Natural and anthropogenic transformation of geosystems of Tunkinsky national park: identification and mapping

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Abstract. The paper focuses on the specifics of landscape medium scale mapping employing traditional methods. We selected a key site in Tunkinsky National Park (Republic of Buryatia) and the Tunkinskaya depression located within it and its mountain framing (south of Eastern Siberia) to display the modern structural and dynamic features of the geosystem functioning. The map compiled at a scale of 1:100 000 illustrates the differentiation into categories of landscape structures by types of altitudinal-belt conditions of the natural environment, differing in morphological and phytocenotic properties, as well as the nature of natural-anthropogenic transformation. The main factors of landscape discreteness are morphological features of the surface structure of the intermontane territories; the complexes with natural vegetation and their derivative biocenoses, formed as a result of agricultural and pyrogenic transformation, reflected the dynamic nature of the geosystem functioning. The complexes have been formed in river valleys due to debris flows and are assigned to variable states.

1. Introduction
The landscape map is one of the main tools in considering the creation of a scientific geographical basis for determining the ecological potential of specially protected natural areas. The intermontane depressions of the Baikal type on the territory of Tunkinsky National Park, which have been economically developed for a long time, are geodynamically active morphostructural elements. The processes of modern relief formation are intensely manifested here. Therefore, that is an ideal testing ground for synthesized study and cartographic reproduction of the features of landscape formation under the influence of natural and anthropogenic factors. The focus of the study addressed in this paper is on the mapping the modern landscape structure of the Tunkinskaya depression and its mountain framing at the topological level using the structural-dynamic approach to reflect the nature of the transformation of geosystems. The map at a scale of 1:100 000 is distinguished by the accuracy and confidence of determining the boundaries of the smallest taxonomic units due to the integrated application of well-established methodological tools of compiling maps and modern geoinformation data. This map prepared to allow the development of mechanisms and models for the national park management, considering the peculiarities of the geosystem functioning.

We selected the central part of the Tunkinskaya depression and its mountain frame as a representative area of our research. The unique feature of the terrain consists in the combination of various relief forms within a small area – from the alpine-type highlands of the Tunka Goletz Range to the wetland on the bottom with a complex network of arms of the Tunka river and its tributaries. The functioning and dynamics of geosystems are influenced by intensively pronounced exogenous
processes – debris flows, waterlogging and aeolian processes. Anthropogenic impact complicates the natural differentiation of the modern landscape structure. There are more than a dozen settlements here, the inhabitants of which are historically employed in agriculture. A dense network of roads connects the local settlements. Thousands of tourists come to the thermal springs of the villages of Arshan and Zhemchug in the summer season.

Thus, the main factors of transformation that enhance the polychronism of the modern landscape structure of the key sites are the implementation of economic activities and the manifestation of modern exogenous processes.

2. Models and Methods

The basic materials used for mapping the geosystems of the key sites were topographic maps of different times at a scale of 1:100,000, forest inventory materials, field survey materials, and remote sensing data (RSD). During the pre-field period, visual decryption of highly detailed DigitalGlobe images with a resolution of 0.6 m/px used by the GoogleMaps service was carried out; the preliminary boundaries of the vegetation cover were determined within the high-mountain, mountain-taiga and subtaiga altitudinal belts. In the field survey of various geomorphological surfaces of the intermountain depression, we collected 198 geobotanical descriptions, which formed the basis of landscape indication of the outlined areas. At the stage of conjugate analysis of the obtained geobotanical data, forest management materials and topographic maps of the beginning, middle and end of the 20th century, we identified the boundaries of associations with natural and derivative vegetation. These data enabled the differentiation of landscape areas at the level of facies groups.

The structural-dynamic dimension of the theory of geosystems by V B Sochava [1] became the basis for landscape mapping in this study. The map legend includes system-hierarchical differentiation, that is, each geosystem is considered as a subsystem of a larger one, which in turn represents a generalized reflection of the main regional regularities [1-3]. Based on the technique of landscape mapping by V S Mikheev [4], we used a 5-step structure of the legend (type of natural environment - class of geoms - geom - class of facies - group of facies) in our work, which unites geosystems of three orders of dimensions - planetary, regional and topological. The basis for identifying the units, which characterize the regional specificity, was the map “Landscapes of the south of Eastern Siberia” [5]. Its generalized territorial structure is applicable after a certain cartographic processing when creating maps of the current state of landscapes on a larger scale [2, 3].

According to the above map, the planetary and regional complexes of the Tunkinskaya depression and its mountain framing are represented by North Asian goletz and taiga geosystems, consisting of two classes of geoms - goletz and subgoletz of East Sayan, as well as mountain taiga of South Siberia. Within the area, five geoms are revealed - the lowest subdivisions of the regional dimension, characterized by certain hydroclimatic conditions for the development and functioning of the biota. In the event of separating the boundaries of facies classes, we addressed the morphogenetic features of the surface, which, in turn, influenced the special development situations of biotic components.

