Identification the areas of concern for pine forest and soil cover conditions in the Predbaikalie region

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Abstract. The article summarizes and analyzes monitoring results for Scots pine (Pinus sylvestris L.) forests of Southern Predbaikalie (Eastern Siberia, Russia) exposed to technogenic pollution and high recreational loads. The surveys were carried out in areas adjacent to large industrial centers and in recreational areas of the National Park Pribaikalsky. It is shown that vital state of treestands weakened by industrial exposure is comparable to forest health in areas with high recreational loads. The results show that in terms of contamination levels the most problematic areas are those which are adjacent to Shelekhovsky, Irkutsky, Usolsky and Angarsky industrial centers; as for recreation impact, its unacceptably high levels were found in the vicinity of Listvyanka and Khuzhir villages as well as in many sections of the Circum-Baikal Railway. In these areas, the values of the vital state index (VSI) and the soil resistance potential (SRP) index were the lowest, amounting to 3.2-4.4 points for pine stands VSI and 4.7 points for SRP near Khuzhir and 4.8 points for SRP near Usolsky industrial center, while in the background areas, both the VSI and SRP values were close to 10 points. Based on the obtained results, we have developed a schematic map of the problem areas of the Southern Predbaikalie. The data were also used to create a relational database on the elemental chemical composition of pine needles, including those in technologically polluted parts of the region.

1. Introduction
Performing climate regulation, water protection, anti-erosion and other environmentally significant functions, forests are the most important environment-forming resource. In industrialized regions, which include the Southern Predbaikalie, the state of that resource is largely determined by intensity of a number of environmental risk factor, including industrial pollution and forest recreation. The negative impact of industrial pollution affects all components of the forest ecosystem, in which (from the point of view of biogeochemical process disruption) the negative impact is manifested in uncontrolled flow of polluting elements [1]. For example, technogenic flows of such dangerous pollutants as sulfur compounds and heavy metals become commensurate with the quantities of substances naturally participating in the nutrient cycle [2, 3]. A significant influx of anthropogenic pollutants causes an imbalance of biogenic elements in ecosystems, which can trigger a significant deterioration in forest nutritional status, leading to structural and functional transformation up to biogeocenosis destruction [4, 5]. To assess the state of forests exposed to anthropogenic factors researchers use a large range of indicators characterizing the vital
(physiological) state of trees [6–9]. This approach significantly increases the reliability and information value of assessment. In our opinion, when studying the health of technogenically polluted forests, levels of pollutants accumulated by assimilating phytomass and tree physiological state parameters should be considered as mandatory [10].

As for forest disturbance caused by high recreational loads, it often occurs in conditions of rapid increase in tourist flows to natural ecosystems. This dramatically effects on soil cover, primarily causing destruction of forest litter and upper humus horizons that are of priority importance for the processes of humification and mineralization, therefore, for the formation of the nutrient regime of soils [11]. In the Southern Predbaikalie region, forests are affected by both of those anthropogenic factors. Therefore, the situation requires examining the current state of forests in order to obtain reliable information about this important resource, about the localization of areas where forests are disturbed and where measures are urgently needed to optimize their condition. The purpose of this work is to investigate the state of Southern Predbaikalie pine forests, which exposed to technogenic emissions and high recreational loads, using a complex of toxicological, biochemical, morphometric, edaphic parameters, identify the most problematic areas and make a schematic map of their location.

