Potential landscape stability of recreational zones on the southern shore of Lake Baikal

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Abstract. The article deals with the landscape stability of five recreational zones on the southern coast of Lake Baikal: Portbaikal’skaya, Kultuk-Slyudyanskaya, Utulik-Baikal’skaya, Murinskaya and Snezhinskaya, the boundaries of which were previously defined during the tourist and recreational zoning of the central ecological zone of the Baikal natural territory between 2017 and 2019. We studied the natural stability of recreational areas on a landscape basis using the results of component-wise assessments of vulnerability and stability. The landscape-typological structure of recreational zones and component-wise stability within the boundaries of specific landscape sections were analysed, the integral stability of landscapes was obtained, and a comparative analysis of the landscape stability of the selected recreational zones has been carried out.

1. Introduction
The principal objective of the study was an assessment of the potential landscape stability of five recreational zones on the southern shore of Lake Baikal: Portbaikal’skaya, Kultuk-Slyudyanskaya, Utulik-Baikal’skaya, Murinskaya and Snezhinskaya. The boundaries of the zones were defined earlier during the tourist and recreational zoning of the central ecological zone of the Baikal natural territory between 2017 and 2019 [1-3]. All tourist and recreational zones are located in the coastal zone; their area varies from 5 to 50 km². Assessment of the potential stability of landscapes is necessary for large-scale zoning of areas allocated for recreation in order to separate recreational flows, plan recreational facilities ecologically and calculate recreational loads on individual sections of recreational zones.

We studied the natural stability of recreational areas on a landscape basis using the results of component-wise assessments of vulnerability and stability. Different landscapes and their components have different properties and, consequently, different natural stability. The analysis of the landscape structure revealed the natural prerequisites for the development of ecological restrictions for recreational use.

2. Models and methods
The study consisted of three stages: landscape analysis of the territory of tourist and recreational zones; analysis of the stability of individual components, its spatial distribution and association to types of landscapes; assessment of the integral stability of landscapes and its mapping.

To analyse the landscape structure of recreational zones, we used a landscape map of the Slyudyansky district, developed by E G Suvorov [4, 5], and to assess the landscape stability – the component-wise assessments of vulnerability and stability obtained by specialists from
the Sochava Institute of Geography, Siberian Branch of the Russian Academy of Sciences [5, 6]. The following maps were used as the main sources of information for assessing stability: “Geomorphological processes”, “Soils. Significance and vulnerability”, “Stability of plant communities”, “Stability of animal communities”, “Mesoclimatic potential for self-purification of the atmosphere”, “Vulnerability of the unconfined water exchange zone to changes in the runoff-regulating functions of a landscape”, “Flood hazard” and “Fire hazard class”.

The mesoclimatic potential of self-purification of atmosphere, assessed through the climatic potential of self-purification of the atmosphere, is low on the territory of all recreational zones under study due to their coastal location (low absolute altitudes) and mountainous surroundings. Only a few small fragments of mountain-taiga landscapes on slopes and watersheds with absolute elevations above 600 m have an average potential for self-purification. High vulnerability is observed only in the Slyudyansky district, very low in the village of Murino and the Snezhnaya River. In all recreational areas except Portbaikal’skaya there is a high risk of floods. The fire hazard class is mostly medium, and high in some places [6-8].

We assessed the relief stability by means of catastrophic and dangerous geomorphological processes. Catastrophic geomorphological processes on the territory of recreational zones are represented by two types: 1 – mudflows of high and very high risk (often in the valleys of the rivers Kultuchnaya, Talaya, Slyudyanka, Utulik, Babkha, Kharlakhta, Khara-Murin and Snezhnaya); 2 - landslide, talus, creep, mudflow of cut slopes (in the area of the Circum-Baikal railway). The hazardous processes - landslide, talus, creep of the mountain-taiga belt - are associated to the valleys of the Kultuchnaya River and its tributaries (the slopes of the valleys are steeper than 25-30°) [6, 7]. In the presence of catastrophic geomorphological processes, the stability was considered as low; in the presence of hazardous geomorphological processes as moderate; in areas with a predominance of relatively safe geomorphological processes as high.

