Manifestation of altitudinal differentiation of climatopes and phytocoenoses on the slopes of the Maly Yamantau Ridge (South Ural Nature Reserve, Russia)

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Abstract. The altitudinal variability in the vegetation structure was studied for the Maly Yamantau Ridge (Ural Mountains, Russia). Previously, a number of original assumptions regarding the peculiarities of the altitudinal differentiation of forest formations in the region of deciduous-dark coniferous forests of the Southern Urals have been made, and a generalized scheme of altitudinal differentiation of climatopes and forest formations in this area has been presented. The study aims to search for the ways of manifestation of general patterns of altitudinal differentiation of forest formations on a particular mountain range. The Maly Yamantau Ridge was considered as a model area, since its vegetation has been studied in detail. A network of sample sites, serving as the markers of climatopes, was set in primary and secondary phytocoenoses. In general, the primary broadleaf and dark coniferous phytocoenoses may serve as the reliable markers of altitudinal belts and their climatopes. Secondary phytocoenoses blur the manifestation of altitudinal differentiation of the climatopes. The altitudinal ranges occupied by climatopes on the slopes of the Maly Yamantau Ridge have been defined. The altitude spectrum of climatopes and forest formations is pronounced much on the western slope of the ridge; on the southern slope, it is not expressed.

1. Introduction

Altitudinal differentiation of forest formations has been noted by researchers on highlands and in mountainous regions of Russia, including the Middle Urals [1, 2, 3], the Southern Urals [4, 5], on the Ufa Plateau [6, 7, 8], and in the Cis-Ural Region [9].

A number of original assumptions regarding the peculiarities of the altitudinal differentiation of forest formations in the region of deciduous-dark coniferous forests of the Southern Urals has been made earlier. A generalized scheme of the altitudinal distribution of climatopes and forest formations in this area was developed [10, 11]. According to the original ideas, the altitudinal differentiation of forest formations in this area is governed by the two major factors: (1) altitudinal differentiation of the climate; (2) lack of thermal resources for broad-leaved arboreal thermophytes. Altitudinal differentiation of the climate is due to the altitude temperature gradient; as a result, a certain number of high-altitude mesoclimates are formed, differing in overall thermal regime and the cumulative temperatures. The pronounced lack of thermal resources for broad-leaved tree species (limiting factor) is responsible for the spreading of the broad-leaved phytocoenoses in warm ecotopes only.

Four groups of ecotopes (climatopes) have been defined; they differ by the heat amount and the nature of the thermal regime. These are cryothermal (Kr), mesothermal (Mz), microthermal (Mi), and nanothermal (Na) climatopes. Each one occupies a certain altitude range; together, they form an altitude spectrum (figure 1). The sequence of climatopes in this spectrum is largely due to the temperature inversions, which precondition the location of the warmest ecotopes at the tops of low mountains, as well as on the slopes of high mountain ranges at an altitude of 450-550 meters above sea level. The so-called "warm belt" or the belt of mesothermal climatopes is formed here. The belts of microthermal climatopes locate below and above the "warm zone". The uppermost belt, located on the tops of high-mountain ranges that rise above 750
meters above sea level, forms nanothermal climatopes. The lowest belt is formed by cryothermal climatoposes; they occupy the lowest areas of small river valleys located at an altitude of 200-350 meters above sea level.

The distribution of a certain forest formation is associated with each of the climatoposes described above. Dark coniferous forests are presented in nanothermal and cryothermal climatoposes, deciduous forests, in mesothermal climatoposes, and deciduous-dark coniferous forests, in microthermal climatoposes. The thermal regime of mesothermal climatoposes is favorable for broad-leaved species; here, they are characterized by maximum coenotic activity, so they dominate in coenoses. The environment of microthermal climatoposes is less favorable for broad-leaved species; here, both broad-leaved and dark-coniferous species have similar coenotic activity. The conditions of cryothermal and nanothermal climatoposes are unfavorable for broad-leaved species, so dark-coniferous species have the leading coenotic role here, and the coenotic activity of broad-leaved species is reduced down to a minimum.

The full altitude spectrum of forest formations includes five of them in the following sequence (from bottom to top): dark coniferous forests — deciduous-dark coniferous forests — deciduous forests — deciduous-dark coniferous forests — dark coniferous forests (Figure 1). This spectrum is observed on the slopes of the highest mountain ranges (Belyagush, Zilmerdak, etc.) On the slopes of low mountains, a truncated spectrum is observed, including three formations (from bottom to top): dark coniferous forests — deciduous-dark coniferous forests — deciduous forests. We argue that these structures of altitudinal differentiation of forest formations are typical for the entire zone of deciduous-dark coniferous forests.

![Figure 1. Altitude spectrum of climatoposes and forest formations in the area of deciduous-dark coniferous forests of the Southern Urals (climatoposes are indicated in brackets as abbreviations).](image)

The study aims to find out how the general patterns of altitudinal differentiation of forest formations, established by the authors suggested originally for the region of deciduous-dark coniferous forests of the Southern Urals, manifest on the slopes of particular mountain range. The Maly Yamantau Ridge was selected as a model territory, since its vegetation has been studied in detail [3].

