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SEED QUALITY OF *Larix sibirica* Ledeb. DEPENDING ON THE DISTANCE BETWEEN FOREST AREAS AND POLLUTION SOURCES AROUND ULAANBAATAR CITY OF MONGOLIA

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Abstract. Seed quality and seed germination are the major indicators determining the success of regeneration and structure in natural forest ecosystems. This study focuses on problems associated with seed quality and seed germination under air pollution impacts in the surrounding forest ecosystems of Ulaanbaatar city of Mongolia. The objectives were to test whether there was any negative effect of air pollutants on the site index, and to analyze the relationship between seed quality and distance from the city center (maximum pollution). The study was carried out in natural larch forests (*Larix sibirica* Ledeb.) growing in the vicinity of the capital of Mongolia. A total of eight 100×100 m (1 ha) sample plots were laid out using completely randomized sampling design along the main wind direction. Remoteness from the city center was 10, 15, 20 and 30 km both to the north and to the south. Results showed a high variation in stand mean height ($p > 0.001$) and diameter ($p > 0.001$) among selected forest areas. In general, all sampled forests belonged to bonitet / quality classes III, IV and V, which are considered as relatively poor growing conditions in terms of site index. Therefore, greater site index and seed quality were observed in the most distant locations from the city center, and contrary, the poorest seed quality was detected in locations close to the city center. This emphasizes that forests growing close to pollution sources exist with a potential risk of degradation, and their reproductive organs are more sensitive to the effects of pollutants.
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Keywords: Siberian larch (*Larix sibirica* Ledeb.), seed quality, germination, site index, air pollution, Ulaanbaatar, Mongolia.

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Introduction

Natural regeneration is an important element in ensuring the sustainability of the forest ecosystem [22]. Depending on the growing environment and other influencing factors, regeneration performance and reproductive capacity vary greatly in different regions of the world.

Among these factors, air pollution has a serious negative impact on the health and productivity [3, 9] of trees and their physiology [1]. Here, forests are subject to higher depositional loads than other ecosystems, depending on tree species and canopy structure. Dry deposition accumulated on the tree crown is washed off by precipitation and enhances the deposition in the forest soils [3, 7, 12, 13, 25]. Several studies have reported that the main air pollutants causing forest damage are O_3, SO_2, NO_2 and NH_3, as well as heavy metals, which show visible damage to leaves and needles in the forests [10, 17, 24], and Hg, Cd, and Pb are currently of the greatest toxicological concern. Therefore, FAO [20] reported that, the air pollution also causes water and nutrient imbalances and higher sensitivity to frost, droughts, insect pest attacks, and fungal diseases. However, the spread of air pollutants and their movement from the different sources of pollution are closely related to wind velocity and direction. Forest areas remote from the industries and big cities, raised concerns that forest decline might be caused by long-range atmospheric transport of pollutants [24, 25]. High concentration of pollutants derived from industrialized urban areas treat an adverse damaging effect to surrounding forest ecosystems, which resulted in forest decline [27] and decreased reproduction [9, 10]. Ulaanbaatar is the biggest city (capital city) of Mongolia, and become main social and economic center of the country. According to statistics, over 1.5 mln people live in Ulaanbaatar. Moreover, air pollution in Ulaanbaatar becomes one of the pressing issues, which treat a severe negative effect on public and environmental health [16, 18]. The high level of air pollution during the cold season (from November to April) is associated with the regular use of large quantities of charcoal for heating and electricity production at power plants and in the Ger district of Ulaanbaatar [28]. The forest growing around the capital city, called "Green Zone of Ulaanbaatar", plays an important role in maintaining environmental sustainability for residents and is the southern continuation of the distribution of the Great Siberian boreal forests [14]. These forests are characterized by relatively high pollution exposure rate, and occupy a territory of 227,263 ha [26]. There are very few studies on the effects of pollutants derived from large settlements on surrounding forest ecosystems in Mongolia. The objectives of this study are: to evaluate the effect of air pollution on stand and site quality; and to detect a relationship between seed quality and remoteness from the pollution sources.

Materials and methods

Study area. The present study was carried out in natural larch forests growing around Ulaaanbaatar city, which belong to the southwestern end of the Khentii Mountains [6, 23]. Ulaanbaatar city is characterized by accelerated population growth rate and industrialization, which has had a serious negative impact on the natural forest environment. The climate in the study area is cold semi-arid and harsh continental with a precipitation peak between June and August.