2. Materials and Methods
Studies of Scots pine (Pinus sylvestris L.) forests were carried out in the Southern Predbaikalie region in the territories adjacent to large industrial centers (Shelekhovsky, Irkutsky, Usolsky, Angarsky, Cheremkhovsky, Sayansko-Ziminsky). We have also examined forest health in main recreational areas of the National Park Pribaikalsky (NPP), which was established to preserve natural diversity on the southwestern and western shores of Baikal Lake. Within the territory of the national park, forest health surveys were carried out in the vicinity of Listvyanka, Khuzhir, Nizhny Kochergat villages and on a number of Circum-Baikal Railway (CBR) sections. As a background we chose not experiencing anthropogenic impact forest areas in the vicinity of Taliyany village and near the protected natural area Krasnyj Yar. The predominant forest types in the study area are mixed herbs and mixed herbs-sedge pine forests, rhododendron pine forests are less common; the most common soil type is gray forest one. Forest surveys were carried out by establishing sample plots in accordance with the accepted forestry techniques and guidelines of the international programme ICP forests [12]. In each plot we sampled previous year needles, estimated pine crown defoliation values and measured pine needle and shoot morphometric parameters. Soils were studied by the method of soil profiles with detailed characterization study of each genetic horizon. In the laboratory, we assessed concentrations of pollutants, nutrients, pigments, protein and non-protein nitrogen and other substances in each sample. For soil samples we determined actual acidity, humus content, total nitrogen content, levels of pollutants and exchangeable cations in the soil-absorbing complex (SAC). Chemical analysis was performed according to certified methods using the shared equipment of the Baikal Analytical Center of the Siberian Branch of the Russian Academy of Sciences [13, 14]. Air pollution impact on forest was assessed by determining accumulation levels of sulfur, fluorine, heavy metals, PAHs in pine needles. Physiological condition of pine stands was estimated by the vital state index (VSI). This index was calculated as the average of the sum of representative visual, morphometric, physiological and biochemical parameters, normalized by converting the raw data to 10-point range scale with a score of 10 points for background values [15]. In total, 30 indicators were determined (the level of Scots pine crown defoliation, morphometric parameters of needles and shoots, the needle content of photosynthetic pigments, nutrients, proteins etc.). Soil resistance potential (SRP) was assessed by the change in the complex of such pedochemical indicators (cation exchange capacity, acid-base balance, intensity of the humification, toxicity of soil) and was calculated as the degree of reduction of the values relative to their background levels, which was taken as 10 points. Statistical processing of the data was carried out using the «Environment for statistical calculations R», version 3.1.1. (2014). The
tables show the average values of each parameter and their standard deviations (mean ± SD), the differences discussed are reliable at $P \leq 0.05$.

3. Results and Discussion

The study results show that inorganic pollutant levels accumulated by pine needles collected near industrial centers exceed by 2.5–4.5 times the background levels. Needle concentrations of organic pollutants exceed by 2.0–5.0 times the background values with the exception of samples from the Shelekhovsky industrial center, in which PAH levels exceed background ones by 30 times, due to the effects of emissions from the aluminum plant located there. Among the inorganic pollutants, for samples collected near industrial centers, the highest needle concentrations were found for fluorides, sulfur, aluminum and some heavy metals (table 1). These results suggest that technogenic pollution of pine stands near industrial centers is strongly pronounced, and this factor is the main one determining tree stand health.

Table 1. Pollutant concentrations (mg/kg dry weight) in pine needle samples collected near industrial centers.

| Element-pollutant | Background area | Industrial centers |
|-------------------|-----------------|---------------------|
|                   | Khuzhir village | Listvyanka village  | CBR   | Nizhny Kochergat village | Background areas |
| F                 | 10.21 ± 0.62    | 37.53 ± 2.71        | 85.13 ± 10.41 | 28.14 ± 8.81 | 26.25 ± 1.82 | 20.83 ± 1.31 |
| S                 | 252.35 ± 18.12  | 612.15 ± 33.26      | 572.32 ± 62.11 | 693.25 ± 42.13 | 511.33 ± 52.14 | 581.48 ± 23.21 |
| Al                | 125.16 ± 10.09  | 454.26 ± 62.13      | 695.17 ± 72.31 | 238.17 ± 46.15 | 182.28 ± 34.21 | 439.35 ± 41.18 |
| Fe                | 86.45 ± 12.22   | 588.65 ± 78.21      | 188.11 ± 22.36 | 353.45 ± 70.38 | 323.56 ± 45.15 | 441.37 ± 21.17 |
| Zn                | 40.53 ± 2.33    | 41.31 ± 1.14        | 48.38 ± 2.93  | 47.42 ± 0.91  | 59.32 ± 4.92  | 39.91 ± 0.94  |
| Pb                | 0.15 ± 0.02     | 0.85 ± 0.05         | 0.22 ± 0.01  | 0.76 ± 0.01  | 0.66 ± 0.02  | 0.72 ± 0.05  |
| Cd, ×10^-2       | 1.60 ± 0.11     | 4.54 ± 0.43         | 4.91 ± 0.94  | 1.65 ± 0.33  | 1.14 ± 0.16  | 2.44 ± 0.10  |
| Hg, ×10^-2       | 0.52 ± 0.10     | 1.13 ± 0.12         | 0.73 ± 0.14  | 0.91 ± 0.13  | 9.11 ± 0.40  | 0.50 ± 0.17  |

In the recreation areas of the NPP, the main influencing factor is a high level of soil disturbance. A particularly severe deterioration of upper soil horizons occurs in the most visited recreational areas of the park, where recreational load reaches 400 thousand people per year and more (table 2).

