Methods for mapping information on the structure and dynamics of ecosystems of mountains of the Baikal region

S A Sedykh
Sochava Institute of Geography SB RAS, Irkutsk, Russia

E-mail: sedykh@li.ru

Abstract. The paper presents the results of the ecological study, with the analysis of landscapes and mapping of the area of the testing ground. The testing ground is located in the Eastern Transbaikalia, covering the part of the central part of Primorskii Range and south-eastern macroslope of this mountain range (having an easterly aspect for the Primorskii Range). For the analysis of the structure of geosystems and the estimation of disturbance, the basic geosystem approach is applied to modern geoinformation-cartographic and remote methods. Based on V.B. Sochava’s theory of geosystems it is assumed for use in processing and ordering a large volume of information. In the paper we analyzed the regional background and main factors of the landscape differentiation of the study areas. The pyrogenic impact, which increased by the 21st century and caused the transformation of the natural structure of the Baikal mountains, caused the need to improve the methods of mapping the geosystems of topological level, their dynamics, landscape-forming processes and individual local phenomena. We identified negative digressions of geosystems for the period 1989-2019 at the experimental site, when 42% of 100 km² of natural systems of highlands, mountain-taiga middle mountains and lowmountain-slope forests were lost.

1. Introduction
The Primorskii Range stretches for 250 km along the western shore of Lake Baikal and has the highest point in the Trekhkolovyi goletz with a height of 1746 m. The central upland of the ridge stretches from the Anginsky-Kuchulinskaya to the Zaminskaya intermountain depression. The study site with an area of 100 km² (location 3 at figure 1) belongs to the watershed of Lake Baikal and is included in the western part of the Central Ecological Zone of the Baikal Natural Territory (BNT). Undisturbed and slightly disturbed mountain areas, which are now more sensitive to natural and anthropogenic fires, remained here until the beginning of the 21st century. The results of comprehensive landscape studies in the central part of the Primorskii Range, which began in 2012, are presented in a number of papers [1].

Forest fire frequency is increasing across the planet [3]. The beginning of the 21st century is characterized by an increase in the frequency of fires and in areas exposed to pyrogenic effects both in the Northern Hemisphere and in Russia as a whole [4, 5]. At the same time, according to available estimates, the territory of Siberia accounts for up to 70-80% of the annual number of forest fires in Russia, which is directly related to the stable increase in average annual air temperatures in the past 100 years [6]. This
process causes fundamental changes in the structure of geosystems of the Baikal region [7].

Figure 1. Hypsometric map of the Baikal Natural Territory. Based on the map of A.V. Bardash [2]. Location of the key study areas. Ranges: 1 – the southern part of Barguzinskii and Svyatoy Nos, 2 – Primorskii, 3 – the central part of Barguzinskii.

The geosystems of the range within the Pribaikalskaya goletz-mountain-taiga and hollow province of the Baikal-Dzhugdzhur mountainous region develop mainly in limited and reduced development conditions. The mountain-taiga, less stable geosystems, lower in absolute altitude, transform into slope
insolated areas, where drier and more sensitive landscapes of low-mountain taiga pine forests and mountain steppes with sparse larch are developed. According to their distribution area, the latter belongs to the mountains of Southern Siberia and the arid areas of Central Asia. The combination of unique natural components and factors that allow such different landscapes to function in the mountainous surroundings of Lake Baikal makes the Primorski Range so valuable.

In view of the above, the study aims to identify changes in the structure of geosystems within a 100 km² polygon in the central part of the range in the time frame from July, 1989 till July, 2019.

2. Materials and methods

The mapping of geosystems structure and dynamics includes a spatial mapping of temporal changes of various levels under the influence of natural processes induced by global and regional climate changes, as well as pyrogenic and anthropogenic impacts. The main approach to the study and GIS mapping of geosystems was the regional-typological approach, which was tested in different regions of Siberia [8, 9].

In response to our analysis and landscape-typological mapping on a large scale we focused on topogeosystems of the level of facies and groups of natural complexes that are characterized by a homogeneous internal structure in their natural state [8]. Local variations of deviations are taken into account, including the influence of active cryogenic and gravity-slope processes specific to the region.

The relevance of mapping the objects and phenomena within the Primorski Range (figure 2) is associated with a pronounced regional character, i.e. a combination of barrier-shadow (determined by the southeastern strike of the range within the "rain shadow" zone when air masses are transferred from the northwest), arid-hollow, alpine and submountain effects [10].