The dry season extends from March to June in spring and from September to October in autumn. The mean temperature is 1.4 °C and annual precipitation averages 269.2 mm (fig. 1). The soils in the area are mainly Umbrisols, Chernozems and Kastanozems [15].

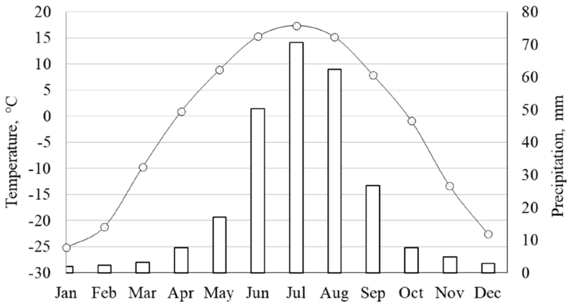


Fig. 1. Climograph of the area around Ulaanbaatar, Mongolia (1988–2018)

Sampling design. Long-term meteorological data showed that the main wind direction around Ulaanbaatar dominates from north-west to south-east. In order to detect an environmental impact of pollutants originated from settlement area on surrounding forest ecosystems, sampling plots were established along the main wind direction in different radiuses (10 to 30 km) from the city center. Rectangular 100×100 m sample plots were laid out in natural larch forests using completely randomized sampling design. A total of eight forest sites were sampled in 2014, namely Shadivlan (Sh), Yargait (Yt), Jigjid (Jd), Oin bulag (Ob), Ikh tenger (Ikht) in 10, 15, 20 and 30 km to the north, and Khureltogoot (Kht), Chuluut (Cht) and Shajin hurh (Shh) in 10, 15, 20 and 30 km to the south from the city center, respectively (fig. 2).

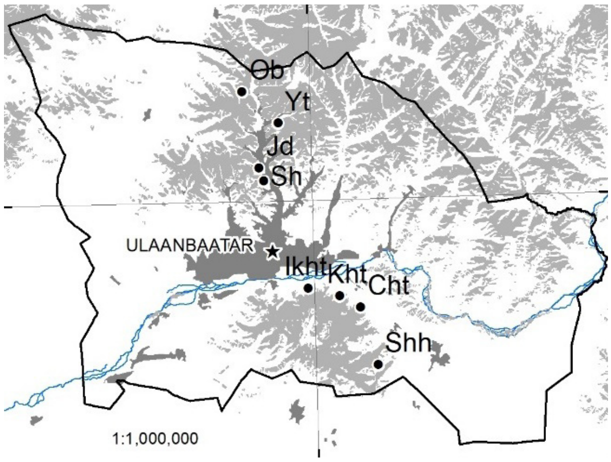


Fig. 2. Location of the sample plots

Measurements and data collection. Tree morphometric measurements in the sample plots were carried out according to Anuchin N.P. [2]. Here, tree height and stem diameter were measured using Haglöf Vertex IV Hypsometer and Digital Tree Caliper. The site index was used to determine the quality of the forest area. According to Orlov's classification, based on the average height and age of the stand, the tallest trees belonged to quality class I, and the smallest belonged to quality class V, respectively. Therefore, stand density was defined based on sum of stem basal area at the sample plots. The stand density was determined based on the sum of the tree stem basal area on the sample plots. However, the Kraft's growth rate, A.A. Korchagin's tree seed crop classifications [4], and tree selection criteria were used to assess the growth rate at the stand level, the crop of tree seeds and distribution of trees by the relative tree position (plus, normal and low quality trees) [5, 8, 11], respectively.

Seed collection was carried out from larch trees growing on the sample plots in September, 2015 and 2016 [14]. A total of 400 seed trees were subjected to seed collection on the inventoried sample plots. Therefore, the morphometric measurements (length and width) of sampled cones and seeds were measured using Mitutoyo Digital Vernier Caliper with an accuracy of 0.01 mm.

Laboratory tests of seed quality were performed in accordance with the International Rules for Seed Testing [21]. Here, the weight of 1000 seeds of larch, and their germination energy and germination capacity were examined. 100 seeds with four replications from each seed sources were subjected to germination test. Germination capacity is the proportion of total germinated seeds to that of sown seeds, which is expressed in percentage. Germination energy (also expressed in percentage), which is one of the commonly employed indices of germination speed [21] was computed as the proportion of total germinated seeds after 7 days to that of total germinated seeds after 15 days. Seed germination was tested under laboratory conditions in a Plant Growth Chamber at the temperature of 20 to 30 °C for 15 days. The differences in cone, seed and seed germination characteristics between different seed sources were determined by analysis of variance (ANOVA). Duncan's multiple range test (DMRT) was used for multiple comparisons.

