Landscape-typological mapping of the Baikal region (within the boundaries of the Irkutsk region)

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Abstract. The aim of the work is to create a landscape-typological map of the territory to study the territorial differentiation of recreational activities. The variety of landscapes of the Baikal region is determined by a large number of landscape-forming factors, as well as the heterogeneity of the conditions in which geocomplexes are formed. A landscape-typological map of the territory was created on a scale of 1: 500 000. As an input data for creating the map, electronic topographic maps of the territory, space images of Landsat 5, 7, 8 for different seasons and years (including mosaic of MrSID for 2000 and Hansen mosaic for 2016), digital elevation models, landscape, geological, soil and geobotanical maps of different scale were used. A total of 56 landscape units were identified: 13 highland (goltzy, sub-mountain, reduced development mountain-taiga), 6 medium-mountain (limited development taiga), 14 lowland (optimal development mountain-taiga, steppe), 13 foothill (limited development taiga, optimal development taiga, subtaiga, steppe), 10 - intermontane depressions and valleys (limited development taiga, optimal development taiga, steppe). The conclusions drawn about the landscape structure and recreational properties of the territory are generalized. More detailed landscape research is needed, including comprehensive field work to clarify the landscape map and assess the recreational significance of landscapes.

1. Introduction
The territory of the Baikal region, which is, on the one hand, promising for the development of various types of economic activity, and on the other hand, unique and highly valuable from an ecological point of view, needs scientifically based planning of nature management. The information basis for such planning should be a reliable medium-scale landscape map reflecting the potential and current state of the landscapes of the territory. Landscape maps of different scale on the territory of the Baikal region, created by employees of various laboratories of the Institute of Geography SB RAS in different years, are mostly fragmentary and require generalization and reduction to a single one [1].

The aim of the work is to create a landscape-typological map of the territory to study the territorial differentiation of recreational activities. Different landscapes with certain properties (vegetation, relief, humidification conditions, aesthetic appeal, comfort, resistance to recreational loads) are appropriate for the development of one or another type of recreational activities.

The themes of planning recreational activities on a landscape basis, sustainable tourism development, assessment and mapping of cultural ecosystem services are widely represented both in Russian and foreign studies [2].
2. Objects
As the object of the study, the territory of the Baikal region within the boundaries of the central ecological zone of the Baikal natural territory within the Irkutsk region was chosen.

The variety of landscapes of the Baikal region is determined by a large number of landscape-forming factors. The geological structure of the territory is very contrasting. Precambrian acid magmatic and metamorphic rocks (granites, gneisses, stannites, argillites and conglomerates) prevail in the area. On the east coast, granitoids with the metamorphic (crystalline schists, biotite-garnet plagioclases, amphibolites) and sedimentary (sandstone, gravel) rocks predominate, and on the western side - Proterozoic sedimentary and metamorphic deposits (sandstones, siltstones, various shales, gneisses and tuffs), as well as igneous rocks (granites, granosyenites, porphyries, granodiorites) [3].

The climate of the Baikal region is determined by the location of the territory in the belt of temperate latitudes, considerable distance from the oceans, and also by the features of the mountain-hollow relief. Average annual air temperatures are negative throughout the territory. The lowest temperatures are recorded in January (-16 above the water area of Lake Baikal, down to -28 on the periphery), the highest - in July (from 8 above the water area of Lake Baikal, to 20 in the basins of the Baikal region). The western transport of air masses with a possible chill of cold air from the north, and a warm moist one - from the south prevails. The annual amount of precipitation varies from 200 mm or less in Priolkhonye to 1000 and more on Khamar-Daban ridge [4].

The complexity of the geological history and modern conditions of the Baikal region determine the contrast of the soil of the territory. In the goltsy belt - stony, low-power organogenic-gravelly, substructures and podzols, in the forest zone - soddy taiga with accompanying podzolic, soddy-carbonate and brown soils, in the steppes of Priolkhonye - chestnut, sod steppe and chestnut soils predominate. Meadow, meadow-marsh, and marshsoils prevail in valleys, and saline soils - near saline lakes in Priolkhonye under saline meadows [3].

The distribution of vegetation in the area is determined by high-altitude zones, complicated by the bolson effect, aspect, lithology, microclimate of the lake Baikal, latitudinal and meridional zoning. Ehe alpine, mountain-tundra, subalpine, subgoltsy, light coniferous taiga, dark coniferous taiga, steppe and shrub-meadow-marsh plant complexes are distinguished in the area [5].

