Geosystem transformations forecast of the Northern Priolkhonye Region

A Y Bibaeva
Sochava Institute of Geography SB RAS, Russia, Irkutsk

E-mail: pav_a86@mail.ru

Abstract. The current trend of climatic changes in the northern hemisphere is accompanied by an increase in the number of cases of extreme weather events; droughts have become typical for the Baikal region. In the changing conditions of the regional geosystems background impact, the pyrogenic factor acts as a catalyst for the transformation of geosystems. The research is aimed at identifying and mapping the dynamic and structural transformations of the geosystems in the northern Priolkhonie region (the western coast of Lake Baikal), influenced by pyrogenic factor. Spatial analysis of the location of the burnt territories was carried out on the basis of Landsat 8 (OLI) remote sensing in the GIS. Groups of facies in the territory of the northern Priolkhonye region influenced by destructive pyrogenic factor in the period of 2014–2015 were designated. Long-term degradation of forest-growing conditions with a long renewal stage, replacement of dark-coniferous forests by light-coniferous forests in a certain part of their range, replacement of larch-pine steppe forests, mainly in the southern slopes, by steppe communities are therefore forecast. In the highland part of the Primorsky Range, the dwarf siberian pine Pinus pumila communities destructed by fire contributes to a wide expansion of stone placers (kurums).

1. Introduction
In the last two years, the problem of the preservation of unique geosystems and environmental management within the Central ecological zone of the Baikal Natural territory is being discussed by the Government of the Russian Federation. According to the Federal law № 94-FZ "On protection of Lake Baikal" (The Federal Law "On the Protection of Lake Baikal" dated 01.05.1999 N 94-FZ amended on June 28, 2014), the geosystems of the Baikal region are some of the most important components of the preservation of Lake Baikal as a unique ecological system of the Russian Federation and a world natural heritage site. For this purpose, an expanded system of specially protected natural areas (nature reserves, reserves, national parks) has been developed in the Baikal region.

The current climate warming trend in the Northern hemisphere is accompanied by a number of negative consequences. Atmospheric blocking and disruption of air mass transport in the western direction are detected in certain areas, followed by an increase in the number of extreme weather cases in other areas [1]. There is also an increase in the number of extreme drought cases in the Baikal region, accompanied by rising annual temperatures and a decrease in annual precipitation amounts [2]. In 2014, the water inflow to Lake Baikal was only 67% of the total norm [3], which contributed to a decrease in the lake water level below the established minimum level of 456 m. It has led to a
reduction in the water surface area, a decrease in the groundwater level in the lake's watershed area, changes in the microclimates of different areas, etc.

The latter factor aggravates the pyrogenic situation in the region. One of the impacts is a continuous detection of a significant number of areas affected by the forest fires of different intensity. The most devastating consequences affect the unique geosystems of the Olkhon area in the Irkutsk region located entirely in the confines of the Lake Baikal Watershed and its central ecological zone.

Research territory is the Priolkhonie region located the central part of Lake Baikal's western coast opposite the island of Olkhon. The geosystem structure is determined by the research area located in the Baikal-Dzhugdzhursky physical-geographical region. Climatic conditions are formed mainly under the influence of local physical and geographical factors - orography and lake water mass, - which determine the formation of barrier-shadow, arid-hollow and foothill effects. In accordance with the scheme of fire hazard zoning of The Baikal Natural Territory [4], the Priolkhonie forests refer to the area of potential fire danger. The above-mentioned factors lead to the change in the structural and functional geosystem characteristics of the unique region, loss of their stability, and further radical transformations.

2. Models and Methods
Space images of Landsat 8 (OLI) were used to identify the territories subject to the pyrogenic factor and to calculate areas of burnings. The priority was given to the images referring to the autumn season from the end of a fire danger period to the beginning of a snow cover formation (i.e. from the end of September to the beginning of October) and to the images with the cloud cover of less than 20%. If such images were not available, spring season images of the following year in the after-snow cover period (early June) were used.

