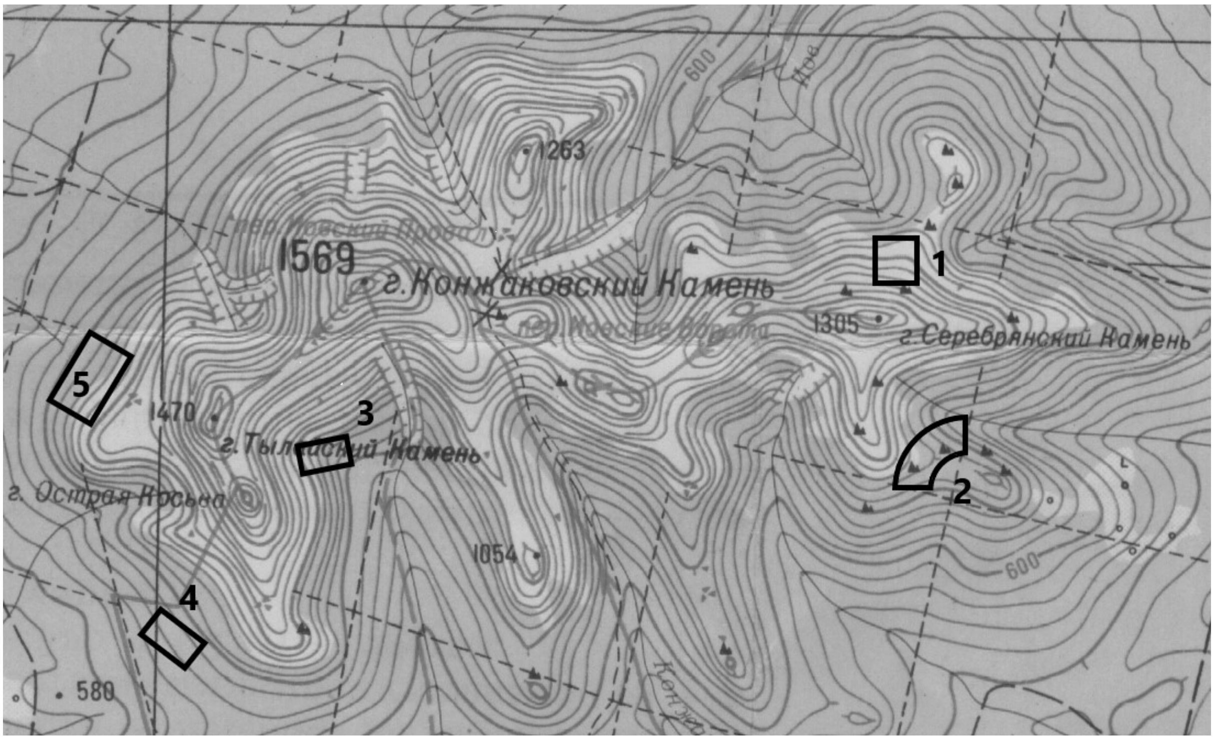


Figure 1. Altitude profile locations: 1, 2 - larch stands; 3 - birch; 4, 5 - spruce forests.

On the altitude profile, levels were recorded at three elevations: the upper one was 905 m, the middle one was 950 m, and the lower one was 1000 m above sea level. The work was carried out on trial plots (from 3 to 6 pieces at each level, depending on its length), the size of each of which is 20x20 m. The following parameters were instrumentally determined for each specimen of larch on the site: the height of the tree, its diameter at two marks (0 and 1, 3 m), crown length in two directions (N-S, W-E) and its length. Wood samples (core) were taken to determine the age.

In this article, we will consider the structure of forest stands in accordance with the topic outlined above, using the example of profile 1 larch forests (the northern slope of Serebryansky Kamen), divided into altitudinal levels, where forest stands are at different stages of formation.