Soil stability is closely related to the manifestation of modern exogenous soil-destructive processes and is inversely related to vulnerability. Soils in the river valleys of the Khamar-Daban Range have high vulnerability (low stability respectively), and low vulnerability (high stability) on the coastline between the villages of Murino and Novosnezhnaya. Soils in the main area have moderate vulnerability (moderate stability) [5, 7]. Areal localization of catastrophic and hazardous geomorphological processes and soils of low stability does not always coincide with specific types of landscapes. Therefore, different landscape plots of the same typological category were assigned to different categories of stability in some cases.

Vegetation stability presented in 4 categories (stable, moderate, low and unstable) and mapped was based on biotope analysis [5-7, 9]. The level of detail of the biotope map used it as a basis for characterizing other environments and assessing stability.

The results of the component-wise assessment for each typological unit of the landscape were tabulated. Then we assessed the landscape stability based on the following approach. We assumed that the stability of a particular landscape is not a simple sum of component-wise stability assessments or their mean value. For each type of landscape, the minimum component-wise stability, the critical component (the component with low stability), and the mean component-wise stability were determined. The stability of vegetation, soil and relief was taken as a basis. These three components were considered as leading in determining the integral stability. A landscape usually was assigned the low stability of one of these components. The stability of other components and wildfire hazard were additionally taken into account.

Thus, the integral stability was obtained on the basis of a combination of the minimum indicator of the component-wise stability of vegetation, soils, relief and the mean component-wise stability. On the basis of the obtained integral assessment, landscape stability maps were created for each recreational zone.
3. Results and Discussion

3.1. Characteristics of landscapes of recreational zones

Out of 49 landscape types, widespread within the boundaries of the Slyudyansky district, 15 are represented on the territory of recreational zones (Table 1) [6, 10, 11]. The designated recreational areas can be divided into three groups according to the type of landscape structure.

Table 1. Integral stability of landscapes.

