Impact of Climate Change on the Forests of the Ural Mountains

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Abstract

Climatic factors are the main factors determining the structure and dynamics of natural ecosystems of the Ural Mountains. The climate of the Urals was not constant in the past. This led to the glaciations, warm (dry and wet) periods. Vegetation structure changes constantly. Currently, a strong anthropogenic factor added to the natural tendencies. Global warming is manifested clearly in the Ural Mountains. We can see vegetation changes along the entire length of the Ural Mountains. This is reflected in the shift of the boundaries between vegetation types (and forest types), change in ecosystem structure, outbreaks of diseases and insects. The speed and scale of change are high.

Keywords: Climate, forest, vegetation, Russia, Ural Mountains

1. Introduction

Climate change is recognized as the most pressing problem of our time from the decision of which the future of human existence depends[1, 2]. Climatic instability leads to the increased probability of local and global food crises. Frequent hot periods, uneven rainfalls and increased water scarcity lead to_ decrease in the stability of agricultural production [3, 4, 5].A large-scale reduction of natural ecosystem areas accompanied by the destruction of biodiversity on the planet, will inevitable lead to a decrease in their regulatory capacities [6]. In the past, the consequences of anthropogenic disturbance of ecosystems led only to locally or regionally environmental damages; presently, however, a global scale of this process is becoming more apparent [7].

The problem of climate change is given a lot of attention all over the world. Nevertheless, solution of this problem is not found. A lot of questions have not been decided by this day [8, 9]. Regional features of the manifestation of this global process are not determined until.

It is well-known that forests have exclusive environment-modifying and climate-regulating value. Therefore, the researches of climate impact on the forests (impact of forests on the climate) are acutely topical nowadays.

2. Field study

Our study area is located in the Ural Mountains. Ural forests (Russia) are part of the belt of coniferous forests in the Northern Hemisphere. The Ural Mountains are located on the border between Europe and Asia, at the junction of two floras (Figure 1). They are one of the 200 hot spots of biodiversity, the preservation of which is necessary for the future survival of mankind on the planet Earth.

Figure 1: The Ural Mountains are located on the border between Europe and Asia

The Ural Mountains are among the oldest mountains on the planet. Their history is long and complex. It begins in the Proterozoic era with the breach of the crust. This breach extended for almost two billion years, and the ocean was formed on the site of the future mountains. The convergence of lithospheric plates began about 300 million years ago, and the mountains were formed.

Now the Ural Mountains are a whole system of mountain ridges, which extend parallel to one another in the meridional direction. Ural Mountains consist of low ridges and arrays. The Ural Mountains are divided into five areas: the Polar Urals, Subpolar (Nether-Polar) Urals, the Northern Urals, Middle

(Central) Urals and Southern Urals. The highest of them have a height of 1200-1640 meters above sea level. They are located in the Polar Urals, the North Urals and Southern Urals. The height of the Middle Ural Mountains is not more than 600-650 meters above sea level (Figure 2).

Figure 2: The Ural Mountains are divided into five areas: the Polar Urals, Subpolar Ural (Nether-Polar Urals), the Northern Urals, Middle (Central) Urals and Southern Urals.

The complex history of the formation of the Ural Mountains has led to the richness and diversity of natural ecosystems (from tundra to steppe).Forests are the most common type of vegetation. The forests stretch along the mountain slopes of the Ural Mountains continuous strip.Dark-coniferous forests prevail on the western slopes. Spruce forests and fir forests are dominant ecosystems. Pineforestsprevailontheeasternslopes.

Geographical location, great distance from north to south, the complex history of the formation of the Ural Mountains and the extreme heterogeneity of landscapes make the Ural Mountains a unique object for studies of the effect of climate change on vegetation.

We conducted our study in Zauralsky (Trans-Ural) hilly piedmont province (Russia, the Middle Urals): between 57°00´–57°10´ N and 60°10´–60°30´E. It is divided into foothills formed by alternating meridional low mountains and ridges with wide, intermountain elongated low lands, in which there are large lakes surrounded by moors[10]. The mountains have altitudes of 200 to 500 m a.s.l. The mountains have soft contours, blunt and broad peaks, while the slopes are long and flat. The climate is moderately cold and humid. Frostless periods last 90 – 115 days, the average annual temperature is 1°C, and the average snowfall is between 40 and 50 cm[10]. The main factors of soil formation in the Urals are mountainous terrain, continental climate, both for ancient and young forming soils, which, combined with a great diversity of vegetation, alters soil characteristics. Mountain soils are characterized by relatively small depth, light mechanical composition (dominated by light and medium loam), different degrees of skeleton (skeletal soil), going up with decreasing soil depth. In the soil distribution of Zauralsky (Trans-Ural) hilly piedmont province of the Middle Urals the dependence on the terrain is clearly visible. The tops and upper thirds of steeper slopes, where the thickness of eluvial deposits is least of all, are occupied by shallow, underdeveloped soil with a high degree of skeleton and relatively light texture. Brown non-podzolized and podzolized soils are confined to the middle and lower thirds of the gentle slopes. Flat-topped low ridges, gentle slopes and well-drained downward slopes are occupied with sod-pale-yellow-podzolic soil, which differs in thickness of the soil profile and the degree of podzolization. The soil of smoother slopes, intermountain depressions, and the lows are often characterized by greater depth and moderate skeleton[11].