![Figure 2. 3D model of the central part of the Primorski Range based on ALOS (30 m) and Landsat 8 (30 m, 2019, RGB 4-5-1) data.](image)

However, the mechanical anthropogenic impact has been limited since 1990 along roads and power lines in the Preolkhon plateau, and fires regularly occur during hot and dry periods in the subalpine belt and all parts of the mountain-taiga belt of the Primorski Range, especially since 2015. So, only near the Trekhgolovyi goletz about 110 km² of mountain-taiga and mountain shrub geosystems burned down in the main watershed, along the western and eastern macroslopes in 2015-2016.
Thematic mapping of the geosystems of the Primorski Range and their dynamics is carried out on a large scale at the level of facies and their groups. Further scientific and cartographic generalization into smaller scale levels requires a combination of the most advanced tools of remote, geoinformation and cartographical methods. Below is a conceptual approach to mapping at the test site Trekhgolovyi goletz – Yator tract in a combination of three main directions (table 1).

Table 1. Database based on cartographic, remote and field sources.

| Information sources | Microlevel 1:500 – 1:50 000 | Mesolevel 1:50 000 – 1:200 000 | Macrolevel finer 1:200 000 |
|---------------------|-----------------------------|-----------------------------|-----------------------------|
| Basic cartographic | Topographic plans for sites (Gauss-Kruger projection, PZ-90) | Topographic and thematic maps (Gauss-Kruger projection in Krasovsky ellipsoid systems and PZ-90) | General geographic maps regionalization and zoning maps |
| Remote data | of ultra-high resolution (QuickBird-2, GeoEye, Ikonos, RapidEye, aerial photography), Resource P, Sangur-U scanner (2-0.7 m) | of high resolution Landsat 4, 5, 7, 8 TM images (combinations 4-5-1, 4-3-2, 7-3-1), Landsat MMS archives, digital models based on SRTM 4.1 and ALOS radar data (DAICHI with resolution of 30 m), Sentinel 1, 2 images (with a resolution of 10, 20 and 60 m) | Low and medium temperature remote sensing data for fire monitoring and derived layers |
| Field and geodetic | GPS-GLONASS, field descriptions (from 50 or more per a test site), photo and video material with GPS position | | |
| Thematic data | Landscape maps for test sites, test site-transects, areal and point objects, geochemical data | Database of monitoring data points, landscape maps and components, forest management | Regionalization maps |
| Other information | Statistical data, literary descriptions, photographic material metadata | | |

An innovation in the remote sensing is the availability of summer images of multispectral imagery of the Resource P series satellite by Roskosmos (with a Sangur-U scanner with a maximum resolution of 2 to 0.7 m) on the studied territory. For the period from 2018, data provided by the European Aerospace Agency became available for Sentinel 1 and 2 systems (with a resolution of 10, 20, 60 m) with 12-channel scanned images, regularly updated on the BPT. For the digital altitude model (figure 2), steepness and slope polarization models, data from the ALOS satellite (DAICHI of the Japanese Aerospace Agency JAXA) are used. The latter are well recommended in GIS mapping of the inland part of the North Asian subcontinent, as they give a small number of gaps and errors in one-degree survey sectors when processed in the QGIS software environment. We used the MapInfo Professional 15 GIS environment to compile the final vector maps, which has advanced spatial analysis capabilities (2- and 3-D), tools for the syntax of cartographic symbols and operations with semantics in GIS-relational tables and map legends, work with
remote WMS servers, etc.

The central part of the Primorskii Range is the highest part of the range, taking in about 80 km out of 250 km of the western shore of the Baikal watershed, with the main summit Trekhgolovyi goletz (1746 m). Basic scanner images from the GLOVIS USGS database were selected for the key values of the required time intervals: Landsat 4 (1989-07-12), Landsat 7 (2000, LGC, 12.7 m/p), Landsat 5 (2014-07-10, 2015-07-20, 2017-07-27)) and Landsat 8 (2019-07-19).

3. Results and discussion
The study area is included in the West Pribaikalskii pyrological district, with a variation in the number of fires from 0.1 to 7.0 per year [11]. The evaluation of pyrological districts took into account the assessment of the relief (height and dissection) and climate (seasonal dynamics). In the investigated part of the range we identified 16 fires since 1999 (totally, about 500 km²). One catastrophic fire in 2016 (more than 2,000 hectares, approximately 10,000 hectares) covered the highlands in the watershed to the north of the Trekhgolovy (Three-head) goletz. Further, 3 of these are large fires (from 201 to 2000 ha, approximately 1000 ha), the rests are medium (from 21 to 200 ha, approximately 100 ha) and small ones. Large fires were characterized by a high degree of burnout, when the stand dies by 60% or completely. Soils burnt out up to the mineral layer (figure 3).