The landscape structure of the Baikal region is characterized by high complexity and contrast. Two large regions of the North Asia - Baikal-Dzhugdzhursky and South-Siberian physico-geographical regions - are in contact here; three types of natural environment are combined: tundra, taiga and steppe; a wide range of landscapes: goltsy, subgoltsy, mountain-taiga, mountain-forest, mountain-forest-steppe (subtaiga) and mountain-steppe [6].

3. Data, methods, results and discussion
A landscape-typological map (figure 1) of the territory was created on a scale of 1: 500 000. As an input data for creating the map, electronic topographic maps of the territory, space images of Landsat 5, 7, 8 for different seasons and years (including mosaic of MrSID for 2000 and Hansen mosaic for 2016), digital elevation models, landscape, geological, soil and geobotanical maps of different scale were used. [7]. With the use of a digital elevation model, maps of slope and aspect were constructed. When creating the map, methods of automatic processing of space images were used. Using the methods of visual interpretation of Landsat images of different seasons, as well as using maps of slope and aspect, the territory was differentiated into homogeneous landscape units and their typological affiliation was determined. In the legend (table 1) of the landscape map landscapes are grouped into clusters of high-altitude belts (high-mountain, middle-mountain, low-mountain, piedmont, intermountain depressions and valleys), developmental conditions (optimal, reduced and limited), features of mesorelief and vegetation.
Figure 1. Landscape map of the area. Stages: 1 – new (0-3 years) burnt areas, 2 - regenerating burnt areas, 3 - small-leaved forests in place of old burnt areas, 4 - light coniferous stages of restoration of dark coniferous forests. Landscapes: see table 1.

A total of 56 landscape units were identified: 13 highland (goltzy, sub-mountain, reduced development mountain-taiga), 6 medium-mountain (limited development taiga), 14 lowland (optimal development mountain-taiga, steppe), 13 foothill (limited development taiga, optimal development taiga, subtaiga, steppe), 10 - intermontane depressions and valleys (limited development taiga, optimal development taiga, steppe).
### Table 1. Legend of the landscape map.

