Mapping and monitoring recreational disturbance of the territory for the recreational nature management

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Abstract. Recreational nature management becomes vital in the context of continuously developing recreation. Regulation of recreational impact and control of acceptable changes in natural territorial complexes (landscapes) due to recreation is one of the main tasks of recreational nature management. The paper considers the approach to the analysis of the interaction of recreation and landscape based on a landscape-dynamic concept, as well as the method of mapping and monitoring recreational disturbance of the territory for managing recreational use of natural protected areas. We analyze the experience of monitoring recreational disturbance of the test area (Schuchye Lake Natural Reserve, Saint-Petersburg) during 2008 - 2019 years. There is a relationship of the distribution of recreants with landscape structure of the territory, namely, with the features of landscape sites and long-term states of landscapes. We have revealed a decrease in recreational disturbance despite an increase in the number of recreants. Positive dynamics is due to both the restriction of vehicle access to the coast of the lake and providing the territory with the special places for rest. We give recommendations for making priority management decisions related to the development of recreation in the studied area. Further attention should be focused on controlling the most attractive and vulnerable areas, especially complexes of sand hills near the lake coast.

1. Introduction
Cities with a population of over a million people inevitably generate the highest demand for land and face related conflicts of nature management. One of the critical conflicts is a collision between the need of metropolis residents for recreation and the need to preserve areas of a relatively undisturbed natural environment that make the urban "ecological carcass". At the turn of the XX-XXI centuries, megacities in Russia and other countries began to create networks of natural protected areas (NPA), which perform both environmental and recreational functions. The second function and a relatively small size distinguish the majority of urban NPA from their counterparts (especially nature reserves) usually located at remote distances from large cities and sometimes inaccessible to mass visitors. The intensity of recreational flows in urban NPAs is a result of both the availability of recreational areas and their attractiveness as opposed to blocks of multi-storey buildings. Recreation affects NPA landscapes, which cannot but experience significant changes. Therefore, it is important not only to create an urban protected area but also to ensure its sustainable goals (functions) under increasing recreational loads, which are inevitable in the largest cities. To identify recreational disturbance and control recreational loads in NPAs, it is necessary to monitor them regularly and ensure a set of measures aimed at redistributing recreational flows to minimize their negative impacts. Such studies
cannot be effective without taking into account NPA landscape heterogeneity.

2. Objects, data and methods
Distribution of recreationists within the area depends on many factors: landscape structure, special features of elementary landscape units (landscape sites), water bodies availability, accessible and developed territory. In this study, we use landscape-dynamic mapping to identify the relationship between recreational disturbance and recreational loads in various types of natural territorial complexes (landscapes). Landscape-dynamic maps consist of two main "layers": a layer of landscape sites and a layer of long-term states. Sites, as the most stable part of the landscape, are a combination of relatively stable elements: relief mesoforms (landforms), the composition of the upper (one-meter) layer of soil-forming bedrocks and soil moistening regime. Boundaries and basic characteristics of landscape sites do not change under the effect of most anthropogenic factors (including main recreational loads) and can exist unchanged for several hundred or thousand years. At the same time, long-term states change by one-three orders of magnitude faster than landscape sites, depending upon plant communities, some soil characteristics and degree of anthropogenic disturbance. Using landscape-dynamic maps to model recreational loads, state characteristics can include various indicators of recreational disturbance (digression) of landscapes. These indicators, related to a basis of landscape sites, serve as a background for making a series of maps that allow comparing results of recreational effects in different types of natural and natural-cultural landscapes and offer a differentiated approach to recreational development of the area.

A set of methods for dynamic landscape mapping of recreational loads and disturbance in natural systems was shown in [1]. For its development, we relied upon the evaluation principles of recreational loads and acceptable changes in natural systems according to [2] as well as Limits of Acceptable Change (LAC) method used in some countries [3-6].