The research territory is distinguished by a variety of morphological structures. These are the steep slopes of the Tunka Goletz Range and the gentle side of the Khamar-Daban Range (the landscape structure of the latter is not considered in this work), as well as the Elovskii spur connecting them. This is an area of young subsidence, represented by a multi-lake area along the middle course of the Tunka river, as well as a relict aeolian relief of the Badary sandy massif [6]. The facies classes indicated in the legend territorially coincide with the boundaries of the above morphological surface elements, the landscape features of which include a wide range of facies groups representing a set of facies with plant communities of the same type on genetically uniform surfaces.

The dynamic criterion in this study is shown through the identification of groups of facies with a natural state and groups of facies that characterize their derived state. The main indicator of transformation is the vegetation cover, as a component of geosystems, which most sensitively reacts to anthropogenic and spontaneous (natural) impact. It is for this reason we paid special attention to the current state of vegetation without taking into account the soil features of the territory, while insulating the groups of facies.
3. Results and Discussion

Based on the above defined principles of landscape mapping, we compiled a map at a scale of 1:100 000 (Figure 1), showing the natural heterogeneity of the key areas of the Tunkinskaya depression and its mountain framing, taking into account the degree of natural disturbance and anthropogenic transformation.

![Figure 1. Landscape map of the key area of the Tunkinskaya depression (1-22 – see Table 1).](image)

The paper gives priority attention to the specifics of distinguishing units of a topological order – classes and groups of facies. The main landscape-forming factors in the formation of geosystems of the key site are the features of the surface structure and the intensity of relief-formation processes. Taking into account these factors as the main criteria for identifying geosystems at the level of the facies class, we identified their boundaries by an integral analysis of the topographic base, geological map and DigitalGlobe satellite images obtained from available open sources (GoogleEarth).

The principles of separation of the main morphological elements of the surface, indicated in the studies of the relief and the leading modern processes of relief formation, formed the basis for determining the boundaries of the facies classes [6-8]. Given the present decisive role of relief formation processes in the development and functioning of the soil-plant component of geosystems, we adjusted the boundaries of facies classes in accordance with the analysis of the zoning schemes for soil [9] and vegetation covers [5, 10]. As a result, six facies classes were identified at the key site.
Table 1. Legend of the landscape map of the key area of the Tunkinskaya depression (Figure 1)*.