| Topographic feature                          | Landscape                                                                 | Number on the map |
|----------------------------------------------|---------------------------------------------------------------------------|-------------------|
| **High-mountain, Goltsy, Alpinotype**        |                                                                           |                   |
| Sharp ridge watersheds, rocky and steep      | With sparse vegetation cover (fragments of lichen tundras)               | 1                 |
| rockfall-talus slopes                         |                                                                           |                   |
| Of watersheds and slopes                      | Herbaceous with areas of alpine meadows                                   | 2                 |
| **Subalpinotype**                             |                                                                           |                   |
| Goltsy planate surfaces, adjacent gentle      | Lichen tundra                                                             | 3                 |
| slopes                                       |                                                                           |                   |
| Of rounded tops and adjacent gentle slopes,   | Moorland                                                                  | 4                 |
| detrital-block                               |                                                                           |                   |
| Slopes                                       | Gravity-solifluction lichen with sparse thicket of Siberian dwarf pine   | 5                 |
| Of configured surfaces and gentle slopes      | With Siberian dwarf pine moss-lichen                                      | 6                 |
| **Tundra**                                   |                                                                           |                   |
| Of steep slopes                               | With Siberian dwarf pine                                                 | 7                 |
| Of top surfaces and slopes                   | Larch with Siberian pine, fir and birch sparse wood subshrub-lichen      | 8                 |
| Planate surfaces of watersheds, upper and    | combined with rare thicket of Siberian dwarf pine                         |                   |
| lower slopes                                 |                                                                           |                   |
| Planate surfaces of watersheds, upper and    | Siberian pine and fir sparse wood with yernik subshrub-true moss and     | 9                 |
| lower slopes                                 | grass-subshrub-lichen                                                    |                   |
| Of flat surfaces                              | Siberian pine sparse wood with yernik or Siberian dwarf pine             | 10                |
| Of trough bottom                              | With Siberian pine and firry sparse wood herbaceous, grass-subshrub and   |                   |
|                                              | subshrub                                                                 |                   |
| **Subgoltsy, Shrub**                          |                                                                           |                   |
| Of gentle slopes                              |                                                                           |                   |
| **Sparse wood**                               |                                                                           |                   |
| Of gentle slopes                              |                                                                           |                   |
| **Mountain-taiga of reduced development**    |                                                                           |                   |
| Planate surfaces of watersheds, upper and     | Siberian pine and fir-Siberian pine (with larch on northern slopes)      | 12                |
| lower slopes                                 | sparse wood subshrub-true mosses with short grass (with Siberian dwarf   |                   |
|                                              |   pine and rhododendron golden – on northern slopes, with bergenia on    |                   |
|                                              |   steepe slope                                                           |                   |
|                                              |   – on southern slopes, with planate surfaces                           |                   |
| Planate surfaces of watersheds, upper and    | Fir and Siberian pine-fir (with spruce and Siberian pine on northern     | 13                |
| lower slopes                                 |   slopes)                                                                 |                   |
|                                              |   subshrub-true mosses (with bergenia on steepe slope, with Siberian     |                   |
|                                              |   dwarf pine on northern slopes) in combination of subshrub-herbaceous   |                   |
|                                              |   and herbaceous on southern slopes                                      |                   |
|                                              | **Middle-mountain, Mountain-taiga of limited development**               |                   |
| Of flat surfaces                              | Larch with admixture Siberian pine cowberry-bergenia                     | 14                |
| Plans                                        | Larch with admixture Siberian pine, spruce with mixed undergrowth        | 15                |
| Flat watersheds and southern slopes           | Larch with pine                                                          | 16                |
| Largely gentle slopes                         | Fir-Siberian pine and Siberian pine-fir subshrub-short grass-true mosses| 17                |
|                                              | (short grass-subshrub- true mosses in places)                            |                   |
| Slopes of different light                    | Siberian pine and fir-Siberian pine (with admixture of spruce and larch  | 18                |
| aspects and steepness                         |   in places)                                                             |                   |
|                                              |   subshrub-true mosses with short grass (subshrub- true mosses with      |                   |
|                                              |   marsh tea on northern gentle slopes)                                   |                   |
|                                              | **Low-mountain, Mountain-taiga of optimal development, Baikal-Dzudzhuks**|                   |
| Slopes                                       | Larch with shrub undergrowth                                             | 19                |
| Gentle slopes                                | Larch с участием pine and pine-larch forb and cowberry-forb and         |                   |
|                                              |   grass-mosses                                                           |                   |
|                                              | Larch rare forests with rare shrub undergrowth gramineous-forb combined  |                   |
|                                              |   with steppes                                                          |                   |
| **Southern-Siberian**                         |                                                                           |                   |
| Slopes                                       | Siberian pine-fir bilberry-true mosses                                   | 20                |
| Of flat surfaces                              | Polydominant Siberian pine-spruce                                       | 21                |
| Slopes                                       | Pine with rhododendron undergrowth (Rhododendron dauricum)              | 22                |