| No. in the legend | Landscape type | Critical components | Integral stability |
|-------------------|----------------|---------------------|--------------------|
| **Mountain-taiga belt** | | | |
| 1 | Watersheds and gentle southern slopes Siberian stone pine, occasionally with rhododendron, small grass–subshrub–long moss–true moss | Soils, vegetation | Moderate |
| 2 | Gentle northern slopes, Siberian stone pine with larch subshrub, subshrub long moss–true moss with wild rosemary | Soils, atmospheric air | Moderate |
| 3 | Steep eroded southern slopes Siberian stone pine forb–cowberry with bergenia | Vegetation | Low |
| 4 | Steep northern slopes Siberian stone pine with larch small-grass–subshrub–true moss bergenia with wild rosemary | Soils, vegetation, atmospheric air | Moderate |
| 5 | Steep northern slopes Siberian stone pine–fir cowberry–small-grass, small-grass–true moss and subshrub–true moss with bergenia | Soils, vegetation, atmospheric air | Moderate |
| 6 | Steep southern slopes and of interposed exposure facing Lake Baikal, with parvifoliolate and light-coniferous often sparse forests of a subtaiga nature, reed–forbs, forbs–bracken with spirea and Daurian rhododendron with steppification attributes and steppe islands | Soils, animals, atmospheric air | Moderate |
| 7 | Steep northern slopes, influenced by Lake Baikal, Siberian stone pine with larch small-grass–subshrub–true moss bergenia with wild rosemary and dwarf Siberian stone pine in the undergrowth | Soils, vegetation, surface water, atmospheric air | Moderate |
| 8 | Mountain–valley larch–spruce with Siberian stone pine herb–horsetail–pine purple grass shrubby | Soils, surface water, atmospheric air | High |
| 9 | Valley light-coniferous and dark-coniferous with poplar herb–reed wet grass–herb shrubby (willow and alder) floodplain regime | Relief, soil, atmospheric air | Low |
| **Piedmont and intermontane depressions taiga** | | | |
| 10 | Submontane plain larch and pine–larch gramineous–forb and cowberry–forb, derivatives of birch forb in places | Soils, atmospheric air | High |
| 11 | Submontane plains along low watersheds dark- coniferous (Siberian stone pine, fir and spruce) blueberry-green moss and small-grass–blueberry–green moss | Atmospheric air | High |
| 12 | Submontane lowland gramineous–forb meadows of anthropogenic origin, in combination with birch groves and sedge lowland bogs | Soils, atmospheric air | Moderate |
| 13 | Peat bog and transitional foothill plains sedge–sphagnum and subshrub (wild rosemary, cranberry, cassandra)–sedge–sphagnum with open stands of Siberian stone pine, spruce and birch | Atmospheric air | High |
| 14 | Submontane dark-coniferous (Siberian stone pine, fir and spruce) on drift trains with the participation of forb–blueberry birch | Atmospheric air | High |
| **Anthropogenically transformed territories** | | | |
| 15 | Residential | Soils, vegetation, animals, atmospheric air | Unstable |
The Kultuk-Slyudyanskaya and Utulik-Baikal’skaya recreational zones are located in the places where the spurs of the northern macroslope of the Khamar-Daban Range go to Lake Baikal. Here, the contrast of the relief determines the contrast of landscapes: steep-slope mountain-taiga dark-coniferous landscapes with pronounced exposure differences (Siberian stone pine forb-cowberry with bergenia on the southern slopes and Siberian stone pine small-grass–subshrub–true-moos bergenia with wild rosemary on the northern slopes) alternate with piedmont-coastal gramineous forb meadows of anthropogenic origin, birch groves and sedge wetlands. A distinctive feature of two recreational zones is the pronounced disturbance of the native landscape structure by industrial cuttings and wildfires; large areas are occupied by light-coniferous and parvifoliate variants of the native landscapes.

The landscapes of the Murinskaya and Snezhinskaya recreational zones were formed on the plane areas of debris cones, river and lake terraces, composed of loose sediments at high-humidity conditions. Piedmont plain landscapes, dark-coniferous (Siberian stone pine, fir and spruce), small-grass–blueberry–true moss and forb–blueberry prevail here. A characteristic feature of the landscape structure of these zones is the presence of peat bogs and transitional sedge–sphagnum bogs.

The Portbaikal’skaya recreational zone is located on the steep southern slopes facing Lake Baikal with parvifoliate and light-coniferous sparse reed–forb, forb–bracken forests; they have a subtaiga character and steppification attributes.

Based on the obtained integral assessment, we created maps of landscape stability of each recreational zone. Thus, the mapped stability can be called potential, that is, the one that characterizes each landscape in an undisturbed state. Stability decreases in disturbed landscapes. These are post-fire parvifoliate and light-coniferous variants of mountain-taiga and sub-taiga landscapes, meadows of anthropogenic origin, residential areas and adjoining heavily degraded areas.

3.2. Characteristics of landscape stability of recreational zones

The recreational zones under study differ significantly from each other in their size, location on the shore of Lake Baikal, the degree of human-induced transformation, landscape structure and, as a consequence, in the landscape stability. Two zones are defined with due regard of human-induced impact - Kultuk-Slyudyanskaya and Utulik-Baikal’skaya. The share of unstable residential landscapes is high in them, stable landscapes are completely absent in the Kultuk-Slyudyanskaya zone and are almost absent in the Utulik-Baikal’skaya zone (no more than 5% of the area of the zone).

![Figure 1. Landscape stability of the Utulik-Baikal’skaya recreational zone.](image-url)
Landscapes with low stability in the Kultuk-Slyudyanskaya recreational zone occupy about half of the total area. In the Utulik-Slyudyanskaya zone, the area of low stable landscapes is small and is confined to the valleys of the Utulik, Babkha and Solzan rivers (Figure 1).