The studies were carried out in 2008-2019 at a test area adjacent to the Schuchye Lake (Kurortny District of St. Petersburg). This area located 50 km from the center of St. Petersburg has hilly kame relief, dominant dry pine forests and water body suitable for swimming, and is one of the most popular recreation areas within the city boundaries. Schuchye Lake has an area of approximately 0.5 km²; the coastline is 4.5 km long. The test site area (excluding the water surface of the lake) is approximately 90 hectares. In 2011, the entire study area became a part of the Schuchye Lake State Nature Reserve of regional significance. Recreational disturbance of landscapes in the test area was assessed in 2008 and 2019, i.e. before the NPA creation and eight years after it. The intensity of recreational flows and distribution of recreational loads were studied in 2008, 2012 and 2018.

3. Results and discussion
At the initial stage, a map of landscape sites (scale 1:10000) served as a background of the study. Within the test site, we distinguished 40 polygons of 9 types of landscape sites (table 1). The largest area in the coastal part of Schuchye Lake is occupied by kame hills and ridges (44% of the test site area) as well as drained terraced sandy plains (32%). They all are covered with forests, predominantly pine (Pinus sylvestris) and spruce (Picea abies), aged 60-120 years. Mapping recreational disturbance of the territory on a landscape-dynamic basis (landscape-dynamic mapping) includes several stages: 1) selecting recreational disturbance indicators; 2) determining actual values of the selected indicators; 3) developing a gradation scale for the selected indicators in relation to the study area; 4) mapping indicators of recreational disturbance; 5) calculating the total indicator of recreational disturbance and determining stages of recreational digression; 6) mapping recreational digression of landscapes; 7) analyzing recreation effects in different types of landscapes. Below, we describe each stage separately.

Stage 1. Selecting recreational disturbance indicators. To determine recreational disturbance for each landscape, we recorded the following indicators:
Table 1. Types of landscape sites within the Schuchye Lake test area (St. Petersburg).

| Number in the map | Types of landscape locations |
|-------------------|-----------------------------|
| 1                 | Hills and ridges made of outwash sands (kame) with predominant medium-steep and steep (5-20°) slopes; pine forests dominate |
| 2                 | Hills made of outwash sands (kame) with predominant gentle slopes (up to 5°); pine forests dominate |
| 3                 | Wavy and slightly inclined terraced plains on outwash sands, naturally drained; pine and spruce forests prevail |
| 4                 | Gently undulating terraces on outwash sands cultivated in the past; birch forests prevail |
| 5                 | Gently undulating and flat terraced plains on outwash sands and sandy loams with low peat, waterlogged; spruce forests prevail |
| 6                 | Mesotrophic and meso-oligotrophic peat-bogs, including floating bogs along the shores of lakes (peat thickness more than 0.5 m) |
| 7                 | Mesotrophic and meso-oligotrophic peat-bogs being drained or drained in the past (peat thickness more than 0.5 m); spruce forests prevail |
| 8                 | Shallow (up to 5 m) valleys of streams with a predominantly peaty floodplain |
| 9                 | Sandy beaches (including those with fill-up ground) |

- K₁ – degree of trampled soil cover (part of an area with exposed soil or ground, %);
- K₂ – part of area (%) occupied by secondary plant groups with prevalent trampling-resistant, mainly ruderal herbaceous species (*Taraxacum officinale*, *Plantago major*, *Trifolium repens*, *Agrostis capillaris*, *Poa annua*, *Lepidotheca suaveolens*, *Juncus tenuis*, *Achillea millefolium*, *Leontodon autumnalis*, etc.) and some pioneer species of mosses (*Pohlia nutans*, etc.);
- K₃ – number of bonfire sites (pcs/ha);
- K₄ – number of stumps of sawn and felled trees (pcs/ha);
- K₅ – damage to woody vegetation (% of damaged trees of their total number);
- K₆ – littered area (total amount of garbage in kg/ha);
- K₇ – the presence of micro waste dumps (pcs/ha).

The set of indicators may vary, depending on the objectives of the study.

Stage 2. Determining actual values of the selected indicators. Within the test site in summer 2008, the recreational effect was assessed for each landscape unit in a strip approximately 20 m wide, starting from the coast of Schuchye Lake. Outside this coastal strip, profiles (transects) with a width of 6 m and a length of 80 to 450 m at intervals of 25 m were laid. Thus, for each landscape unit, we obtained a set of recreational disturbance indicators.

