Ecosystem, vegetation and soil diversity of the mountain forest-steppe of West Altai (a case study of the Tigirek State Natural Reserve)

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Abstract. The quantitative assessment of ecosystem diversity is a basic tool for the evaluation of its resilience to anthropogenic loads and climatic changes. Our work is devoted to the large-scale predictive ecosystem mapping of hard-to-reach West Altai Mountain areas as well as vegetation, soil, and ecosystem quantitative diversity assessment (basing on Shannon and Simpson indices). The key site (7x4.5 km area) located in the Tigirek State Natural Reserve in the humid climate of the windward part of Altai. The predominance of shrub meadow communities and forb meadows on Gleyic Chernozems and Gleyic Chernic Phaeozems, Gleyic Cambisols, as well as the development of larch forests on the slopes of shady exposures on Greyzem Chernozems are the regional specificities of the forest-steppe Altai ecosystem. Steppe communities (located on the Haplic Chernozems, Cambisols, and Leptosols), occupy less than 2% of the key site. The studied mountain forest-steppe ecosystem of West Altai is characterized by an extremely high level of spatial diversity: the Shannon index is 3.28, the Simpson is 0.95; an increase in soil diversity leads to a linear increase in vegetation diversity.

1. Introduction
Diversity is a fundamental ecosystem property, reflecting not only the abundance, difference, and spatial organization of the ecosystem, but also its resistance to anthropogenic load and climatic change [1]. The territory of the Altai mountainous region is characterized by high ecosystem diversity, however, due to its inaccessibility, it has been studied extremely unevenly. Some provinces in general and part of the natural regions of Altai are still not covered by large-scale ecosystem maps, and all the existing maps are conventional [2]. At the same time, the development of digital approaches and predictive mapping challenged to map hard-to-reach areas and assess ecosystem diversity on the basis of these maps [3]. The aim of the study is the quantitative assessment of vegetation, soil, and ecosystem diversity of the mountain forest-steppe of the Tigirek Reserve (Altai region) based on predictive ecosystem mapping. The objectives of this study were to: (1) collect the field data on soil cover and plant communities at sampling points in the key site and the remote sensing data; (2) predictive mapping of ecosystem components: soil and vegetation due to linear discriminant analyses, topography due to classification of digital elevation model; (3) ecosystem mapping; (4) quantitative assessment of vegetation, soil, and ecosystem diversity of the mountain forest-steppe belt.
2. Materials and methods
The study site (figure 1) is located in the Altai Krai, Khankharinsky section of the Tigirek Reserve and the adjacent buffer zone (Dragunskoye plateau, forest-steppe belt of West Altai); the area of the key site is 7x4.5 km. The absolute height changes from to 600 to 1,200 m; the average annual precipitation is about 600 mm/year, the temperature in June is +17°C, in January −15°C. The parent materials are loess-like loams, gravelly diluvial deposits, and eluvium of carbonates [4].

The soils of the key site are (based on 92 soil point description): Gleyic Chernic Phaeozems (16 descriptions), Gleyic Chernozems (10 descriptions), Haplic Chernozems (10 descriptions), Greyzemic Chernozems (6 descriptions), Calcaric Cambisols (12 descriptions), Gleyic Cambisols (11 descriptions), Rendzic Leptosols (20 descriptions) and Novic Retisols (7 descriptions). Typological diversity of plant communities includes 12 typological subdivisions of the level of formations and is represented by light coniferous and small-leaved forests (larch (Larix sibirica), birch (Betula pendula) and aspen (Populus tremula); 8 relevés), forb meadows (communities of Bromus squarrosus, Calamagrostis arundinacea, Dactylis glomerata; 24 relevés), shrub-meadow and meadow-steppe communities (communities of Caragana arborescens, Cotoneaster melanocarpa, Rosa acicularis, Spiraea crenata, S. trilobata; 27 relevés) and meadow steppes (sedge (Carex pediformis) and grass (Helictotrichon altaicum) communities; 5 relevés).

We calculated more than 60 morphometric parameters and spectral indices using SRTM digital elevation model and multispectral images of Landsat-8 with completely cloudless coverage for the key area (dates 15 June 2014, 11 August 2014, and 10 February 2015) and Landsat-5 (date 13 October 2011). The stepwise linear discriminant analysis [5] was used for the prediction of the vegetation and soil spatial structure. We classified the digital elevation model (according to exposure and slope angle) to produce a topography map. The resulting ecosystem map was compiled through an overlay of soil, vegetation, and topography maps. The Shannon and Simpson indices [6] were used to characterize the spatial diversity of soils, vegetation, and ecosystem of the forest-steppe of West Altai.

Figure 1. Digital elevation model of the key site with vegetation (1) and soil (2) points description.
3. Results and discussion

The altitude, slope, and reflection (Landsat 5, October 2011) are the main factors that determine the soil spatial structure; the user’s accuracy of the model is 64%. Chernozems and Phaeozems are predominantly located on the summits and gentle slopes, Leptosols, Cambisols, and Retisols – on the steep slopes. Novic Retisols and Gleyic Cambisols are formed in depressions (with low altitude). Greyzemic Chernozems are confined to the slopes of shadow exposures. The values of the brightness index are associated with the characteristics of the vegetation cover and help to separate the soils, mainly formed under forest communities (Greyzemic Chernozems, Gleyic Chernic Phaeozems), from soils formed on the shrub (Haplic Chernozems, Calcaric Cambisols, Rendzic Leptosols), meadow (Gleyic Chernozems and Gleyic Cambisols) and steppe communities (Rendzic Leptosols).