2. Materials and Methods
A network of forest sites used as climatoposes markers was set on the Maly Yamantau Ridge. This network included fourteen 0.25-ha model sites (50 m × 50 m each). The height above sea level was determined for each site. Three areas were analyzed in primary broad-leaved plantations, two areas, in conditionally primary dark coniferous plantations (Table 1). These sample areas can serve as reliable markers of mesothermal, nanothermal, and cryothermal climatoposes. Nine areas located in secondary phytocoenoses. The successional status of these secondary communities was determined based on the analysis of the composition of the tree layer and undergrowth; the primary phytocoenoses at these sites were reconstructed as well. Two secondary phytocoenoses were identified as short-term, five phytocoenoses, as long-term. The broad-leaved-dark coniferous forests were the primary formations in these ecotopes. This gave grounds to use the studied secondary phytocoenoses as markers of microthermal climatoposes. Detailed information about the sites is presented in the monograph [1].
Table 1. Model sites.

| Absolute height above sea level (m) | Phytocoenosis | Tree species composition | Sampling site no. |
|-------------------------------------|----------------|--------------------------|-------------------|
| 521                                 | Birch forest  | 7Bp2Tc1As; s. Pt, Ps, Ap, Ug | 25                |
| 385                                 | Linden forest | 10Tc+Ap, Pt; s.As, Ug    | 26                |
| 386                                 | Aspen forest  | 8Pt2Tc; s.Bp, Ul, Ap     | 22                |
| 399                                 | Birch forest  | 6Bp1As1Tc; s.Ps, Ug, Pt  | 23                |
| 647                                 | Aspen forest  | 9Pt1Tc; s.Bp, As, Ap, Ug | 27                |
| 530                                 | Oak forest    | 5Qr3Ap2Tc+Bp; s.Ug      | 59                |
| 552                                 | Oak forest    | 5Ap4Qr1Tc+Ug; s.Bp      | 60                |
| **Western slope**                   |                |                          |                   |
| Northern slope                      |                |                          |                   |
| 495                                 | Fir-spruce forest | 5Po3As2Ps+Bp; s.Pt, Tc | 6                 |
| 560                                 | Aspen forest  | 7Pt1As1Po+Bp; s.Tc      | 11                |
| 523                                 | Birch forest  | 6Bp2As1Pt1Tc; s.Po, Ap  | 28                |
| **Eastern slope**                   |                |                          |                   |
| 675                                 | Fir-spruce forest | 7Po3As+Pt, Bp; s.Tc, Ap, Ug | 2          |
| 630                                 | Aspen forest  | 8Pt1As1Tc; s.Bp, Ap, Ug | 21                |
| **Low mountains extending from the western slope** | | | |
| 332                                 | Pine forest with linden | 9Ps1Tc; s.Bp, As | 33                |
| 552                                 | Oak forest    | 7Qr2Ap1Tc; s.Ug, Bp, Pt | 58                |

* Abbreviations: s. – singularly; Po - Picea obovata, As - Abies sibirica, Qr - Quercus robur, Ap - Aser platanoides, Tc - Tilia cordata, Ug - Ulmus glabra, Ps - Pinus sylvestris, Bp - Betula pendula, Pt - Populus tremula.

3. Results and Discussion

The Maly Yamantau Ridge is a part of the mountain range, formed by the Zigal'ga, Nara, Maly Yamantau, and Karatash ridges. The ridge is located within the Karyazinsk-Zilmerdak physico-geographical region [12]. The 6-km ridge stretches from south to north. The highest point locates at 976.3 meters above sea level. Groups of low mountains run from the western and eastern slopes of the ridge, their height reaches 500-550 m above sea level. The valleys of the Maly Inzer and Revet rivers are located at 280-350-m altitude.

The Maly Yamantau Ridge differs by appearance and relief from other mountain ranges in the region. The axial line of the ridge is composed of quartzites, i.e. the rocks resistant to weathering [13]. As a result, the ridge has steep contours, which are characteristic of high ridges located in the central part of the South Urals. The ridge is rocky, the upper parts of the slopes are steep (figure 1). By botanical-geographical zoning, the Maly Yamantau Ridge belongs to the Zil'merdak Region of deciduous-dark coniferous forests [14].

Primary plant communities are the associations of broad-leaved-dark coniferous, broad-leaved and dark coniferous forests, which are distributed locally and cover small areas. The main area is occupied by secondary communities (aspen and birch forests), which have developed as a result of various timber activities, including clear felling. On the sunny slopes, pine forests are common, they exist due to periodic fires. Secondary phytocoenoses, which do not have dark coniferous and broad-leaved tree species in the tree layer and undergrowth, blur the boundaries of climatopes extremely. Fragments of primary phytocoenoses, as well as phytocoenoses with a significant admixture of dark coniferous and broad-leaved tree species in the tree layer, may serve as markers of the altitudinal zones and their climatopes.