Table 2. Physical parameters of upper horizons of forest soils in recreational areas of the NPP and in the background areas.

| Parameters                        | Khuzhir village | Listvyanka village | CBR | Nizhny Kochergat village | Background areas |
|-----------------------------------|-----------------|--------------------|-----|--------------------------|-----------------|
| Bulk density in Ad, g/sm³         | 1.15            | 1.28               | 0.96| 1.28                     | 0.71            |
| Solid phase density in Ad, g/cm³  | 2.73            | 2.71               | 2.36| 1.96                     | 1.91            |
| Soil moisture content in Ad and A, % | 28.70           | 25.40              | 28.30| 41.20                   | 48.90           |
| Disruption of organic layer in Ad and A, % | 60.25           | 55.15              | 40.35| 15.10                   | 5.05            |
| Total porosity in Ad, %           | 44.50           | 48.20              | 53.60| 68.60                    | 70.30           |
| Aeration in Ad, %                 | 12.50           | 15.80              | 44.60| 41.50                    | 48.30           |

The density of upper soil horizons increases by an average of 60-80%, humidity, porosity, aeration are reduce by 45, 35 and 70%, respectively. Contents of sodium and calcium exchangeable forms in soil
absorbing complex are increased by 30–40%, while contents of potassium and magnesium exchangeable forms are decreased. The buffer capacity of those soils is 45–60% lower than background values, the phytotoxicity index of soils reaches 35–40% (while for background soils it does not exceed 5%), CO₂ emission from upper soil horizons increased by 2.5 times, which indicates a significant disruption in organic matter formation process. The calculation of SRP showed that a sharp decrease in values of the index occurs not only under exposure of a strong recreational load (Khuzhir, Listvyanka), but also near industrial centers.

Both negative factors cause a change in a number of pine needle biochemical parameters compared to background values, including photosynthetic pigment pool. The greatest decrease in photosynthetic pigment levels is recorded in samples collected near industrial centers and in the vicinity of Khuzhir village, in which recreational loads are extremely high. On these sample plots, chlorophyll a and b needle content is 2.2–3.0 and 2.4–3.3 times lower, respectively, compared to background values, and carotenoid concentrations are 2.7–4.0 times lower than background values. A pronounced decrease in pigment concentrations per shoot needle mass is due to changes in pine needle morphostructural parameters – a reduction of photosynthesizing surface area due to a decrease in shoot length and amount of needles on shoots, decrease in needle weight and length (table 3).

| Surveyed territories | Crown defoliation, % | Needle number per shoot | Shoot needle mass, g | Shoot length, sm | Needle length, mm |
|----------------------|----------------------|-------------------------|----------------------|-----------------|------------------|
| **Background area**  |                      |                         |                      |                 |                  |
|                      | 20                   | 192.80±24.62            | 4.18±0.65            | 19.60±2.79      | 53.50±5.11       |
| **Industrial centers** |                      |                         |                      |                 |                  |
| Irkutsky             | 60-65                | 96.08±18.28             | 1.40±0.30            | 5.24±1.57       | 52.30±3.75       |
| Shelekhovsky         | 60-70                | 87.20±27.70             | 1.37±0.52            | 8.68±3.23       | 52.28±5.12       |
| Angarsky             | 55-65                | 94.89±25.26             | 0.95±0.24            | 7.82±2.85       | 50.30±9.23       |
| Usolsky              | 60-70                | 83.60±22.94             | 1.10±0.37            | 4.69±2.40       | 46.59±6.07       |
| Cheremkhovsky        | 45-55                | 79.64±19.28             | 1.04±0.33            | 5.11±2.53       | 52.84±6.05       |
| **Recreational areas** |                      |                         |                      |                 |                  |
| Khuzhir              | 60-65                | 121.64±32.88            | 1.01±0.20            | 4.97±1.75       | 33.45±4.27       |
| Nizhny Kochergat     | 35-40                | 132.30±15.08            | 1.85±0.32            | 11.39±2.04      | 51.09±5.86       |
| Listvyanka           | 50-55                | 125.10±43.52            | 1.83±0.70            | 8.84±2.89       | 40.43±5.73       |
| CBR                  | 45-50                | 143.46±35.84            | 1.97±0.63            | 9.69±2.37       | 45.51±5.64       |

According to our data, the decrease in Scots pine vital state parameters in areas near industrial centers is comparable to those in areas with a high recreational load. Thus, impacts of those factors – high recreational loads on soil and technogenic air pollution – are similar in terms of VSI values decrease in pine forests. In most cases, the SRP index decreased to a lesser extent than VSI, however, in the vicinity of Usolsky industrial center and near Khuzhir village the both indices show an equally sharp decline.