3. Research Objects

All major mountain habitats are included in our study. We climbed to the most-capped mountains. The steep and gentle slopes of the northern, southern, eastern and western exposure were investigated by us. We are not left unattended swamp forests and marshes. We examined all the most common forest types. It is diverse pine and spruce forests.

4. Sampling Procedures

The 0.5 ha sampling plots were laid according to commonly used methods[12]. The plots were studied with regard to their tree stand, understory, and grass layer. We counted all the trees on the sampling plot, measured their diameter, height, and we identified the age by the annual rings. For shrubs we defined the projective cover. We took dry biomass as an integral characteristic role of plants. In order to determine the productivity of grass-dwarf shrub layer we established from 10 to 20 record subplots of 1×1 m over period of maximum grass stand (July). The subplots are situated on two perpendicular lines. The plants were cut at soil level, sorted by species, dried to an absolutely dry condition at the temperature of 105 °C and afterwards weighed. The mass of tree species was determined by calculation [13, 14]. We used reliable forest taxation data. The weight of the crown was calculated on the basis of regression equations that take into account physiological patterns (pipe model)[14].

5. Data Analysis

For data analysis we used Detrended Correspondence

Analysis (DCA). This analysis is a reliable and useful tool for researching in community ecology. Algorithm of DCA-analysis is well described in the literature[15, 16, 17, 18, 19].The method is implemented in a number of software packages and applications: CANOCO[20], DECORANA[21].

6. Results and Discussion

We analyzed the variety of forest types and the effect of various climatic factors on the structure of forest ecosystems. Forest types are allocated according to the geographical and genetic typology [22]. Pine forest types and dark-coniferous forest types were divided into DCA axes well. Two large groups (pine forest and spruce forest) clearly seen in Figure 3.

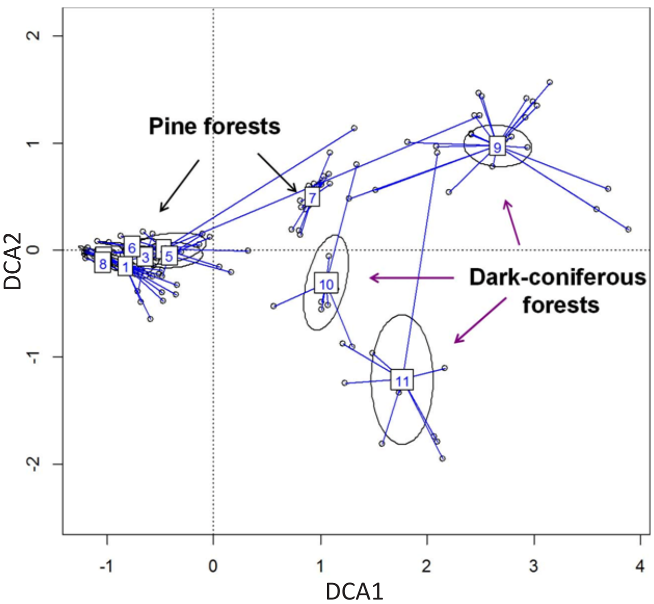

Figure 3: DCA- ordination of Trans-Ural hilly piedmont province forests of the Middle Urals: the nos.- no. of forest types

Various dark-coniferous forests are located in Figure 3 is also apart. Therefore, they have great differences in the structure of the vegetation. Forest type №11 is shown in Figure 4. It

Figure 4: Dark-coniferous forest with Siberian pine and continuous cover of mosses (photo by Natalya Ivanova)

is waterlogged spruce forests with Siberian pine. They grow along the edges of the marshes. The subordinate layer is a continuous layer of moss. In this forest type are many species of marsh plants.

Forest type number 10 is shown in Figure 5. These coniferous forests grow along the edges of the marshes on powerful well-watered soils. Soil is waterlogged only in the spring time. Grassy layer is well developed. It is represented by large grasses.

Figure 5: Pine-spruce forest with well developed herbaceous layer and undergrowth of *Picea obovata* and *Abies sibirica* (photo by Natalya Ivanova)

Forest type number 9 is shown in Figure 6. These forests are located in the lower parts of the slopes. The soils are deep. The soil can be waterlogged only in the spring.