3. Results

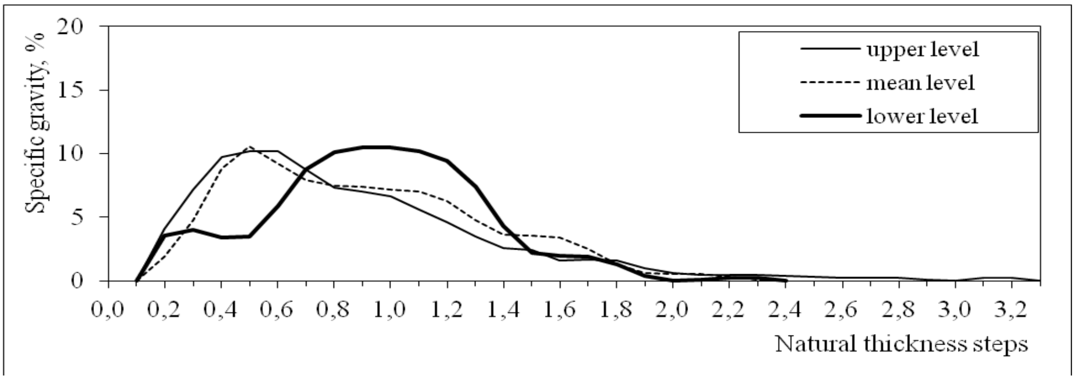
The main characteristics of tree distributions by diameter and height are given in table 1.

Larch stands are distinguished by a wide range of variation in trunk diameters (from 39% to 60%). The average value of this indicator decreases with an increase in the altitude level (from 15.5 cm at the bottom to 4.4 cm at the top). The variability of tree heights in the studied forest stands is somewhat lower than that of diameters. It is 37% in the lower part of the profile, in the middle - 46% and in the upper - 32%. The reasons for the appearance of the identified patterns are the decrease in the age of trees and the deterioration of conditions for growth up the slope.

We used the method of natural steps by A.V. Tyurin, which makes it possible to compare the distribution rows of trees at different height levels (different average diameters and heights). Figure 2 shows the percentage distribution of the number of larch trees in terms of thickness and height at different height levels. It should be noted a large amplitude of fluctuations in the values of natural thickness steps (reduction numbers in tenths of the average value).

Table 1. Main statistical characteristics of larch stands in terms of diameter and height at different altitude levels of the first profile.

Statistical characteristics	Profile part		
	upper	average	lower
	Diameter		
Average value, cm	4.4 ± 0.18	7.7 ± 0.21	15.5 ± 0.53
Minimum value, cm	0.6	1.1	2.4
Maximum value, cm	16.2	20.0	35.0
Standard deviation, cm	2.6 ± 0.13	3.8 ± 0.15	6.0 ± 0.37
The coefficient of variation, %	60 ± 3.8	49 ± 2.4	39 ± 2.7
Asymmetry coefficient	1.39 ± 0.167	0.61 ± 0.139	0.00 ± 0.213
Kurtosis coefficient	2.66 ± 0.335	-0.27 ± 0.278	0.26 ± 0.446
Error probability, %	4.1	2.8	3.4
	Height		
Average value, cm	2.6 ± 0.06	3.6 ± 0.09	6.3 ± 0.20
Minimum value, cm	1.5	1.5	1.6
Maximum value, cm	4.8	8.5	11.0
Standard deviation, cm	0.8±0.04	1.6±0.07	2.3±0.14
The coefficient of variation, %	32 ± 2.0	46 ± 2.0	37 ± 2.7
Asymmetry coefficient	0.72 ± 0.167	0.83 ± 0.139	-0.29 ± 0.213
Kurtosis coefficient	-0.29 ± 0.335	-0.12 ± 0.278	-0.79 ± 0.426
Error probability, %	2.2	2.6	3.1



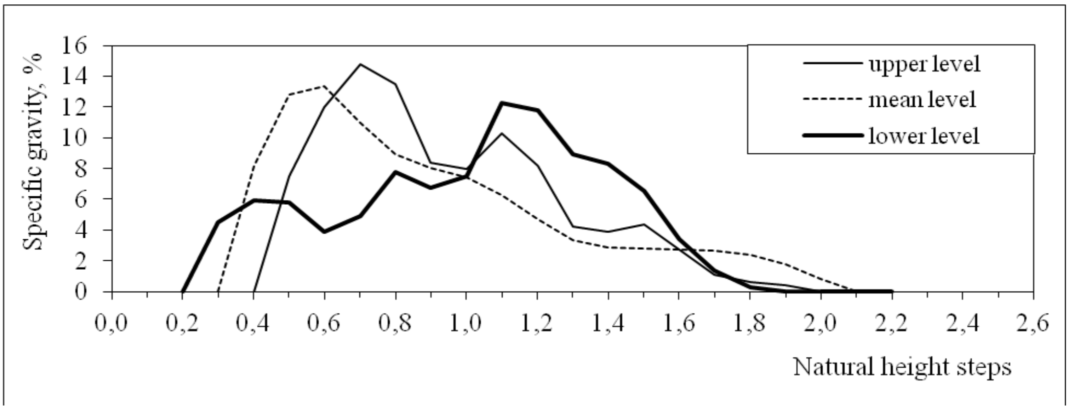


Figure 2. Distribution of larch trees according to natural thickness and height steps.