Forrest Resource Management maps with a scale of 1: 25 000 from the Ministry of Forestry of the Irkutsk region and the Pribaikalsky State Natural National Park served as the sources of information about the species composition of burnt forests in the specified period. The information on the geosystems structure of the research area was obtained from the map "Landscapes of the southern part of Eastern Siberia" (1977). The overlay of the burning’s contours on the species composition map and on the landscape map was created in the Geoinformation System Quantum GIS.

When recognizing the burnt areas with the help of multizone images, their color tone changes depending on the spectral channel. In this paper, a color RGB image is obtained by the synthesis of the spectral channels 7-6-7 of the multi-zone Landsat 8 OLI image. Using the combination of channels, the visual noise associated with the smoggy atmosphere is isolated, water objects are determined by black color, primary forest vegetation by green color tones, steppe and previously burnt areas by white and light pink color tones respectively, recently burnt areas are identified as heavy purple color tones from bright pink to dark purple.

The identification of burnt areas was carried out in the GIS under a supervised classification method. The maximum likelihood method was used as a classification algorithm. Three class categories of groups of pixels (reference areas) were determined, each relating to water surface, primary vegetation and burnt areas respectively.

Forecast of the Priolkhonie geosystems transformation after the pyrogenic effects was carried out using published materials referring to the research of dynamic changes in the geosystem components: biogeocenosises succession series (A.V. Belov, V.N. Molozhnikov, N.S. Gamova [5], etc.), structural changes of soil cover [6], evolutionary development of geosystems [7], and using the map "Vegetation of the South of Eastern Siberia" edited by A.V. Belov (1971), forest inventory maps from the Ministry of Forestry of the Irkutsk Region and the Pribaikalsky State National Park.

3. Results and Discussion
According to the geoinformation analysis of remote sensing data [8], the total burnt areas equaled: in 2013 - 0.29 square kilometers (29 ha), in 2014 - 24.7 square kilometers (2 470 ha), in 2015 - more than 178 square kilometers (17 850 hectares), of which approximately 87 square kilometers (8 665 ha) are
the territories of the Pribaikalsky State National Park. In 2016-2017, according to the interpretation of space images Landsat 8 OLI dating to September 24, 2016, and May 22, 2017, no new fire sources were detected in the study area.

The largest burnt areas are confined to the upper zone of the mountains, i.e. geosystems of the dwarf siberian pine (Pinus pumila) and dark-coniferous mountain-taiga stone pine (Pinus sibirica) forests. Pine, larch and deciduous forests are less affected by the fire. This is due to the spread of the fire from the western macro-slope of the Primorsky ridge to the study area through the watershed. After the fire passes through the area, the geosystem components are subject to various degrees of change. In the case of ground fires, the lower vegetation layers and especially the ground cover are first to be exposed to the destructive impact, and the duration of their restoration period differs depending on a forest type. Thus, in the burnt areas of green moss forest types, mosses and lichens die not only from fire, but from heat exposure of a fire of any intensity [9], and the initial formation of ground cover occurs after 2-3 or more years [10].

The pyrogenic factor causes dynamic transformations of the natural complexes associated with the changes in all the components. In this case, the regenerative dynamics of the geosystems is determined by the processes of self-organization in a changing climate, and for this reason it may also develop in the direction of a radical transformation of geosystems with the change of the invariant (figure 1, table 1).

**Figure 1.** Forecasting of the Priolkhonye geosystems transformation after pyrogenic impact in 2014-2015: 1-6 – transformation of geosystems structure (see table); 7 - recovery dynamics of geosystems.
Table 1. Forecasting of the Priolkhonye geosystems transformation after pyrogenic impact.