Figure 6: Spruce forest with Oxalis *acetosella* (photo by Natalya Ivanova)

Pine forests with multi-species herbaceous layer (Figure 7) grow on the deep and rich soils.25-30 species of herbs is 1 square meter.

Marked 1-6 and 8 forest types formed one group (Figure 3). They grow in the upper and middle parts of the slopes with shallow stony soils. Herbaceous layer developed more weakly (Figure 8).

Figure 7: Pine forest with well developed multispecies herbaceous layer (photo by Natalya Ivanova)

Figure 8: Pine forest with *Vaccinium vitis-idaeaon* the mountain tops and the upper parts of the southern slopes (photo by Natalya Ivanova)

We conducted a special research to answer the question: what factors led to the formation of such a diversity of forest types. The analysis included the study of climatic and soil factors. E. Zolotova[23, 24] has identified factor values on environmental scales. The results are shown in Figure 9. The length of the vector indicates factor impact on the vegetation structure. Figure clearly shows that soil factors (soil nitrogen wealth) related to the first DCA axis, and climatic factors are associated with the second DCA axis. Factors listed below are of great importance in the formation of forests. They can be considered the main acting factors. These climate factors are temperature, moisture and severe winters.

Thus, climate change will lead to changes in ecosystem structure and diversity. The boundaries of forest types will shift. Some forest types will replace the other. Forests that grow in extreme conditions of habitat will be the most vulnerable. These conditions are the steep southern slopes and wetlands habitats. Climate change will have the greatest impact here.

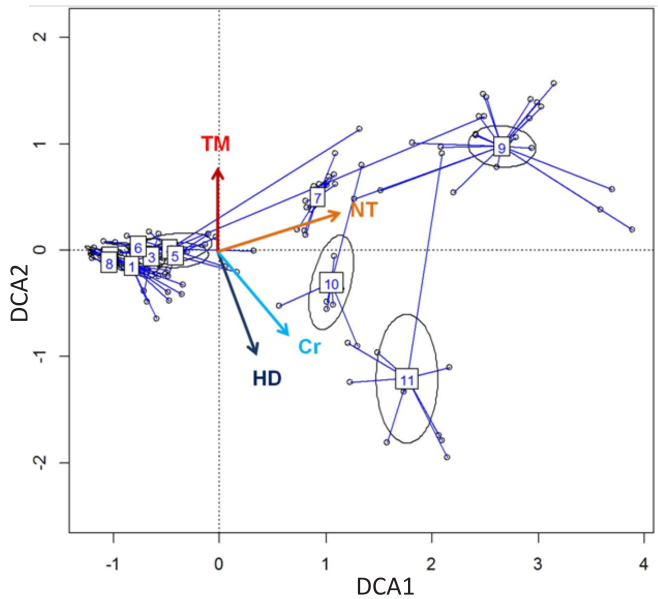

Figure 9: Effect of climatic factors on the forest ecosystem differentiation of Trans-Ural hilly piedmont province forests in of the Middle Urals: the nos.-no. of forest types; HD: moistening; TM: temperature; Cr: severe winters; NT: nitrogen

Also, the influence of climate is well traced on the upper border of the forest. Such research has been going on many years in the Ural Mountains [25, 26, 27, 28]. The earliest distinct maximum in stand density occurred in the 11th to 13th centuries, coincident with Medieval climate warming. Climate warming in the 18th century appears to have resulted in a second stand-density maximum. The recent temperature increase observed in the 20th century is reflected in the high number of young trees observed. The analysis of vertical and horizontal shifts in the upper boundaries of open and closed forests on the eastern macroslope of the Polar Urals provides evidence for widespread and active expansion of tree vegetation to higher elevations over the past 90 years, which is apparently explained by favorable changes in climatic conditions.

Stepan Shiyatov has been having more than 3 thousands of landscape photos for years of research work. He compared the photos which are taken at different times in the Southern, North, Sub polar and Polar Urals (Figure10). His study found that forest boundary rose to 4-8 meters in all four regions over the past decade, and the forests became more dense[28].

Climatic factors are keys in appearance outbreaks. A periodic droughts have a great importance in the occurrence of outbreaks of reproduction. The full spring-summer drought have a great importance for occurrence of outbreaks [29]. Exposure of factor abiotic stress (drought) accompanied with temporary decrease of their stability and entomoresistance. The full rank structure of the outbreaks mechanism is revealed [30]. The factor of the first rank is abiotic stress caused by drought. The factor of stands response to abiotic stress has second rank. The low resistance stands response is especially significant. The reaction rate is determined by the degree of

Figure 10: Landscape photos by Stepan G. Shiyatov (photographed with single pointin different years)

reduction of the annual radial growth in the year of drought. It is accompanied by shifting of physiological and biochemical parameters of leaves and needles stands significantly increase their feeding value. The factor of the third rank is population-genetic: the presence of a group species of insects (Figure 11) of high biotic (flash) the potential which enables fast