4. Discussion

The forest stands under consideration differ in the degree of variation in trunk diameters. In our opinion, this can be explained by the significant difference in age of the studied larch plantations. There is a reasonable decrease in asymmetry values with a decrease in height above sea level. In the upper and middle parts of the slope, there is a left shift of the distribution curves with respect to the normal distribution. Moreover, the values of the asymmetry coefficients under these conditions are determined at a high level of reliability ($t > 3$). This suggests that the shape of the empirical tree thickness distribution curves differs significantly from the normal distribution. In the rows of distribution of trees by diameter at the lower and upper levels, the largest number is concentrated near the arithmetic mean value to a greater extent, and at the middle level - to a lesser extent than for the normal distribution curve. The results of our research indicate that the curve r of the x-distribution can be used as satisfactory approximation functions of the empirical series by the diameter of the trees in the upper part of the profile, the curve r of the γ-square distribution in the middle part, and the normal distribution at the lower level.

The coefficient of asymmetry in the rows of distribution of trees by height changes from negative to positive values with increasing height above sea level. At the same time, Student's criterion ($t > 3$) indicates the reliability of this indicator only at the upper and middle levels. In general, the mode of tree height distribution relative to the mode of diameter distribution is to the right, which is quite consistent with the data in other works.

The distribution of trees by height in forest stands at all levels of the profile is characterized by negative values of the kurtosis coefficient. It is impossible to give a conclusion about the steepness of the distribution curves relative to the normal distribution curve - the values of the kurtosis coefficients at all levels are unreliable ($t<3$). With a decrease in height above sea level, the rank of the average tree in height gradually decreases: at the upper level it is 74.4%, at the middle level - 75.9% and at the lower level - 59.4%. This pattern, as in the case of the rank of the average tree in terms of diameter, can be explained by the increase in the age of stands as we move down the slope.

5. Conclusion

Larch stands formed in the subalpine belt in their growth and development differ significantly from stands developing in flat conditions, which is confirmed by the results of our work. The investigated larch forests have a high level of variability in diameters and heights. The coefficient of variation exceeds the values typical for lowland forests. The distributions of trees in diameter and height are different from the normal distribution, and differ in shape indicators. The variability of taxation indicators, the type of distribution of trees in forest stands in different parts of the profile differ significantly. This suggests that forest stands are at different stages of formation in different parts of the slope. Similar patterns are noted in the authors' works on other regions of the Urals.

References

[1] Gao L, Zhang Y, Wang X, Zhao Y, Liu L and Gao L 2018 Sensitivity of three dominant tree species from the upper boundary of their forest type to climate change at Changbai Mountain, Northeastern China. *Tree-Ring Research* **74(1)** 39-49

[2] Jaeger L and Kessler A 1997 Twenty years of heat and water balance climatology at the Hartheim pine forest, Germany. *Agricultural and Forest Meteorology* **84(1-2)** 25-36

[3] Kimiko H and Michi-nori S 2003 Spatial distribution of canopy and subcanopy species along a sloping topography in a cool-temperate conifer-hardwood forest in the snowy region of Japan. *Ecol. Res.* **4** 443-454

[4] Kullman L 2001 20th century climate warming and tree-limit rise in the Southern Scandes of Sweden. *Am-bio* **30(2)** 72–80

[5] Lloyd A H and Graumlich L J 1997 Holocene dynamic of treeline forests in the Sierra Nevada. *Ecology* **78** 1199-1210

[6] Payette S and Lovoie C 1994 The arctic tree line as a record of past and recent changes.

Environment Review **2** 78-90
[7] Taylor A H 1995 Forest expansion and climate change in the mountain hemlock (Tsuga mertensiana) zone. *Arctic and Alpine Res.* **27** 207-216
[8] Zhang S-Q, Wang W-M, Sun G, Chen C-Y and Wang Y-Q 2019 Late Cenozoic palynofloras revealing significant environment and climate changes in Changbai Mountain area. *Review of Palaeobotany and Palynology* **261** 1-10
[9] Woodward A, Schreiner E G and Silsbee D G 1995 Climate, geography, and tree establishment in subalpine meadows of the Olympic Mountains. *Arctic and Alpine Res.* **27** 217-225
[10] Yang W, Wang Y, Webb A A, Wang S and Yu P 2018 Influence of climatic and geographic factors on the spatial distribution of Qinghai spruce forests in the dryland Qilian Mountains of Northwest China. *Science of the Total Environment* **612** 1007-1017