The Utulik-Baikal’skaya recreational zone is characterized by a predominance of landscapes with moderate stability (piedmont lowland dark-coniferous blueberry–true moss along low watersheds (No. 11 according to Table 1 hereinafter) in combination with unstable landscapes of residential areas of the city of Baikalsk and the village of Utulik (No. 15). The moderate stability of these landscapes is due to the moderate soil stability. Small areas with low stability are confined to the valleys of the Utulik, Babkha and Solzan rivers, with valley light-coniferous and dark-coniferous with poplar herb–reed grass shrubby wet meadow floodplain landscapes are widespread here (No. 9). Landscapes with high stability are represented by six small-sized areas adjoining the Khamar-Daban Range – these are dark-coniferous piedmont on drift trains with the participation of birch forb–blueberry (No. 14) and piedmont plain larch and pine–larch gramineous and cowberry–forb (No. 10).

The Murinskaya and Snezhinskaya recreational zones are distinguished by insignificant human-induced disturbance in comparison with the two zones considered above. High-stability landscapes of foothill plains prevail here, which directly border on low-stability landscapes of valleys. There are practically no landscapes with moderate stability.

The Murinskaya recreational zone (Figure 2) is characterized mainly by high stability of landscapes due to the prevalence of piedmont lowland dark-coniferous blueberry–true moss landscapes on this territory (No. 11). However, their near-valley part, adjacent to the Khara-Murin River, has moderate stability due to the moderate soil stability. For the same reason, piedmont lowland gramineous–forb meadows of anthropogenic origin (No. 12) are of moderate stability.

Low sensitivity is typical only for the valley light-coniferous and dark-coniferous with poplar forb–reed of floodplain landscape regime (No. 9). The territory of the village of Murino (No. 15) is classified as unstable.

High-stability landscapes prevail in the Snezhinskaya recreational zone - piedmont plains along low watersheds dark coniferous small-grass–blueberry–true moss (No. 11) and peat bogs and transitional foothill plains sedge-sphagnum with open stands of Siberian stone pine, spruce and birch (No. 13). They occupy the entire coastal area west of the Snezhnaya River valley. The Portbaikal’skaya recreational zone differs from the other four zones in its small area and lack of landscape diversity. There are no high-stability landscapes. The prevailing landscape is the steep southern slopes facing Lake Baikal with parvifoliate and light-coniferous often sparse reed-forb forests (No. 6). They have low stability due to the manifestation of active geomorphological processes of a catastrophic nature.
4. Conclusion
Assessment of landscape stability of 15 landscape types revealed that only one is classified as unstable and two as low stable, seven as moderately stable and five as high stable. Anthropogenically transformed residential landscapes having large area within the Kultuk-Slyudyanskaya recreational zone, are classified as unstable. The landscapes of steep eroded southern slopes are of low stability, Siberian stone pine forb-cowberry with bergenia, as well as valley light-coniferous and dark-coniferous with poplar shrubby of floodplain regime. They are widespread in the Kultuk-Slyudyanskaya and Utulik-Baikal’skaya recreational zones. Recreational use of these types of landscapes should be limited.

Landscapes of moderate stability (mountain taiga on slopes of different steepness and exposure) are widely represented in the Kultuk-Slyudyanskaya and Utulik-Baikal’skaya recreational zones.

Lowland piedmont landscapes are high-stable: dark-coniferous blueberry–true moss and forb–blueberry, pine–larch gramineous and cowberry–forb, sedge-sphagnum wetlands. They are widespread in the Murinskaya and Snezhinskaya recreational areas.

Thus, landscapes with moderate stability prevail in the territory under study. Only in two of the five considered recreational zones - Murinskaya and Snezhinskaya - low-sensitive landscapes prevail and here we can recommend recreational use without significant restrictions.

Acknowledgement
The work was done with the financial support of the Russian Foundation for Basic Research and the Government of the Irkutsk Oblast within the framework of project No. 20-45-380012 r_a.

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