| № | Geosystems subject to the influence of the pyrogenic factor | Eventual geosystems |
|---|-----------------------------------------------------------|---------------------|
| 1 | Moss-lichen area in combination with dwarf siberian pine (*Pinus pumila*) in the area of watersheds and gentle slopes | Slow restoration of dwarf Siberian pine (*Pinus pumila*) biogeocenoses (approximately 80-100 years, according to V.N. Molozhnikov [11]). Restoration occurring through *Alnus fruticosa* and *Betula middendorfii*. Substitution by rock fragments is possible a certain part of the area. |
| 2 | Siberian pine (*Pinus sibirica*) shrubby rhododendron aureum green moss forests on slopes | Restoration occurs through Siberian pine, but in a certain part of the area, it may occur through larch and pine forests. |
| 3 | Larch (*Larix sibirica*)-Siberian pine (*Pinus sibirica*) bilberry-small grass green moss forests on slopes | Restoration occurs through the pine-larch blueberry-green moss forests. In the conditions of intense aridity, substitution by larch and pine forests might occur in a certain part of the area. |
| 4 | Larch (*Larix sibirica*)- pine (*Pinus sylvestris*) *rhododendron daurica* steppe forests | Long-term recovery through steppe communities or development of small-grain-grassy lithophilic steppes in a certain part of the area. |
| 5 | Pine-larch rare-growth forests in combination with wormwood low-grass lithophilic and low-bush grass steppes on steep slopes | Long-term recovery through birch communities or substitution by small-grain-grassy lithophilic steppes. |
| 6 | The Siberian pine (*Pinus sibirica*)-fir (*Abies*) bilberry-green-moss forest on low-lying locations | Restoration of the Siberian pine forests of the green-moss group through the succession of small-leaved species (poplar, aspen). |

After passing fires, groups of facies of moss and lichen in combination with dwarf Siberian pine *Pinus pumila* on the watersheds and gentle slopes located in the zone of active frost weathering are replaced by rock fragments in the parts of the study area. Destruction of vegetation cover, mainly dwarf Siberian pine (*Pinus pumila*) which suppresses water erosion, leads to the activation of dwarf soil loss processes and fine earth removal. On the flat surfaces, slow restoration of dwarf Siberian pine (*Pinus pumila*) biogeocenoses (approximately 80-100 years, according to V.N. Molozhnikov [11]) takes place. In the areas of permafrost soils, water-logging processes that impede the renewal of the dwarf Siberian pine (*Pinus pumila*) develop due to an increase in the solar radiation flux to the underlying surface.

The geosystems of dark-coniferous forests are characterized by the shrinking and death of the forest stand. The succession restoration stages of the climax community often occur with a change of tree species.

Fire influence on the facies groups of the Siberian pine (*Pinus sibirica*)-fir (*Abies*) bilberry-green moss forest is characterized by the fir tree death, destruction of the geosystem structures, and formation of the Siberian pine forests of the green-moss group in their areas through the succession of deciduous species (poplar, aspen).
A significant feature of the Siberian pine (*Pinus sibirica*) forests restoration is its close connection with the nutcracker activity. The bird hides the seeds only under the moss cover. For this reason, the restoration of the Siberian pine (*Pinus sibirica*) forest begins only after the moss cover restoration [12]. Restoration of facies groups of Siberian pine (*Pinus sibirica*) shrubby rhododendron aureum green moss forests on slopes occurs without the change of edificatory. However, in the conditions of increasing climate aridity in the region, the Siberian pine (*Pinus sibirica*) forests located the lower border of the distribution range along the southern slopes are replaced by groups of facies of larch and pine forests (see Table). The forest stands thinning leads to the formation of windfall trees that were not affected by the fire due to the "Gornaya" wind. The activation of exogenous processes associated with the dwarf soil losses occurs.

Restoration of the structure of facies groups of larch (*Larix sibirica*)- Siberian pine (*Pinus sibirica*) bilberry-small grass green moss forests on slopes passes through the stage of the formation of the pine-larch green moss forests. In the changing conditions of the background impact of the geosystems at the regional level, this intermediate community in the part of the study area can stay unchanged for a long time. In the upper parts of the slopes along the river valleys, permafrost melting leads to the intensification of bogging processes, degradation of forest-growing conditions, and development of erosion processes develop on the slopes [13].

Geosystems of larch (*Larix sibirica*)-pine (*Pinus sylvestris*) rhododendron daurica steppe forests on the gentle slopes of southern exposures are restored through steppe communities. Transformation of facies groups of pine-larch rare-growth forests in combination with wormwood low-grass lithophilic and low-bush grass steppes on steep slopes in the coastal part of Lake Baikal affected by medium and high-intensity fire is accompanied by the shrinking of the forest stand and the development of small-grain-grassy lithophilic steppes in their area.