| Of gentle slopes                              | Pine and larch-pine with mixed undergrowth                              |                   |
| **Low-mountain, Mountain-taiga of optimal    | Pine with additive of larch grass-cowberry                               | 23                |
| development, Baikal-Dzudzhuks**              |                                                                           |                   |
|                                              |                                                                           |                   |
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**Notes:**
- **High-mountain, Goltsy, Alpinotype**: High-altitude landscapes with sparse vegetation cover, often found in rocky and steep areas.
- **Subalpinotype**: Subalpine landscapes with lichen tundras.
- **Tundra**: Tundra landscapes with lichen tundras and sparse vegetation.
- **Sparse wood**: Forested landscapes with sparse shrub cover.
- **Mountain-taiga of reduced development**: Subalpine-montane ecosystems with reduced forest cover.
- **Middle-mountain, Mountain-taiga of limited development**: Montane-montane ecosystems with limited forest cover.
- **Low-mountain, Mountain-taiga of optimal development, Baikal-Dzudzhuks**: Low-altitude montane-montane ecosystems with optimal forest development.
- **Southern-Siberian**: Siberian landscapes with specific vegetation and climatic conditions.
| Topographic feature                                      | Landscape                                                                 | Number on the map |
|----------------------------------------------------------|---------------------------------------------------------------------------|-------------------|
| plains                                                   | Pine grass, with rhododendron undergrowth (Rhododendron dauricum)          | 28                |
|                                                           | steppificated in places                                                   |                   |
| Steep northern slopes, facing the lake Baikal            | Siberian pine, with Siberian dwarf pine undergrowth                       | 29                |
| Steep precipitous slopes facing the lake Baikal          | Pine and larch rare forests steppificated lithophile                       | 30                |
| Slopes and watersheds                                   | Deforested forb-small reed shrub-dominated with washed away the soil and  | 31                |
|                                                           | spots of stony outcrop                                                    |                   |
| Steep precipitous slopes                                | Forb-fescue combined with small forb and sagebrush lithophile             | 32                |
| Gentle slopes with spots of stony placers               | Submountain, Taiga of limited development                                 | 33                |
| Of piedmont high plains                                 | Siberian pine-subshrub-small grass-true mosses                            | 34                |
| Bottom of depressions                                   | Siberian pine-larch and larch with addition of spruce, with shrub        | 35                |
|                                                           | undergrowth subshrub-mosses in places                                     |                   |
| Of piedmont high plains                                 | Siberian pine-fir bilberry-grass-moss with tall grass                     | 36                |
| Of submountain plains                                   | Fir-Siberian pine moss-grass                                              | 37                |
| Of depressions bottoms, submountain plains              | Pine with shrub undergrowth grass, steppificated in places               | 38                |
| Submountain plains                                      | Gramineous-forb meadows of anthropogenic genesis, combined with birch    | 39                |
|                                                           | Grove and sedge lowland swamps                                            |                   |
| Of piedmont high plains                                 | Siberian pine-larch subshrub                                              | 40                |
| Slopes facing the lake Baikal except for north steep    | Light coniferous and small-leaved, usually rarefied forests small reed-  | 41                |
| slopes)                                                 | forb, forbracken                                                          |                   |
| Bottoms of gullies                                      | Pine sparse psammophyte                                                  | 42                |
| Terraces                                                 | Small sod-gramineous lithophile                                           | 43                |
| Bottoms of depressions                                  | Large gramineous feather grass-wheatgrass                                 | 44                |
| Bottoms of gullies                                      | Small sod-grass spotted combined with halophytic meadow                   | 45                |
|                                                          | Psammophyte plant aggregation                                            | 46                |
| Intermontain hollows and valleys, Taiga of limited      | Yernik                                                                    | 47                |
| development, Baikal-Dzhugdzhurski                       | Taiga of optimal development, Baikal-Dzhugdzhurski                        |                   |
| Valleys                                                  | Meadows with gramineous cover steppificated in places                     | 48                |
|                                                           | Taiga of limited development, Southern-Siberian                          |                   |
| Valleys                                                  | Fir-Siberian pine with spruce horsetail-short grass-true mosses           | 49                |
|                                                           | Fir and larch-spruce mixed shrub grass-true mosses and forb-small reed   | 50                |
|                                                           | Siberian pine-larch and larch with fir and spruce forest with yernik,    | 51                |
|                                                           | willow                                                                    |                   |
| Valleys                                                  | Fir-spruce and Siberian pine-spruce large grass                           | 52                |
| Valleys                                                  | Grass and grass-moss swamps sparse wood larch with spruce                 | 53                |
|                                                           | Oligotrophic moors and mesotrophic bogs of submountain plains sedge-     | 54                |
|                                                           | sphenugnum and subshrub (marsh tea, cranberry, leatherleaf)-sedge-sphenugnum |                   |
|                                                           | with sparse stand of Siberian pine, spruce and birch                     |                   |
|                                                           | Light coniferous and dark coniferous with poplar forb- moist grass        | 55                |
|                                                           | shrub-dominated                                                           |                   |
| Valleys                                                  | Sedge-gramineous meadow-swamp solonetiz                                   | 56                |
| Settlements and industrial areas                         | Anthropogenic                                                             | 57                |
| Agricultural (arable lands)                              |                                                                          | 58                |