| Topographic feature (class of facies) | Group of facies | Number on the map |
|--------------------------------------|-----------------|------------------|
| **Geosystems of North Asian goletz and taiga** | | |
| **Class of geoms of goletz (mountain-tundra) and subgoletz East Sayan** | | |
| Geoms of goletz alpine-type | | |
| Class of facies of sharply dissected alpine-type relief of high mountains with sparse vegetation on mountain-tundra alpine-sod soils | Dividing crests and kars, landslide-talus with stone heaths and moss-and-lichen tundra | 1 |
| | Steep slopes with Siberian stone pine and larch woodland, mountain avens – Siberian bog sedge | 2 |
| **Class of geoms of mountain-taiga, southern Siberian** | | |
| Mountain-taiga dark-coniferous geoms of limited development | | |
| Class of facies of steep slopes larch-siberian stone pine on mountain taiga cryogenic soils | Steep slopes Siberian stone pine with larch subshrub-true moss, in places with bergenia | 3 |
| | Steep slopes and medium-steepness slopes of Siberian stone pine-pine-larch (with inclusion of birch) green moss-herbaceous | 3a |
| | Steep slopes larch-Siberian stone pine-pine (with inclusion of birch) green moss-herbaceous-subshrubs | 3b |
| **Mountain-taiga larch geomes of optimum development** | | |
| Class of facies of interdepression mountain dam, larch on mountain taiga sod-low podzolic soils | Lateral spurs Siberian stone pine-larch subshrub-green moss (not on the map) | 4 |
| | Lateral spurs birch-larch (with inclusion of Siberian stone pine and singly occurring pine) herbaceous-subshrubs | 4a |
| | Lateral spurs larch-birch (with inclusion of aspen and pine) herbaceous-subshrubs | 4b |
| | Steep slopes and medium-steepness slopes, larch with pine, herbaceous (not on the map) | 5 |
| | Steep slopes and medium-steepness slopes, birch-larch with inclusion of pine, herbaceous-subshrub | 5a |
| | Steep slopes and medium-steepness slopes, aspen-larch-birch with pine, herbaceous-subshrub | 5b |
| | River valleys spruce-larch herbaceous-sedge (not on the map) | 6 |
| | River valleys spruce-birch-larch with willow, swamped, herbaceous-sedge | 6a |
| | River valleys spruce-pine-larch with the inclusion of larch, subshrub-green moss-herbaceous-subshrubs | 6b |
| Class of facies of piedmont inclined plains, pine-larch on mountain-taiga sod soils | Gentle slopes and medium-steepness slopes, larch with Siberian stone pine and pine, subshrub-herbaceous-green moss | 7 |
| | Gentle slopes and medium-steepness slopes, birch-Siberian stone pine-pine, with inclusion of larch, green moss-subshrub-herbaceous | 7a |
| | Gentle slopes and medium-steepness slopes, birch-larch-pine, with inclusion of Siberian stone pine, herbaceous-subshrubs | 7b |
| | Gentle slopes and medium-steepness slopes, larch-birch-pine, with inclusion of Siberian stone pine, herbaceous-subshrubs | 7c |
| | Gentle slopes and medium-steepness slopes, aspen-pine-birch, with inclusion of larch and Siberian stone pine, subshrub-herbaceous, in places subshrub-herbaceous-green moss | 7d |
| | Gentle slopes larch-pine, herbaceous-subshrubs (not on the map) | 8 |
| | Gentle slopes, aspen-birch-pine, with inclusion of larch, subshrub-herbaceous, in places green moss-herbaceous-subshrubs | 8a |
| | Gentle slopes, pine-birch, with inclusion of aspen and larch, subshrub-herbaceous | 8b |
| | River valleys, larch-spruce, green moss-herbaceous (not on the map) | 9 |
| | River valleys, larch-spruce-pine, with inclusion of birch, green moss-subshrub-herbaceous | 9a |
| | River valleys, herbaceous-sedge meadows, in places swamped, with birch and willow shrubs along the channels, involved in hayfields and pastures | 9b |
| Topographic feature (class of facies) | Group of facies | Number on the map |
|--------------------------------------|-----------------|------------------|
| Geoms of piedmont subtaiga pine      |                 |                  |
| Class of facies of gently rugged, wavy relief of fixed and semi-fixed sands pine on soddy-low podzolic and gray forest soils | Dunes and ridge-hollow relief, pine, with inclusion of birch and larch, herbaceous, in places subshrub-herbaceous with arrays of exposed sands fixed and semi-fixed of grass vegetation and willow bushes | 10 |
| | Gentle slopes, pine herbaceous with shrub undergrowth (not on the map) | 11 |
| | Gentle slopes, larch-birch-pine herbaceous-subshrubs, in places green moss-subshrub-herbaceous, disturbed by ground fires | 11a |
| | Gentle slopes, young pine forest with singly occurring birch trees with traces of ground fires, herbaceous-shrub, in places green moss-subshrub-herbaceous | 11b |
| | Gentle slopes, larch-pine sparse, disturbed by fires, with birch-pine and pine-birch young undergrowth, forbs | 11c |
| | Gentle slopes, meadow post-fire forbs, with singly occurring larch and pine trees, with a birch-pine sparse undergrowth | 11d |
| Geoms of piedmont and intermontane depressions subtaiga meadow-steppe |                 |                  |
| Class of facies of flat lacustrine-alluvial plains, largely meadow-swamp on meadow-chernozem and peat-humus-gley soils | Lacustrine-boggy lowland forb-sedge, in places forb-equisetaceous swamped meadows | 12 |
| | Lacustrine-boggy lowland forb and forb-herbaceous swamped, with yernik and willow vegetation, used as hayfields and pastures | 12a |
| | Floodplain and river valleys spruce-larch-birch herbaceous-moss | 12b |
| | Lacustrine-boggy lowlands, gentle slopes, larch-spruce herbaceous-green moss (not on the map) | 13 |
| | Gentle slopes, river valleys, birch-larch-spruce herbaceous-green moss, in places swamped | 13a |
| | Gentle slopes, river valleys, spruce-larch-birch herbaceous-subshrub-green moss | 13b |
| | Floodplain and river valleys, meadow-red osier with spruce and willow (not on the map) | 14 |
| | Floodplains, spruce-birch, with inclusion of pine and larch, subshrub-moss-herbaceous | 14a |
| | Floodplains and river valleys, forb-meadow, in places with willow and yernik vegetation, used as hayfields and pastures | 14b |
| Anthropogenically modified complexes |                 |                  |
| Flat low-inclined terrain of aprons, alluvial cones and internal delta, agricultural lands on agrozems and Residential and transport facilities | Gentle slopes, croplands | 15 |
| | Gentle slopes, forb-wild rye steppe meadows (fallows), in places with pine-birch and birch-pine undergrowth, used as hayfields and pastures | 16 |
| | Gentle slopes forb-meadows with pine-birch and birch-pine young forest (overgrown cropland), used as hayfields | 17 |
| | Settlements | 18 |
| | Motor roads (a - highway, b - ground roads) | 19 |
| Modified debris flow complexes (the state variables of the geosystems of valley complexes) |                 |                  |
| | Deeply embedded river valleys, high mountainous zone of origin and transit of mudstone flows, as well as the area of accumulation of boulder sediments | 20 |
| | River valleys, piedmont zones, transit of water-mud flows and accumulation of transported debris (boulders and trees) | 21 |
| | Floodplain and river valleys, flat areas, as well as linear residential and transportation facilities, the zone of transit of water-mud flows and accumulation of suspended (sand-clay) and wood debris | 22 |