Stage 3. Developing a gradation scale for selected indicators. Based on the objectives of the study and taking into account the characteristics of the studied territory, four gradations for each fixed indicator were formulated (table 2).

Stage 4. Mapping indicators of recreational disturbance. In 2008, indicators K₁ – degree of trampled soil and K₃ – number of bonfire sites were considered as the most representative indicators, reflecting a degree of the natural complexes degradation. Maps of these indicators based on profiles of landscape locations show the most disturbed coastal areas. These were steep kame hills on the north and southwest coasts of the lake, which in 2008 were easily accessible for vehicles, as well as the southeast coast of the lake with beaches and an asphalt road from the Komarovo railway station. It is noteworthy that at this stage, we identified uneven recreational disturbance of areas belonging to the same type of landscape sites, as well as an increasing number of polygons (contours) compared to the background landscape map. Differentiation of the same landscape sites by a degree of recreational impacts can be explained by the difference in the long-term states of landscapes (pine forests are most attractive for and less stable against recreants compared to spruce forests) and other factors (proximity to the lake coast, distance from parking lots, etc.).
Table 2. Gradation of recreational disturbance indicators for the Schuchye lake test area (St. Petersburg).

| Grade of indicators (in points) | \( K_1 \) – degree of trampled soil (\%\) | \( K_2 \) – part of area occupied by secondary plant groups (\%\) | \( K_3 \) – number of bonfire sites (pcs/ha) | \( K_4 \) – number of stumps (pcs/ha) | \( K_5 \) – damage to woody vegetation (\%\) | \( K_6 \) – littered area (kg/ha) | \( K_7 \) – presence of micro waste dumps (pcs/ha) |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| 1                               | <1                              | <1                              | 1-9                             | <50                             | <10                             | <10                             | -                               |
| 2                               | 1-10                            | 1-10                            | 10-49                           | 50-100                          | 10-50                           | 11-50                           | 1-5                             |
| 3                               | 11-50                           | 11-50                           | 50-100                          | 101-200                         | 51-90                           | 51-100                          | 6-20                            |
| 4                               | 51-100                          | 51-100                          | >100                            | >200                            | 91-100                          | >100                            | >20                             |

Stage 5. Calculating the total indicator of recreational disturbance. Comparing the results of this study with studies on recreational digression of forest communities [7, 8], we introduced the total indicator of the recreational disturbance of natural territorial complex (\( K \)). It was calculated by summing values of all single disturbance indicators for each landscape unit:

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K = 2K_1 + 2K_2 + K_3 + K_4 + K_5,
\]

where \( K_1, K_2, K_3, K_4, K_5 \) are point values of recreational loads indicators (see table 2).

The \( K \)-calculation formula has factor 2 for the most stable and significant digression characteristics: trampled soil index \( K_1 \) and part of the area with secondary plant groups \( K_2 \). The indicators of the littered area and micro waste dumps \( K_5 \) and \( K_7 \), respectively) were not taken into account for calculating \( K \) since these characteristics are subject to change even within one season, and their disturbances are most easily eliminated.

Stage 6. Mapping recreational digression of landscapes. We ranked the values of the total recreational disturbance indicator \( K \) (in points) by four gradations:

I (0-9 points) – slightly disturbed (intact) state: there is no trampled soil even as weakly expressed path network; recreational impact includes only cutting down trees whose diameter (referring to the diameter at the cutting or chopping level) rarely exceeds 10-15 cm, and single bonfire sites; secondary vegetation is practically absent.

II (10-14 points) – disturbed (impaired) state: there is a distinct path network, which area does not exceed 10%; there are single bonfire sites and ruderal plant species on paths and old bonfires.

III (15-19 points) – strongly disturbed (severely impaired) state: the forest-stand is poorly closed, groups of trees are limited by paths, roads and clearings; trampled polygon area is up to 50%; increased density of bonfire sites (up to 100 pcs/ha); a larger percentage of damaged trees (up to 50%); secondary plant groups occupy a significant area.