![Figure 3. Dead subalpine Siberian stone pine forest / Subalpine Siberian stone pine survival area (07-07-2018).](image)

To create a retrospective map of the structures of natural geosystems (figure 4), we used the base image Landsat 4 (12.07.1989). Since the channels of different Landsat systems do not coincide, a combined approach was used to construct a retrospective map of the structure of natural landscapes (geosystems). Based on the relief model based on ALOS, we identified the characteristic locations of topological landscapes, taking into account the height, steepness and exposure of the slopes. In addition to the available remote sensing data we analyzed the materials of the old forest inventory related to 1987-1989.

The map of the current post-fire condition (figure 5), was compiled on the basis of the existing collection of satellite images and field data with GPS reference.
Figure 4. The retrospective map of the structure of geosystems for July 1989. Intervals of natural facies groups including typological facies with an individual number: 1-5: Goletz mountain-tundra geosystem group on Lower-Proterozoic quartzites, and shale at 1742-1500 m with physical weathering by gravity-cryogenic processes and nivation; 6-11: Subgoletz shrub and sparse-forest on shale group of facies, plagiogneisses and amphibolites, at 1500–1400 m; 12-4: Subgoletz slope sunalpine tundra meadows at 1500-1400m; 15-23: Subgoletz intermountain depressions at 1400-1300 m. Bottoms of depressions with shrub and sparse larch; 24-27: Subgoletz Sibirian pine and larch sparse forest of limited development conditions at 1300-1100 m; 28-32: Low-mountain light-coniferous forests (pine and larch) conditions of reduced development conditions at 1100-900 m; 33-40: Low-mountain watersheds and gentle slopes light-coniferous forests (pine and larch) of limited development, at 900-600 m; 41-47: Intermountain valleys of limited development conditions (800-600 m).
Figure 5. Post pyrogenic structure of geosystems for July 2019. Numbers of natural typological facies are the same as in Figure 4. Fire damaged areas: td – totally destroyed, pd – particularly destroyed.

4. Conclusions
Forty-two percent of natural facies of the topological level were damaged on the territory of 100 km². 20% of the original landscape units have been lost. Along the subalpine belt of Siberian dwarf pine (which can burn for a long time and with a high temperature) and partly along yerniks, the fires reached almost the summits of goletz mounts in some places, and in the central part, they covered the lowered summits of subgolez. An unpleasant fact is as follows: the burnout of almost 90% of the unique mid-mountain Siberian pine forests with larch leaves the question of their restoration open.

Additionally we revealed by remote sensing data and in field studies and taking into account negative changes, that natural geosystems were preserved in remote areas, never being on fire, as well as fragmentarily in refugia (natural survival areas). The refuges are located within the burnt-out landscape belts (and/or vegetation biomes). The reasons for the emergence of refugia are preliminarily identified: 1)
changes in the climatic situation during a fire; 2) physical barriers (rocky ridges, corroms, damp bottom of intermountain depressions, etc.). An important point is the presence of depressions with groundwater, rivers and streams. However, foci of permafrost soils do not affect the course of the process. In the burnt areas erosion and deflation of soil and grounds, gravity-slope processes, and the temperature regime of the lithological basis of geosystems are increasing. The situation in the refuge is more stable, they can be the cores of the future restoration of nature.

Comprehensive time-expanded damage to natural geosystems and their recoverability has yet to be assessed. Less stable and slowly developing Baikal-Dzhugdzhur facies of Bergenia and moss Siberian stone pine and crowberry-lichen Siberian dwarf-pine belong to the western selvedge of a vast high-mountainous and mid-mountainous region stretching from the Lake Baikal to Dzhugdzhur Range along the Sea of Okhotsk. The question of the recoverability due to new seedlings and undergrowth of young trees or their replacement by similar ones within one location in the landscape belt of the geosystem is worth studying additionally. Alternatively, it is possible to preserve high-mountainous poor wastelands. At the same time, the possibilities of predictive mapping seem to be very broad.

In general, the situation when relatively weakly disturbed low-mountain forests remained only in a narrow strip along the shore of Lake Baikal seems to be extremely unsatisfactory both in terms of the protection of unique geosystems and the development of tourism.

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