The altitude range of the forest formations is visually traced on the western slope of the ridge (figures 2, 3). There are local, small fragments of valley dark coniferous forests among the secondary aspen and birch forests on the lower part of the slope, as well as on the floodplains and on the terraces of the Revet' and Maly Inzer rivers. They are the mark of cryothermal climatopes. The secondary communities found in the northern part of the ridge are lime (P-26) and birch (P-25) phytocoenoses located at 385 and 521-m altitude, as well as aspen (P-22) and birch (P-23) phytocoenoses in the southern part of the ridge (386 and 399 m, respectively). These are the secondary communities that have developed instead of primary broad-leaved-dark coniferous phytocoenoses. They serve as the markers of the microthermal climatopes. Fragments of deciduous forests are present in the middle part of the western slope. There are two primary phytocoenoses — oak (P-59, 514...
m) and maple (P-60, 545 m), they mark the belt of mesothermal climatopes. The studied aspen phytocoenosis (P-27, 647 m) is classified as a secondary community appeared on the site of a primary broad-leaved-dark coniferous phytocoenosis. It may serve as a marker of the microthermal climatopes. In the upper part of the western slope, forest vegetation is not continuous. Fragments of forest, which include dark coniferous species, occupy local areas between rocks and stone fields (figure1).

**Figure 2.** The northern part of the western slope of the Maly Yamantau Ridge.

On the upper part of the eastern slope, a belt of dark coniferous forests is traced visually. Local fragments of boreal dark coniferous forests have been preserved here. The studied pristine fir-spruce phytocoenosis (P-2, 675 m) marks the belt of nanothermal climatopes. In the middle part of the slope, there are secondary birch and aspen forests with an admixture of climax dark coniferous and broad-leaved tree species. The studied aspen phytocoenosis (P-21, 630 m) is classified as a secondary community developed on the site of the primary broad-leaved-dark coniferous phytocoenosis. It serves as a marker of the microthermal climatopes.

**Figure 3.** The northern part of the western slope of the Maly Yamantau Ridge.
On the northern slope, the belts of valley dark coniferous forests are visually traced; they occupy cryothermal climatopes. The belt of deciduous-dark coniferous forests of microthermal climatopes is also clearly seen. The belt of deciduous forests is not pronounced. The belt of cryothermal climatopes with valley dark coniferous forests marks the conditionally pristine fir-spruce phytocoenosis with pine (P-6, 493 m) on the lower part of the slope. The belt of microthermal climatopes with broad-leaved-dark coniferous forests is marked by the studied secondary birch (P-28, 523 m) and aspen (P-11, 560 m) phytocoenoses, classified as secondary communities that developed instead of primary broad-leaved-dark coniferous phytocoenoses.

On the southern rocky slope of the ridge, the altitude spectrum of climatopes is not expressed due to the wide distribution of stone formations and secondary communities (pine and birch groups).

In the low mountains adjacent to the western slope of the Maly Yamantau Ridge, the altitudinal differentiation of formations is also traced. The fragments of dark coniferous forests are found on the lower gentle slopes and terraces of the Maly Inzer and Revet' rivers; the fragments of deciduous-dark coniferous forests are observed on shady slopes and in the logs; and the fragments of broad-leaved forests, on the tops of ridges. The goutweed oak forest (P-58, 552 m), studied at the top of a low ridge, marks the belt of mesothermal climatopes with deciduous forests. On the southern slope, a linden-pine forest (P-33, 332 m) has been studied, which is classified as a secondary community developed on the site of the primary broad-leaved-dark coniferous phytocoenosis; it marks the belt of microthermal climatopes. This belt is also marked by the fragments of survived deciduous-dark coniferous forests.

4. Conclusions
1. The natural vegetation of the Maly Yamantau Ridge is severely disturbed by timber activities. Secondary aspen and birch forests, which have developed instead of primary forests, blur the manifestation of altitudinal differentiation of climatopes.
2. The fragments of survived primary deciduous and dark coniferous forests make it possible to trace the altitudinal differentiation of climatopes. These fragments serve as reliable markers of the altitudinal zones and their climatopes. Secondary phytocoenoses that comprise climax tree species may also serve as the climatope markers.
3. Based on the results of the present study, it is possible to define preliminarily the altitudinal ranges occupied by climatopes on the slopes of the Maly Yamantau Ridge. The belt of mesothermal climatopes with deciduous forests locates at 510—560 m above sea level; the belt of microthermal climatopes with deciduous-dark coniferous forests, at 400—530 m and 560—675 m above sea level; the belt of nanothermal climatopes with mountain dark coniferous forests, above 675-m altitude; and the belt of cryothermal climatopes with valley forests with dark coniferous forests, at 300—400 m above sea level.
4. The altitude spectrum of climatopes and forest formations is traced more clearly on the western slope of the ridge; the altitudinal differentiation of formations is practically not expressed on the southern slope.

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