*Note: the figure denotes groups of facies with a natural state of vegetation, analogous to the figure with the letter – its derivative states.*
The ranking of the Tunkinskaya depression and its mountainous surroundings became the basis for further division into groups of facies according to the criterion of homogeneity of plant communities within genetically uniform surfaces. We distinguished groups of facies based on field research data, topographic maps at a scale of 1 : 100 000 and remote sensing data, the latter of which was assigned a leading role in identifying the dominant forest communities in space indicated on the forest inventory map. At the same time, we paid priority attention to the isolation of forest communities dominated by mature and overmature coniferous trees, which characterizes the natural state of biogeocenoses. Young and middle-aged coniferous stands, as well as small-leaved stands of any age, indicate the transformation of ecosystems because of the manifestation of an anthropogenic factor.

The results of deciphering the space images made it possible to plot facies contours on the topographic basis, characterized by the homogeneity of landscape conditions. The data obtained were combined with the outlined areas of the main morphological relief elements - watersheds, slopes and river valleys. This gradation reflects the influence of gravitational processes and moisture conditions on the formation of plant communities, as well as, in general, on the dynamic state of the geosystem. The combination of facies with similar biogeocenoses within the same surface types resulted in the boundaries of fourteen groups of facies, showing the natural state of ecosystems. Due to the influence of the anthropogenic factor, some of them do not find their manifestation in the landscape structure of the key site. Nevertheless, the reflection in the legend of the natural states of groups of facies is necessary to designate the standard, to the equifinal state of which the geosystem will tend after the termination of economic activity.

When solving the problem of mapping the influence of catastrophic exogenous processes on the landscape appearance of the territory, we separated complexes disturbed by debris flows, based on the experience of colleagues in the field of zoning and mapping of debris flows [11-13]. Given the peculiar conditions for the formation of morphodynamic debris flow zones in the high-mountainous part of the Tunka Goletz Range, we indicated zones of origin and transit of mudstone flows. Within the transition zone from the bottoms of the depression to the mountains, there are zones of transit of water-mud flows and the accumulation of traction load, and on the gentle slopes of the Tunkinskaya depression – zones of transit and accumulation of suspended sandy-clay sediments.

We have identified the first two zones based on the interpretation of satellite images. However, the identification of accumulation zones of suspended sediment within forested areas required clarification. Therefore, it led us to using the unmanned aerial vehicle (UAV) DJI Phantom 3 Advanced. We have performed more than 15 UAV launches in key areas, and received images of the surface from different shooting angles and from different heights (60 to 350 m). Thus, it was possible to determine indicative signs of accumulation zones of sandy-clay sediments in forests, which were similar to areas of bare sand on satellite images. The use of modern tools therefore makes it possible to respond to transformations taking place in ecosystems and contributes to the mapping of new relevant information.

4. Conclusion

The map of the key site of Tunkinsky National Park compiled on a scale of 1 : 100 000 contains information about both the main invariant properties of ecosystems characterizing the natural basis of formation, and about dynamic trends under conditions of intensive impact of economic activities. At the level of facies classes, the influence of natural factors, i.e. the features of the morphological structure of the surface of the intermountain areas, subject to intensively manifested modern processes of relief formation, is well traced. The groups of facies reflect the degree of anthropogenic transformation and landscape discreteness is due to postagrogenic and postpyrogenic restorative dynamics of ecosystems.

Integrated reproduction of natural ecosystems and their anthropogenic modifications characterizes landscape maps as a universal model for solving a wide range of geographic issues, including issues of ecological management in national parks. On their basis, it is possible to predict the development options for both recovery processes and digression dynamic trends in the functioning of the transformed components of intermountain geosystems. The synthesized presentation of the economic development and the unfavourable natural hotspots on a landscape basis can be useful in the analysis, modelling and forecasting of the manifestation of catastrophic natural processes, in the development of adaptation modes to the consequences and in the zoning of the territory for planning decisions.
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