IV (\( > 20 \) points) – degradation of vegetation cover: trampled initial ground vegetation up to 100%; the area of secondary plant groups is often more than 50%; there is almost no undergrowth; new growth is seen in a small number of clumps; the number of damaged trees reaches 100%, tree roots are often exposed; there are many bonfire sites (more than 100 pcs/ha).

The defined gradations of recreational disturbance of landscapes with forest vegetation, in general, correlate with gradations of recreational digression of suburban forests obtained by other researchers [9-11]. From the data on the field studies, we made a map of recreational disturbance of the test site based on landscape locations (figure 1). Analysis of the recreational disturbance map shows that in
2008 approximately 70% of the test site area was disturbed or severely disturbed. For 7% of the area, degradation of the vegetation cover was recorded (table 3).

![Figure 1](image-url)  
*Figure 1*. Recreation disturbance of landscapes of the Schuchye lake test area, 2008. Gradations of integral recreation disturbance index of nature territorial complexes: I – slightly disturbed (intact), II – disturbed (impaired), III – strongly disturbed (severely impaired), IV – degradation of vegetation cover (see explanations in the text). Numbers on the map indicate landscape sites (see table 1); a – areas closed for public access, b – the beach.

| Recreational disturbance                          | Part of test area, % | 2008 | 2019 |
|--------------------------------------------------|----------------------|------|------|
| Intact state (I)                                 |                      | 18   | 54   |
| Impaired state (II)                              |                      | 48   | 28   |
| Severely impaired state (III)                    |                      | 21   | 12   |
| Degradation of vegetation cover\(^a\) (IV)       |                      | 7    | 2    |
| Closed territories\(^b\)                         |                      | 6    | 4    |

\(^a\) Note: this category also includes beaches.  
\(^b\) Note: in 2018, access to the coast site of Schuchye Lake through the private estate became open.

Stage 7. Analyzing recreation effects in different types of natural systems. The map of recreational disturbance allows identifying recreational effects in different types of landscape sites. Recreational digression most severely affected kame hills with gentle slopes and drained sandy plains with predominating pine dwarf shrub-green moss forests. Here, the degree of landscape disturbance in 2008 was close to critical. Along with digression of the ground vegetation, there was significant
damage to the trees, and in some places developing erosion processes were recorded. Areas of drained sandy plains with predominating spruce forests were less disturbed. Undrained and drained peat bogs and gently undulating boggy plains with low peat suffered the least recreational impact. Apart from less recreational attractiveness, these landscapes are more resistant to load; there was significant digression of vegetation cover or development of undesirable processes in these areas.

Studying peak recreational loads. Peak recreational loads were calculated to analyze the ratio of recreational disturbance in the territory to recreational loads in 2008, 2012 and 2018. On a sunny Sunday afternoon in mid-July 2008, from 13:00 to 16:00 (air temperature over 22°C) in the coastal strip of Schuchye Lake, we simultaneously recorded 757 people and 172 cars. Recalculating the figures per 100 m of the coastline, recreational loads amounted to approximately 17 people and 4 cars. Considering that the coasts, which are generally accessible for recreation, occupied only 44% of the total coastline length (24% of the coast was within closed recreation centers and private estates, and 32% were sphagnum floating bogs), there were actually 38 people and 9 cars per 100 m of coastline (table 4).

Table 4. Dynamics of peak recreational loads of the Schuchye lake coast (2008, 2012 and 2019).

|                     | Number of cars (pcs) | Number of recreants (people) |
|---------------------|----------------------|-------------------------------|
|                     | 2008 | 2012 | 2018 | 2008 | 2012 | 2018 |
| Total               | 172  | 113  | 176  | 772  | 432  | 933  |
| Per 100 m of        | 9    | 0    | 0    | 38   | 21   | 37   |
| accessible coastline| 44   | 0    | 0    | 44   | 44   | 56   |

a Note: at the intercept parking lot and near the barrier in one km from the lake.
b Note: in 2018, the length of accessible coastline increased due to opened access through the former private estates.

