Assessment of *Pinus sylvestris* L. forests state near Krasnoyarsk (case study of the Karaul'noe forestry)

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Abstract. The research was conducted in *Pinus sylvestris* L. stands near Krasnoyarsk (subtaiga zone). The aim of the study is to assess the current state of recreational pine forests. Research methods included detailed forest pathological examination on six research plots, assessment of recreational disturbance (digression stage) by the transect method, integral assessment of forest health, graphical and correlation analysis. Recreational disturbance of the studied pine forests corresponds to I-IV stages of digression. From 1 to 40% of ground on the research plots has been trampled down. The vitality spectra of forest stands are characterized by right-sided asymmetry; the proportion of weakened trees is high in severely disturbed pine stands. With an increase in the recreational stress, the state of pine forests worsens significantly, and the proportion of dead trees increases. The absence of a significant relationship between the average health index and the stock of dead wood indicates that trees mortality cannot be used as an indicator when assessing the current state of recreational pine forests, which is explained by wood debris removal. The relative growing stock of healthy trees (with no signs of weakening), however, is an informative indicator.

1 Introduction

Forests are a very important component in urban areas. They help improve environmental quality and have a high value of recreation opportunities [1-4]. At the same time, human impact (primarily constant industrial pollution and disturbances caused by recreation activities), affects forest ecosystems in urban areas [5–9]. A set of adequate forestry, environmental and other measures based on the systematic monitoring is needed to preserve forests near cities and increase their productivity and carbon sequestration potential [1, 10, 11].

Krasnoyarsk is a large industrial city situated along the Yenisey River. Forests growing near Krasnoyarsk belong to the mountain-taiga and forest-steppe zones [12]. The forests are dominated by Scots pine (Pinus sylvestris L.) and birch (Betula pendula Roth.). A long-term

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comprehensive monitoring has been conducted there. The aim of the present study is to assess the current state of recreational pine forests growing at the western outskirts of the left-bank part of Krasnoyarsk. We focused on the following issues during the research: indicating the disturbances by recreational activities, determining vitality spectra of forest stands, assessing forest health.

2 Materials and Methods

The study was carried out in pine forest stands of the Karaul'noe forestry located near Krasnoyarsk. The Karaul'noe forestry is Educational and Experimental Forestry of the Reshetnev Siberian State University of Science and Technology (Reshetnev University). The studied stands are subtaiga forests belonging to the forest-steppe/taiga ecotone. We placed six research plots (RP) in recreational pine stands (Table 1) and conducted a detailed (instrumental) forest inventory there following the generally accepted methodology [13, 14]. We divided all the trees on the research plots into 4 cm-diameter classes and the following health classes: 1 – no signs of weakening; 2 – weakened; 3 – severely weakened; 4 – dying; 5 – dead (including recently dead trees and old snag). Trees diameter was measured at breast hight (1.3 m). The recreational disturbance (digression) level in the studied pine forests was determined by the relative area of the groundcover trampled down to the mineral soil using the transect method established by the industrial standard 56-100-95 [15].

Table 1. Silvicultural and forest inventory of the studied forest stands.

Research plot (forest compartment / forest unit)*	Stand composition, forest type	Average values for Scots pine			Bonitet class	Density	Growing stock, m^3/ha
		age, years	height, m	diameter, cm			
1 (50/27)	100% pine, sedges/herb-rich	115	23	37.5	3	0.7	300
2 (51/19)	100% pine, sedges/herb-rich	130	25	31.0	3	0.5	220
3 (51/20)	100% pine+birch, sedges/herb-rich	130	26	42.8	2	0.6	300
4 (52/8)	100% pine, sedges/herb-rich	130	26	35.7	2	0.6	260
5 (52/3 lower part)	100% pine, sedges/herb-rich	130	26	37.3	2	0.8	380
6 - reference (52/3 upper part)	100% pine, sedges/herb-rich	130	26	35.9	2	1.0	410

Note: *Forestry administrative division in the Karaul'noe forestry of Reshetnev University; 100% pine+birch indicates that birch occupies 2.5-5.0% in the total growing stock on the research plot.