The study area has a high landscape diversity, which makes it possible to develop a wide range of tourism activities [8].
Landscapes of the goltsy belt (3% of the research area) are represented by the near-watershed, slope, rocky and rockfall-talus moorlands and with lichen-tundra complexes and alpine meadows. In the subgoltsy belt (11% of the study area) moss-lichen, yernik, dwarf Siberian pine and shrub-lichen tundra, as well as larch, Siberian pine and fir sparse forest are widespread. They are confined mainly to the peaks and slopes of the Khamar-Daban and the Baikal ridges, to a lesser extent, the Primorsky ridge.

Mountain-taiga landscapes (62% of the investigated territory) of Khamar-Daban ridge are mainly represented by dark coniferous Siberian pine and spruce-fir-Siberian pine forests. The mountain taiga belt of the Primorsky range is represented mainly by larch and pine, as well as Siberian pine with an admixture of spruce and larch forests. The Baikal ridge is dominated by fir-Siberian pine forests. On the Olkha plateau, fir-Siberian pine forests, as well as areas of their light coniferous and small-leaved succession stages predominante.

Submountain and subtaiga complexes (9% of the study area) are characterized by a moderately roughness of relief and a high species diversity. On Olkha plateau they are mainly represented by light coniferous and small-leaved forests on the slopes facing Lake Baikal, on the Khamar-Daban ridge – by Siberian pine-fir forests of foothills, on the Baikal ridge - by larch with Siberian pine forests, on the Primorsky ridge, in Priolkhone and on the Olkhon island – by subtaiga pine and larch forests.

Steppe landscapes of Priolkhone and Olkhon island, occupying piedmont locations and located in the "rain shadow" of the Primorsky ridge, are spatially differentiated depending on the relief and lithomorphic factor and characterized by the predominance of large-grained feather-grass on the bottoms of the basins (9%) and small-grained lithotrophic on terraces (6%).

About 30% of the Baikal Range, 13% of the Primorsky Range, 9% of Priolkhone and Olkhon, 7% of the Olkha plateau within the central ecological zone of the lake Baikal are occupied by new and regenerating burnt areas.

4. Conclusions
Thus, within the territory under study, a number of zones (goltsy, subgoltsy, mountain-taiga, piedmont and subtaiga and steppes) are identified, each of which has unique conditions for the tourism development.

The conclusions drawn about the landscape structure of the territory are generalized. More detailed landscape research is needed, including comprehensive field work to clarify the landscape map and assess the recreational significance of landscapes.

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References
[1] Istomina E A, Solodyankina S V, Vanteeva Y V, Konovalova T I, Bibaeva A Y, Frolov A A and Tsygankova M V 2018 Results of landscape-cartographic studies in the Baikal region Geodesy and cartography 79(2) 36-47
[2] Bezruikikh V A, Antonenko O V, Kostrenko O V, Avdeeva E V and Korotkov A A 2016 Mountain-taiga forests of eastern Sayan as a potential for nature-oriented tourism (within the Krasnoyarsk Territory) Coniferous of Boreal Zone 37 266-9
Bezuglova M S, Sharova I S and Sulejmanov A R 2013 Geoecological approaches in studying the tourist and recreational potential of the territory Geology, Geography and Global Energy 51(4) 132-9
Timoshenko N V 2010 Mapping and study of landscapes for the purpose of creating a scheme for the development of recreation and tourism Izvestiya of Smolensk State University 2 30-9
Fadafan F K, Danehkar A and Pourrebrahim S 2018 Developing a non-compensatory approach to identify suitable zones for intensive tourism in an environmentally sensitive landscape Ecological Indicators 87 152-66
Mann C, Garcia-Martin M, Raymond C M, Shaw B J and Plieninger T 2018 The potential for integrated landscape management to fulfil Europe’s commitments to the Sustainable Development Goals Landscape and Urban Planning 177 75-82
Woźniak E, Kuczyk S and Derek M 2018 From intrinsic to service potential: An approach to assess tourism landscape potential Landscape and Urban Planning 170 209-20

[3] Kuzmin V A 2002 Soils of the Central Zone of the Baikal Natural Territory (Ecology-Geochemical Approach) (Irkutsk: IG SO RAN) p 166
[4] Baikal. Atlas 1993 (Moscow: Roskartografiya) p 160
[5] Belov A V 1973 Map of Vegetation in the South of Eastern Siberia. Principles and Methods of Compilation. Geobotanical Mapping (Leningrad: Nauka) pp 16-30
[6] Mikheev V S 1995 Landscapes of the Baikal region: structure, state estimation, problems Geography and Natural Resources 3 68-78
[7] Frolov A A 2015 Geoinformation mapping of landscape variability (on the example of the southern Baikal region) Geography and Natural Resources 1 156-66
Korol'kova E E 2015 Medium-scale geobotanical mapping of the North-Western Baikal region taking into account the evolutionary-dynamic features of vegetation Geobotanical Mapping (St.Petersburg: Boston-Spectr) pp 42-61
Pljusnin V M and Bilichenko I N 2001 Remote and quantitative methods of studying the landscape structure (on the example of the Khamar-Daban ridge) Geography and Natural Resources 2 127-36
Zagorskaja M V 2004 Landscape structure of Central Priolhonya Geography and Natural Resources 4 58-68
Suvorov E G and Titaev D B 1999 Structure of the landscapes of the Southern Pribaikalye Geography and Natural Resources 4 20-30
Suvorov E G, Antipov A N, Semenov YU M 2002 Ecologically-Oriented Land Use Planning in the Baikal Region: Studyanka Region (Irkutsk: IG SO RAN) p 141

[8] Evstropeva O V 2009 Cross-Border Tourism in Adjacent Regions of Russia and Mongolia (Irkutsk: IG SB RAS) p 143