Matching peak recreational loads with the landscape sites map (figure 2, table 5), we could correlate recreational loads with recreational disturbance of the territory (see figure 1). The comparison showed that the greatest load was experienced by kame hills on the northern and southwestern coasts of the lake, where erosion processes resulted from vegetation degradation; and by drained sandy plains adjacent to the beaches of the southeast coast also characterized by degradation of vegetation. Here, the process of beach formation began: a sandy stretch of coast and devoid of vegetation. In 2008, all these sites were available for vehicles.

After the Schuchye Lake Nature Reserve was created in 2011, car access to the lake’s coast was closed (except for access to recreation centers and private estates); the distance from the intercept parking lot closest to the southeast coast of the lake was at least one km. As a result, the flow of recreants markedly decreased, which studies of peak loads under conditions comparable to those of 2008 confirmed. At the end of July 2012, a one-time recreational load on the lake coast almost twice decreased compared to 2008 and was 21 people per 100 m of accessible coastline (see table 4). In some coastal areas remote from car parks, the load on natural systems decreased sharply (see figure 2). This led to the conditions for the restoration of severely disturbed landscapes of the Schuchye Lake coast.

Studies in July 2018 showed that peak recreational loads, in general, increased again and exceed loads of 2008 (see figure 2, tables 4, 5). We recorded an increasing concentration of recreants in four landscape units (apart from the beach on the southeast coast of the lake). Most vacationers travel by bicycle to the coastal areas remote from the intercept parking lots. The percentage of "permanent recreants", i.e. vacationers who regularly visit the same sites, increased. The "quality" of recreants is also changing; a large part of them treats their rest areas more responsibly: they do not leave litter, do not make bonfires, etc.
Effect of NPA creation on changes in the state of landscapes. The results of a field survey in 2019 showed a significant improvement in the state of natural territorial complexes in the test area, resulting from NPA creation in 2011. No access for vehicles to the coasts of Schuchye Lake\(^1\), ban on making bonfires, arrangement of recreational facilities (construction of pavilion, benches, places for barbecues, etc.) in the most visited areas of the coast, garbage collected into containers and regularly removed, clean-up of micro waste dumps\(^2\) contributed to restoration of natural landscapes, despite an increasing number of recreants. The recreational disturbance map of the test area under the 2019 study has proved that currently, only 2% of the studied area has degraded ground vegetation (figure 3, see table 3).

However, due to different rates of natural processes at different landscape sites, qualitative and quantitative changes in recreational loads are uneven in the changing state of landscapes; we should also keep in mind a relatively young (no more than eight years) age of the “Schuchye Lake” NPA. The map of changes in the recreational disturbance degree over the 2008-2019 period reflects this (figure 4). According to our data, 72% of the territory has a positive dynamics in restoration processes (8% – a significant positive dynamics), 19% of the territory is in a stable state, and only for 3% of the territory, we recorded an increasing degree of anthropogenic disturbance.

\(^1\) It is ensured by installed barriers (including guarded ones) at the entrances to the reserve on public and main forest roads, patrolling, as well as concrete hemispheres that prevent entry of the cars.
\(^2\) All this is ensured by the NPA Directorate of St. Petersburg.
Table 5. Assessment of peak recreational loads on the Schuchye Lake coasts by landscape sites (2008, 2012 and 2018)

| Landscape sites facing the lake | Number of cars per 100 m of coastline | Number of recreants per 100 m of coastline |
|--------------------------------|--------------------------------------|------------------------------------------|
|                                | 2008  | 2012 | 2018 | 2008 | 2012 | 2018 |
| Sandy beaches                  | 36    | 0    | 0    | 162  | 170  | 220  |
| Sandy hills (kame) with        | 14    | 0    | 0    | 52   | 25   | 61   |
| predominating gentle slopes    |       |      |      |      |      |      |
| Undulating drained plains on   | 8     | 0    | 0    | 40   | 21   | 36   |
| sand                          |       |      |      |      |      |      |
| Gently undulating plains on    | 3     | 0    | 0    | 20   | <1   | 0    |
| sand and sandy loam with low   |       |      |      |      |      |      |
| peat                          |       |      |      |      |      |      |
| Peatlands (including floating  | 0     | 0    | 0    | 0    | 0    | 0    |
| bogs)                         |       |      |      |      |      |      |