We assessed the state of *Pinus sylvestris* forest stands using the following indicators: the ratio of trees of different health classes (vitality spectrum), the weighted average health index (K_{av}), tree mortality parameters. K_{av} was calculated using the following formula:

$$K_{av} = (P_1*K_1+P_2*K_2+P_3*K_3+P_4*K_4+P_5*K_5)/100, \quad (1)$$

where Pi is the share (%) that the growing stock of trees of each health class takes in the total growing stock; Ki is the trees health index (1 - no signs of weakening; 2 - weakened; 3 - severely weakened; 4 - dying; 5 - dead). At Kav ≤ 1.5, the forest stand does not have visible

signs of weakening; 1.5 < Kav ≤ 2.5 – weakened; 2.5 < Kav ≤ 3.5 – severely weakened; 3.5 < Kav ≤ 4.5 – dying; Kav > 4.5 - lost viability.

The correlation between the analyzed indicators was assessed by the Spearman's rank correlation coefficient (since the sample is small).

3 Results and Discussion

The studied pine forests are located on the bank of the Yenisei river in proximity of the urban area. There are summer homes located near the forestry. What is more, educational activities are constantly conducted in the Karaul'noe forestry. All these factors have led to long-term recreational disturbances in the forest ecosystem (Table 2). Notably, digression level is unequal in different forest sites, which is determined by the different intensity of recreational activities (especially in summer) and location of forest tracks. The most evident indicator of disturbance level is the variation in the degree of digression of the herb layer, which is the most vulnerable to recreational impact (trampling) (Table 2). We used the extent to what the herb layer is disturbed as the quantitative indicator to determine the level of recreational disturbance in the studied stands in the subsequent analysis.

Table 2. Recreational disturbance level in the pine stands.

Research plot	1	2	3	4	5	6
Relative area of the groundcover trampled down (%)	23	26	28	40	11	1
Disturbance level	IV	V	V	V	IV	I

The vitality structure reveals the state of the studied pine stands (Figure 1). There is positive asymmetry in trees distribution by health classes with a predominance of healthy trees (with no signs of weakening or weakened) on all the research plots. Thus, we can state that the studied recreational stands are mostly healthy. Notably, such a positive asymmetry in the vitality spectrum is most evident in low-disturbed stands: on RP No. 5 and RP No. 6 (used as a reference forest stand in the present research). The average health index (Kav) indicates that the stands growing on these research plots are healthy (viable) (Table 3). Stands with high-intensity recreation (RP No. 1-4) are weakened (Kav ranges from 1.6 to 1.9). The correlation between the average forest stand health index and the recreational disturbance level was 0.812 (<0.05) according to the Spearman criterion (Table 4). Therefore, despite a relative resistance to anthropogenic disturbances in pine [16], long-term recreational stress leads to significant weakening of pine stands, which is consistent with other studies [9, 17-19].

Table 3. Forest stand health indicators.

RP	Weighted average health index (K_{av})	Trees mortality rate (%)		Average diameter (cm)	
		total	current-year	dead trees	forest stand
1	1.6	0.5	0	28.1	37.5
2	1.9	0.8	0	18.0	31.0
3	1.9	2.9	0.8	34.1	42.8
4	1.8	3.9	3.2	32.2	37.5
5	1.5	0.5	0.5	22.0	37.3
6	1.2	0	0	-	35.9