Figure 11: Imago of *Limantriya dispar* L. (photo by Evgeny V. Koltunov)

adaptation to changes in the biochemical composition of feed substrate. This accompanied by a sharp increase in the survival of the population phyllophages-feeding insects that eat it [31]. During the past 100 years in the forests of Siberia and Far East of the Siberian moth defoliation stands had been drying more than 13 millions hectares of coniferous forests [32]. It is known that the periodic exposure to strong and prolonged droughts have a negative influence not only on the entomoresistance stand parameters, but also on their resistance to infectious diseases. The mechanism of cascading reduced of the stands stability initiated factor abiotic stress, can function successfully as a factor contributing to the emergence of diseases, which then initiates the occurrence of outbreaks of reproduction, as well as in on reverse direction[33] (Rosso, Hansen, 1998). It has been shown that the defeat of the stem rots birch accompanied by an appreciable decrease in entomoresistance and increasing defoliation gypsy moth crowns, if compare to healthy trees[34]. Conversely, severe defoliation of birch in weakened caused considerable activation of bacterial hydrops in these stands [35].

In the past, the climate of the Urals experienced repeated cyclical fluctuations, sometimes it was much cooler (which led to glaciation), sometimes it was much warmer than at present. They have led to large changes in vegetation [36, 37, 38].The three periods of the most significant climatic changes are established for the study area [39]. 1) The warming and beginning of the spread of arboreal vegetation at the boundary between the Late Glacial and Eraly Holocene about 11 thousands calendar years ago, or 11 ka; 2) the substantial warming between 9.3 and 8.6 ka resulted in the wide spread of pine and formation of mixed forests with broad-leaved trees; 3) an abrupt decrease of spruce and broad-leaved arboreal plants in forest communities, indicating a dry cooling at about 4.2–3.8 ka. Those periods are related to the changes of archaeological epochs. The other three periods of climate aridification are established by the decreasing spruce frequencies in the pollen spectra and the transition from sapropel to peat due to lowering water levels in the lakes at about 8.3–7.8, 6.2–5.8, and 5.4 ka (Table 1). If we compare

Table 1: Holocene stages of the environmet development on the eastern slope of the Middle Urals[39]

Holocene period	Calendar age, BP	Vegetation	Climatic conditions
Late Holocene	2855±68 3106±106	Pine forests with spruce, fir, birch, with admixture of lime, elm, oak	Moderate warm, some arid
	3366±79	Pine forests with admixture of spruce, fir, birch, lime	
	3841±98	Birch-and-pine forests with spruce and larch	Moderate cooling
Middle Holocene	4259±109 4337±62 4996±125 5398±54 5621±25 5468±99 5466±111 5800±83 5809±96	Pine-and-spruce forests with fir and admixture of broad leaved trees, sometimes - with Siberian pine	Moderate warm, humid

Continue...

Holocene period	Calendar age, BP	Vegetation	Climatic conditions
Middle Holocene	6286±105 6904±88	Spruce-and-pine forests with fir, admixture of lime, elm, oak, aglet, sometimes with admixture of birch	Moderate warm, humid
	7854±62	Pine forest with spruce, Siberian pine and larch	Arid cooling
Early Holocene	8306±63 8566±38 8667±56	Pine forests with admixture of birch, spruce, fir, Siberian pine, with few of broad leaved trees	Moderate warm and some arid
	9386±57 9589±40	Pine forests with admixture of birch and Siberian pine	Arid warming
	9768±130 10 093±109	Birch-and-pine forests with admixture of spruce and larch	Moderate humid, cool
	10 312±58	Birch-and-spruce-and-larch open woodland	Moderate cold and more humid
	10 966±128	Larch-and-birch open woodland	Moderate cold and arid
Late Glacial		Herb and shrubby tundra and forest-tundra	Cold and arid

the climatic situation in the past with the present state, it is possible to predict changes in natural ecosystems.

7. Conclusion

Thus, climatic factors are the main factors determining the structure and dynamics of natural ecosystems of the Ural Mountains. The climate of the Urals was not constant in the past. This led to the glaciations, warm (dry and wet) periods. Vegetation structure changes constantly. Currently, a strong anthropogenic factor added to the natural tendencies. Global warming is manifested clearly in the Ural Mountains. We can see vegetation changes along the entire length of the Ural Mountains. This is reflected in the shift of the boundaries between vegetation types (and forest types), change in ecosystem structure, outbreaks of diseases and insects. The speed and scale of change are high. Our study confirms the necessity of further comprehensive interdisciplinary researches. Their goal should be to foresee the regional manifestations of global warming. The solution to this problem is necessary for the sustainable management of natural resources in today's uncertain world and for the survival of mankind.

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