4. Conclusion

Fire is one of the factors contributing to a sharp change in the dynamics of geosystems. The study area is characterized by arid and semi-arid climatic conditions due to the occurrence of a complex of landscape-forming effects: barrier-shadow, arid-hollow and foothill. In the process of the regional changes in hydrothermal conditions, the dynamic transformations of the Priolkhonic geosystem structures are enhanced by the pyrogenic factor. In the context of the analysis carried out, it should be noted that the area covered by the fires increased, and so did the destructive impact of forest fires. This may be caused by a number of factors, including increasing aridity of the Priolkhonic climate in the recent years, growing popularity of spontaneous tourism in previously inaccessible areas, weak forest protection system that contributes to the spread of the fire to larger areas. The increase of the area of burned moist dark-coniferous forests compared to that of larch-pine forests might be caused by the transition of the fire that has gained strength and significant temperature from the territory of the Kachugsky district through the Primorsky Range under arid and windy weather conditions.

Long-term degradation of forest-growing conditions with a prolonged stage of their restoration, replacement of native dark coniferous forests in some parts of their area by light coniferous forests, replacement of larch-pine steppe forests on the southern slopes by steppe communities, and an increase in the area of rock fragments in mountain-tundra geosystems are therefore forecasted.

Acknowledgments

The work was done under research project № 16-05-00902 RFBR and research project № VIII.79.2.5 IG SB RAS.

References

[1] Antokhina O Y, Antokhin P N and Martynova Y V 2016 Proc. of the International Conference (Tomsk: Center for Scientific and Technical Information) pp 368-71

[2] Maksyutova E V, Kichigina N V, Voropai N N, Balybina A S and Osipova O P 2012 Tendencies of hydroclimatic changes on the baikal natural territory Geography and Natural
Resources 33(4) 304-11

[3] Bychkov I V and Nikitin V M 2015 Water-level regulation of lake Baikal: Problems and possible solutions Geography and Natural Resources 36(3) 215-24

[4] Sofronov M A, Anropov V F and Volokitina A V 1999 Pyrological characteristics of the vegetation of the Lake Baikal basin Geography and Natural Resources 2 52-8

[5] Gamova N S 2014 Post-fire vegetation changes of Central Khamar-Daban (Southern Baikal Region) Problems of Botany of Southern Siberia and Mongolia 13 55-9

[6] Krasnoshchekov Y N 2011 Transformation of Gray-Humus Soils of Pine Forests under the Influence of Fires in Southwestern Lake Baikal Basin Lesovedenie 2 3–12

[7] Bezrukova E V and Letunova P P 2012 Environmental Change in the Middle and Late Holocene Priolkhon Region Izvestiya of the Irkutsk State University. Series: Geoarchaeology. Ethnology. Anthropology 1 91-105

[8] Bibaeva A Y 2016 Analysis of fire-induced influence on the Priolkhonye geosistems by using materials of remote sensing of the Earth Progress in Modern Natural Science 12(2) 347-51

[9] Kovaleva N M, Ivanova G A and Kukavskaya E A 2011 Restoration of the Ground Cover after Surface Fires in Pine Forests of Middle Taiga Forest Science 5 30-5

[10] Sofronov M A and Volokitina A V 2007 The Method of Pyrological Survey and Description of Forest Areas Passed by Fires (Krasnoyarsk: V N Sukachev Forest Institute SB RAS) p 71

[11] Molozhnikov V N 1975 Cedar Sitanik of Mountain Landscapes of the Northern Baikal Region (Moscow: Nauka) p 203

[12] Popov L V 1982 Southern Taiga Forests of Central Siberia (Irkutsk: Irkutsk University Publhing House) p 330

[13] Agafonov B P 1975 Distribution and forecast of physical-geographical processes in the Baikal basin Dynamics of the Baikal Depression (Novosibirsk: Science Pub.) pp 59-138