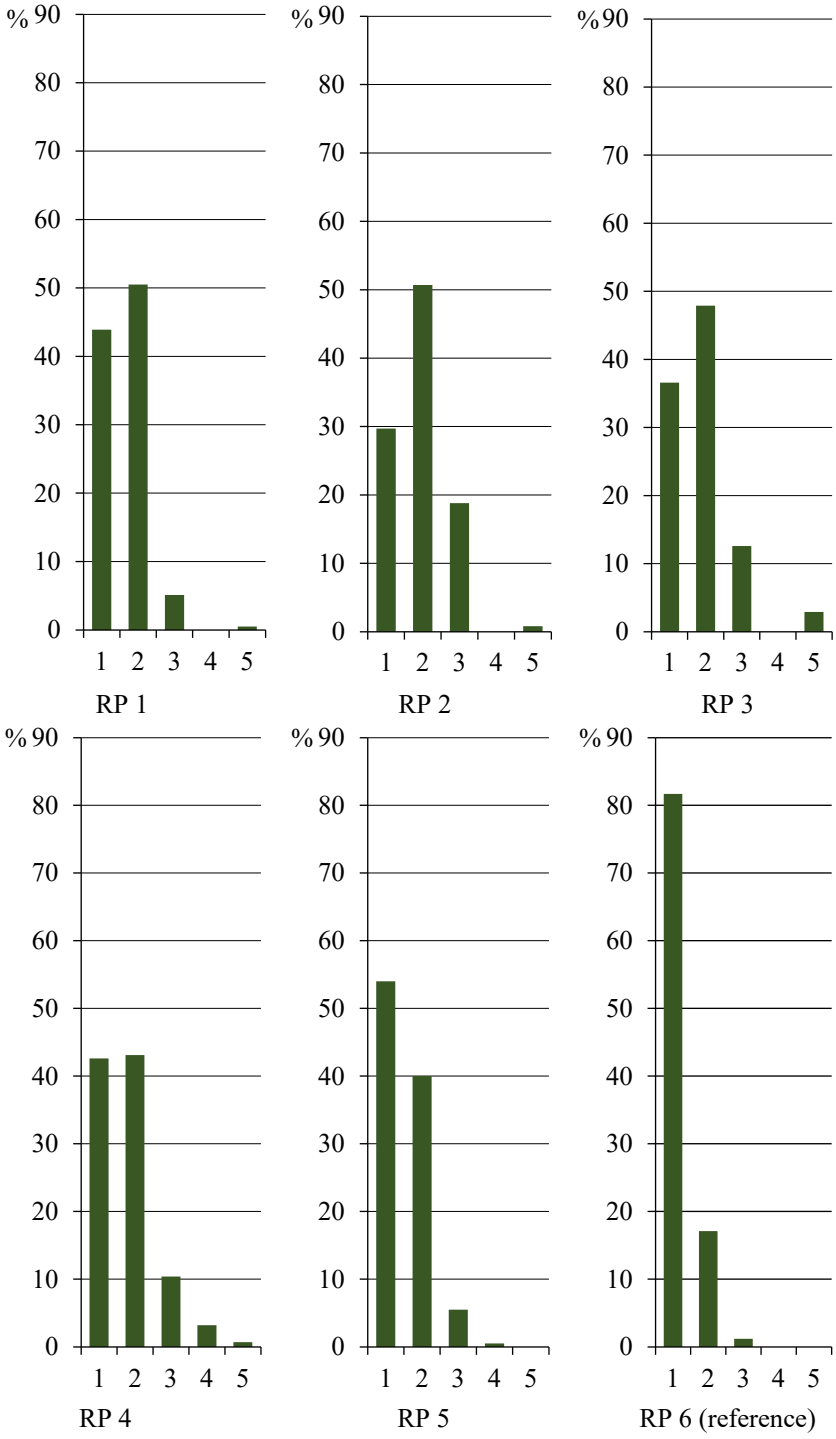

Fig. 1. Vitality spectra of the forest stands: horizontally - health classes; vertical - relative growing stock.

Table 4. Correlation matrix (according to the Spearman's rank correlation coefficient) of recreational disturbance of pine forests (relative area of the herb layer trampled down) and the main forest health indicators.

Indicator	Disturbance level	Share of trees of the first health class	Trees mortality rate	Weighted average health index
Disturbance level	1	-	-	-
Share of trees of the first health class	-0.771	1	-	-
Trees mortality rate	0.986*	-0.754	1	-
Weighted average health index	0.812	-0.986	0.794	1

Note: *numbers in bold indicate significant correlation coefficients ($p < 0.05$)

The relative stock of dead trees in the studied pine forests is insignificant. Even in the most disturbed stands (RP No. 4) it does not exceed 4% (Table 3). Such a low value may be explained by the fact that deadwood and hazardous trees are been timely removed from forests near the city. The average diameter of dead trees is below the average diameter value for the forest stand. The absence of a significant correlation between the share of dead trees and the average health index (K_{av}) confirms that tree mortality parameters are not relevant in assessing the current state of the studied pine forests (Table 4). Nevertheless, we revealed a significant correlation between the deadwood stock and the recreational disturbance level. Therefore, we proved that recreation has a significant negative impact on the health of forest stands. A significant correlation between K_{av} and the stock of trees of the first health class (with no signs of weakening) indicates that this indicator is suitable for assessing the state of pine forests intensively used for recreation.

4 Conclusion

Recreational activities is taking place in pine forests near Krasnoyarsk. The long-term recreation causes serious disturbances to pine forest ecosystems.

We analyzed the vitality spectra and revealed positive right-sided asymmetry. However, long-term recreational stress increases the proportion of trees that are weakened or lost viability. Thus, our correlation analysis proved that recreational activities degrade forests.

Tree mortality cannot be used when assessing the current state of forest stands growing near cities since dead and hazardous trees are being removed there. The growing stock of healthy trees (with no signs of weakening) is more informative indicator, as proved by the statistical analysis of the relationship between forest health indicators.

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