Gentle kame hills on the northern and southwestern coasts of the lake, with the greatest degree of landscape degradation in 2008, changed from IV to III category of recreational disturbance: here, restoration of the ground vegetation is, apparently, associated with no access for cars, whereas the number of recreants in these areas even increased slightly; many of them come by bicycle.

Figure 3. Recreation disturbance of landscapes of the Schuchye Lake test area, 2019. Gradations of integral recreation disturbance index of the landscapes: I – slightly disturbed, 2 – disturbed, 3 – strongly disturbed, 4 – degradation of vegetation cover (see explanations in the text). Numbers on the map indicate landscape sites (see table 1); a – areas closed for public access, b – the beach, c – the area equipped for rest.

The comparison of maps (see figures 3, 4) can easily indicate the most “problematic” areas of the
territory. Thus, in the most visited areas of the drained sandy plains of the southeast coast of the lake (north of the head of the Schukin stream), we recorded a slight decrease in the total recreational disturbance due to a reduction of bonfires and decreasing proportion of damaged trees. However, landscapes here are in critical condition: degradation of the vegetation is continuing and zones of open sandy soil are expanding; a beach is spontaneously forming. Moreover, due to erosion processes, beaches are forming in the most visited areas of kame hills on the north and south-west coasts of the lake, where the total disturbance indicator slightly decreased in 2008-2019 (see figure 4). On the one hand, generation of open sandy soil areas means irreversible degradation of natural systems, but, on the other hand, the sites with such beaches are local, resistant to recreational loads, concentrate recreants, and, thereby, reduce the load on the adjacent territories.

In some areas of the drained sandy plains on the north and southwest coasts of Schuchye Lake that are not visible from the road (NPA patrolled), the ban on making bonfires is breached. According to the 2019 monitoring data, the recreational disturbance degree has increased, and the forest ground vegetation cover is almost nonexistent (see figure 4).

**Figure 4.** Change in recreation disturbance of landscapes of the Schuchye Lake test area, 2008-2019. Change in integral recreation disturbance index (the difference between the K values for 2008 and 2019, points): 1 – significant decrease (4-7), 2 – decrease (1-3), 3 – stabilization (0), 4 – increase (-1 - -2). Numbers on the map indicate landscape sites (see table 1): a – no data; b – recreation center closed for the public; c – the area equipped for rest; d – the beach; e – the formation of the beach resulted from degradation of the ground vegetation.
4. Conclusion
Long-term studies of recreational loads and recreational disturbance of landscapes in the Schuchye Lake test area have confirmed the effectiveness of the landscape-dynamic approach to assessing the recreation impact on landscapes. The study has shown the relationship between the distribution of recreants over the territory with its landscape structure: landscape sites and long-term states of the landscape. Using some indicators, we have assessed the disturbance degree of natural territorial complexes and change in recreational loads after the creation of the Schuchye Lake Nature Reserve, including the test area, by the authorities. Landscape-dynamic maps have indicated the processes of the ground vegetation restoration and reduction of the total recreational disturbance over most of the territory, which manifested in the first years after the NPA creation. Landscape-dynamic mapping of recreational disturbances has allowed identifying problem areas on the territory, where restoration processes are slowing down, or degradation of landscapes is continuing. In these areas, it is necessary to take urgent priority nature management decisions to reduce recreational loads and regulate recreational flows.

With a continuously increasing need in the "proximal" recreation and, accordingly, increasing recreational flows in the cities, regular monitoring of the landscapes state in urban recreational areas, especially NPA, is very important.

Acknowledgments
This article is based on the studies carried out within the grants of the Russian Foundation for Basic Research No. 19-05-00088 and No. 19-05-01003.

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