Results and discussion

Comparison of stand characteristics and site index. The main stand characteristics of the sampled forests are shown in table 1. Overall, most of the stands belonged to pre-mature and mature classes in terms of forest age, and stand density was ranged from 0.6 (Shh) to 0.9 (Kht). Stand mean diameter ($p > 0.001$, $F = 3.06$) and height ($p > 0.001$, $F = 2.36$) were varied among selected stands, and the greatest values were recorded in Shh and Kht, and lowest in Yt and Cht, respectively (table 1). Therefore, growing stocks among sampled stands were averaged 233.9±25.3 m^3/ha. In terms of site quality, all sample plots belonged to III–V bonitet / quality classes of the sites, and the poorest site classes were recorded in Yt and Cht (table 1).

Table 1

Stand characteristics of the forests inventoried for this study

Site ID	Stand density	Stand age (yr)	Mean diameter (cm)	Mean height (m)	Bonitet / quality class of the site	Growing stock, m^3/ha	Geographical location		
							Lat. N	Long. E	Elevation, m
Sh	0.8	110	21.4	16.7	IV	215	107.05	47.50	1545
Yt	0.8	80	15.0	13.9	V	213	106.51	48.09	1498
Jd	0.8	90	20.3	19.0	III	276	107.59	47.52	1439
Ob	0.8	120	21.9	20.5	IV	254	107.03	47.51	1631
Ikht	0.7	80	16.9	14.9	IV	160	107.07	47.45	1648
Kht	0.9	120	25.4	20.0	IV	382	106.53	48.01	1532
Cht	0.7	110	17.1	15.0	V	164	106.55	48.06	1587
Shh	0.6	100	28.9	22.6	III	207	106.53	48.02	1494

According to Kraft's growth rate classification, the trees growing in each sampled stand were varied, and the dominant part belonged to I–III quality classes except for Ikht and Kht, and the remaining part to IV–V quality classes, respectively (fig. 3). The distribution graph of larch trees by growth rate classes showed a steadily increasing percentage of trees with slower growth rate in the selected areas with transition to the city center (fig. 3). This pattern was more pronounced in the southern closest forested areas, which are located along the main wind direction from sources of pollution (fig. 3*b*).

Contrary, in most of sampled forests in the north, the trees from I to III quality class were often higher, and a gradual increase of slower growing trees was also observed (fig. 3*a*). Generally, the highest proportion of faster growing larch trees occurred in the most remote areas in both directions. In addition, a detailed analysis of the trees using selection criteria showed a specific pattern of distribution, where dominance belonged to stands of normal and low quality (table 2).