The total share of soil combinations with Gleyic Chernozems, Gleyic Cambisols, and Gleyic Chernic Phaeozems as well as a combination of Calcaric Cambisols and Rendzic Leptosols is about one-third of the entire key site. Soil combinations with Greyzemic Chernozems occupied about 15% of the studied area. Novic Retisols have limited distribution (less than 5%) and are mainly confined to the bottoms of large hollows.

Altitude and 3 spectral parameters (wetness, brightness, EVI) determine the vegetation spatial structure; the user’s accuracy of the model is 73%. The summit positions and gentle slopes are predominantly occupied by mesophilic and xero-mesophilic meadow and steppe communities, while birch and aspen forests and shrubs dominated by Caragana arborescens, Rosa acicularis tend to steep slopes and depressions.

Shrub communities with Caragana arborescens and Rosa acicularis are predominant for the key site (more than 40% of the territory). About 30% of the territory is covered by forb meadows – the communities of Dactylis glomerata and Bromus squarrosus with a small participation of Calamagrostis arundinacea meadows dominate. About a quarter of the territory is occupied by forests, dominated by larch forests (which occupy about 12% of the total area). The smallest area on the key site (2%) is occupied by meadow steppes of two main formations (Helictotrichon altaicum and Carex pediformis).

Based on the digital elevation model, 12 topography categories were identified according to the exposure (light, shadow and neutral (western and eastern)) and slope angle (flat surfaces (0-3°), gentle slopes (3-8°), slopes of medium steepness (8-15°), and steep slopes – more than 15°). Gentle slopes and slopes of medium steepness with a neutral (western and eastern) exposure are predominant on the key site. The southern slopes are more common than the northern ones and the steep slopes occupy 23% of the entire key site.

The soil, vegetation, and ecosystem maps are consistent with early published data [7-9]. The regional features of the mountain Altai forest-steppe ecosystem result in the dominance of mesophilic meadow and shrub communities on soil combinations with Gleyic Chernozems, Gleyic Cambisols, and Gleyic Chernic Phaeozems due to the humid climate of the windward part of Altai.

Within the key site, the largest areas are occupied by Caragana communities on combinations of Gleyic Chernozems and Gleyic Cambisols. Together with forb meadows formed on a combination of Gleyic Chernozems and Gleyic Chernic Phaeozems, these ecosystems occupy more than 50% of the area of the entire key site. Light coniferous forests (about 13% of the area of the site), occupying mainly shade exposures, are formed on combinations with a high proportion of Greyzemic Chernozems. Small-leaved forests are localized on the slopes of neutral exposures, occupy small areas (about 2%), and are formed mainly on Calcaric Cambisols and Rendzic Leptosols. Meadow steppes occupy the smallest area in the key area. Grass steppes are formed on a combination of soils with the participation of Haplic Chernozems, Calcaric Cambisols, and Rendzic Leptosols on slopes of low steepness (less than 8°); sedge ones are confined to steep slopes (more than 8°) and carbonate-free soils (combinations of Gleyic Chernozems and Gleyic Cambisols). The ecosystem map has 38 units.

The studied ecosystems are characterized by an extremely high level of spatial diversity (figure 2): the Shannon index is 3.28, Simpson is 0.95. The diversity of vegetation cover, when considered in conjunction with the diversity of soil cover components, reveals directly proportional relationships: an increase in soil diversity leads to a linear increase in vegetation diversity. Shannon index of vegetation diversity reach 2.3,
soil – 2.4, Simpson index reaches 0.9 in both cases (figure 2). The formation of the ecosystem diversity of the mountain forest-steppe is the result of the influence of a large number of factors that are not limited to the features of the relief structure [10, 11]. Thus, quantitative indicators of the ecosystem diversity do not reveal a reliable relationship with the absolute height, slope angle, and exposure of the slope. This can be attributed to two groups of factors. The first group is associated with the natural prerequisites for the formation of the diversity of the forest-steppe belt with a complex structure. Altitude differentiation of ecological conditions, which determines the formation of the catena-like structure of ecosystems, characterizes the change of ecosystems from the upper to the lower parts of the slopes. It has its own specificity depending on various indicators of the slopes (exposure, steepness, curvature), the nature of the underlying rocks. The second group is determined by the history of the development of the territory, climate change and anthropogenic load (the impact of agricultural activities before the formation of the reserve), and different sensibility and reflexivity of ecosystem components in relation to environmental changes. All this complicates the search for relationships between the parameters of the ecosystem diversity of the forest-steppe belt of West Altai and the possible factors that determine it.

Figure 2. Simpson diversity index for soil (a), vegetation (b), and ecosystem (c) of the key site.

4. Conclusions
Ecosystem maps are a basic tool for biodiversity conservation and assessment. Predictive ecosystem mapping challenging to map hard-to-reach areas like West Altai, where some regions are still not covered by large-scale ecosystem maps. Our results showed that mountain forest-steppe is characterized by extremely high levels of spatial diversity: the values of the Shannon index is 3.28, Simpson is 0.95, and an increase in soil diversity leads to a linear increase in vegetation diversity. The regional specificity of the forest-steppe ecosystem spatial structure is the dominance of shrub meadow communities and forb meadows on Gleyic Chernozems and Gleyic Chernic Phaeozems, Gleyic Cambisols, as well as the development of larch forests on the slopes of shady exposures on Albic Luvisols. Steppe communities, predominantly on the Haplic Chernozems, Cambisols, and Leptosols, occupy less than 2% of the entire territory.
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