As an integral result of our study, we developed a schematic map of Predbaikal’ie region problem areas (figure 1). The map shows the areas in which a clear deterioration of pine stand health currently occurs, that is, VSI values are low and soils are deteriorated, which results in low SRP values.
4. Conclusion

It is shown that the health of Southern Prebaikalie Scots pine (*Pinus sylvestris* L.) forests is significantly disturbed by impact of technogenic pollution and high recreational loads. Both factors cause a deterioration of pine stand vital state, as indicated by a decrease in VSI. In the vicinity of regional industrial centers, air pollution impact on forests, assessed by pollutant needle accumulation levels, is the main cause of deterioration of a number of tree parameters – biochemical, morphometric and VSI calculated on their basis. In NPP recreational areas, the dominant factor is a strong disturbance of soil, especially its upper horizons. There are significant changes in soil physical parameters, buffer capacity and SAC quantitative composition, which resulted in abruptly reduced SRP values. Nutritional regime of such soils is significantly impaired, which means that the growing conditions for plants are also deteriorated, what results in decrease in pine stands VSI.
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References
[1] Mikhailova T A, Afanasieva L V, Kalugina O V, Shergina O V 2013 Evaluation of forest disturbance in south-west Zabaikalia (East Siberia) *Forest Science and Practice* **15**(4) pp 332–339 doi:10.1007/s11632-013-0421-5
[2] Nouri J, Khorasani N, Lorestani B, Karami M, Hassani A H, Yousefi N 2009 Accumulation of heavy metals in soil and uptake by plant species with phytoremediation potential *Environmental Earth Sciences* **59**(2) pp 315-323 doi:10.1007/s12665-009-0028-2
[3] Selim H M, Gobran G R, Guan X, Clarke N 2004 Mobility of sulfate in forest soils *Journal of Environmental Quality* **33**(2) 488–495 doi:10.2134/jeq2004.4880
[4] Domínguez M T, Marañón T, Murillo J M, Schulin R, Robinson B H 2010 Nutritional Status of Mediterranean Trees Growing in a Contaminated and Remediated Area *Water Air and Soil Pollution* **205** pp 305–321 doi:10.1007/s11270-009-0075-z
[5] Paoletti E, Schaub M, Matyssek R, Wieser G, Augustaitis A, Bastrup-Birk A M, Bytnerowicz A, Günthardt-Goerg M S, Müller-Starck G, Serengil Y 2010 Advances of air pollution science: From forest decline to multiple-stress effects on forest ecosystem services *Environmental Pollution* **158**(6) pp 1986–1989 doi:10.1016/j.envpol.2009.11.023
[6] Burrascano S, Sabatini F M, Blasi C 2011 Testing indicators of sustainable forest management on understory composition and diversity in southern Italy through variation partitioning *Plant Ecology* **212**(5) pp 829–841 doi:10.1007/s11258-010-9866-y
[7] Kovylina O P, Zarubina I A, Kovylin A N 2008 Estimation of the Life Conditions of Scots Pine in the Zone of Technogenic Pollution *Coniferous Boreal Zone* **25**(3-4) pp 284–289
[8] Liira J, Sepp T, Parrest O 2007 The forest structure and ecosystem quality in conditions of anthropogenic disturbance along productivity gradient *Forest Ecology and Management* **250** pp 34–46 doi:10.1016/j.foreco.2007.03.007
[9] Loehle C, Idso C, Wigley T B 2016 Physiological and ecological factors influencing recent trends in United Statets forest health responses to climate change *Forest Ecology and Management* **363** 179–189 doi:10.1016/j.foreco.2015.12.042
[10] Mikhailova T A, Kalugina O V, Shergina O V 2017 The dynamics of pine forests in Prebaikalia under anthropogenic impact *Siberian Journal of Forest Science* **1** pp 44–55
[11] Hueso S, García C, Hernández T 2012 Severe drought conditions modify the microbial community structure, size and activity in amended and unamended soils *Soil Biology and Biochemistry* **50** 167–173 doi:10.1016/j.soilbio.2012.03.026
[12] Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests 2016 (Eberswalde: Programme Co-ordinating Centre of ICP Forests) http://icp-forests.net/page/icp-forests-manual
[13] Gorkhov A G 2008 Determination of polycyclic aromatic hydrocarbons in the needles of a Scotch pine (*Pinus sylvestris* L.), a biomonitor of atmospheric pollution *Journal of Analytical Chemistry* **63**(8) 880–886 doi:10.1134/S1061934808080169
[14] Proydakova O A, Vasil’eva I E 2010 Method to improve schemes of sample preparation and atomic-absorption analysis of geochemical samples *Inorganic Materials* **46**(14) pp 1503–1512 doi:10.1007/S002168510140062
[15] Mikhailova T A, Kalugina O V, Shergina O V 2013 Phytomonitoring of Air Pollution in the Baikal Region *Contemporary Problems of Ecology* **6**(5) 549–554 doi:10.1134/S1995425513050119