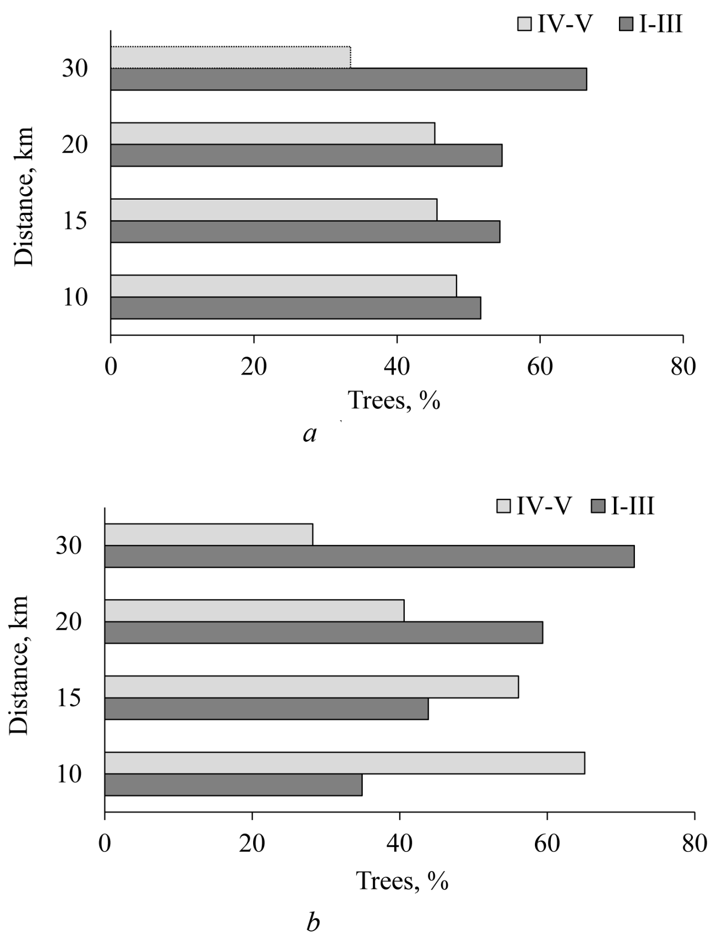


Fig. 3. Distribution of trees according to Kraft's growth rate classification on the northern (*a*) and southern (*b*) sample plots

Table 2

Distribution of the trees by selection criteria

Site ID	Remoteness from the city center, km	Relative distribution of the trees by selection criteria, %			Stand quality
		Plus tree	Normal tree	Low quality tree	
Sh	10	12.0	42.7	45.3	Low
Yt	15	13.1	38.3	48.6	Low
Jd	20	4.8	53.2	41.9	Normal
Ob	30	13.0	47.2	39.5	Normal
Ikht	10	6.6	37.1	56.1	Low
Kht	15	4.5	31.8	63.7	Low
Cht	20	3.3	69.5	27.2	Normal
Shh	30	10.8	45.9	43.2	Normal

The remaining part, which is only less than 8.5±1.45 % belonged to plus tree position. In accordance with the selection criteria, all selected forests basically belonged to normal (45.7±4.31 %) and low (45.8±3.90 %) quality stands. Our results showed a critical high proportion of low quality trees in Ikht (56.1 %) and Kht (63.7 %), which are located in 10 and 15 km from the city center to the south (table 2). The existing difference in tree morphology and growth rate among selected areas may be caused by negative effects of air pollutants originated from the capital city. We found a stronger negative effect of air pollution in the southern points (within 20 km) via comparison of stand characteristics and site classes (table 1). According to Amarsaikhan et al. [16] in Ulaanbaatar city, the annual average concentrations of PM_{10}, $PM_{2.5}$, SO_2 and NO_2 were 165.1, 75.1, 50.5 μg/m^3 and 85 μg/m^3, and critical concentrations were observed in winter season. Rather good site quality is observed considering the wind direction and sources of air pollution, in the forests growing to the north from Ulaanbaatar city. Our findings support the idea of other studies that the distribution of air pollutants in space is closely related to wind direction and velocity. In addition, the long-term meteorological data around Ulaanbaatar city showed that wind velocity and frequency peaked from March to May, which coincides with the driest period of the year.

Variation in morphological characteristics of cones and seeds. The results of the cone and seed morphological measurements are shown in table 3. Duncan's multiple range test revealed that there is a high variation of cone and seed morphometric dimensions not only between selected areas, but also within each plot. Here, cone length and width averaged 31.9 ± 2.2 mm and 21.9 ± 1.1 mm, and in comparison, Ob, Jd and Cht had relatively good morphological dimensions for cone, and Shh, Ob and Cht for seed (table 3).

Table 3

Cone and seed morphological characteristics of larch trees

Site ID	Length, mm			Width, mm		
	max	min	average	max	min	average
Cone morphology (n = 400)						
Sh	40.0	22.6	30.2cd	24.4	15.9	20.6de
Yt	41.6	23.3	29.4.de	28.7	17.3	21.6c
Jd	48.9	22.3	34.3ab	26.1	14.0	20.8d
Ob	44.9	26.0	35.3a	28.7	17.9	24a
Ikht	36.8	16.8	30.4c	32.4	11.1	22.2b
Kht	35.2	24.2	30.0d	26.6	17.7	21.5cd
Cht	41.9	25.5	32.5bc	29.5	17.5	22.7ab
Shh	39.0	26.2	32.9b	27.9	16.5	21.8bc
Seed morphology (n = 400)						
Sh	4.7	2.6	3.8e	3.9	1.9	2.8bc
Yt	5.4	3.7	4.6cd	3.4	2.4	3.0b
Jd	5.4	3.8	4.7bc	3.6	2.6	3.0b
Ob	5.9	4.1	4.9ab	4.8	2.6	3.2a
Ikht	5.2	2.1	4.0de	4.0	1.2	2.7c
Kht	5.6	3.8	4.5c	3.9	2.5	3.1ab
Cht	5.6	3.7	4.8b	3.8	2.4	3.0b
Shh	6.0	3.9	5.0a	3.9	2.1	3.2a

Note: Means with different letters are significantly different according to Duncan's multiple range test at 5 % level.

The lowest mean rates in cone and seed morphology were also found in the forests closer to the urban area. In our study, Ikht, Kht and Sh often showed lower values of site quality and regeneration capacity compared to other selected forest areas due to closer proximity to pollution sources.

The relationship between regeneration capacity and remoteness from the urban area. Depending on growing environment and geographical distribution, the weight of 1000 seeds, and their germination energy and capacity vary among different regions [1, 3, 19]. Two-year tests of seed germination energy and germination capacity have shown that the number of pollutants coming from the capital city causes a serious limiting effect on the reproductive capacity of the forest [10]. We found a high variation among these variables, and the poorest seed germination capacity was also observed in the areas closest to the city center, such as Sh (27.2 %), Ikht (28.1 %) and Kht (29.9 %), which were generally less than 30 % (fig. 4 *a*). Meanwhile, the germination energy level was less than in other areas ranging from 15 to 40 %. Contrary, rather good germination capacity was detected in seeds collected in more remote areas. Moreover, the relatively high means of seed weight and their morphological dimensions were observed in seeds collected in the most remote areas (Ob – 30 km to the north and Shh – 30 km to the south) (fig. 4).

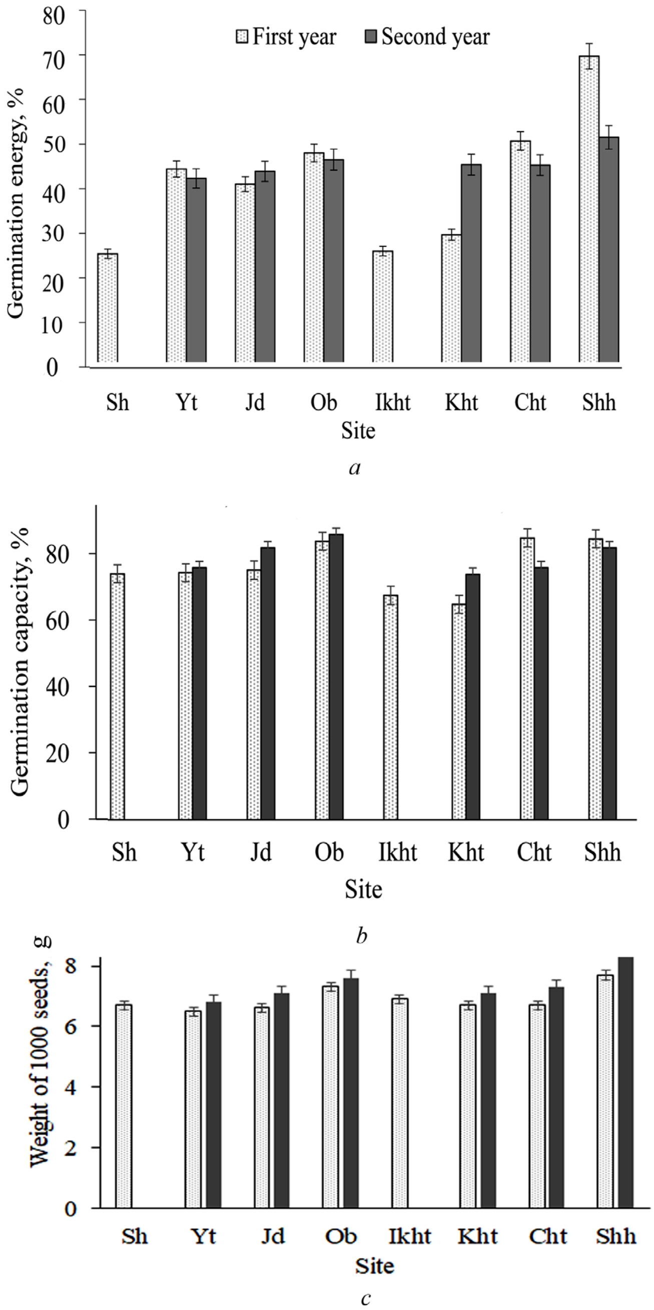
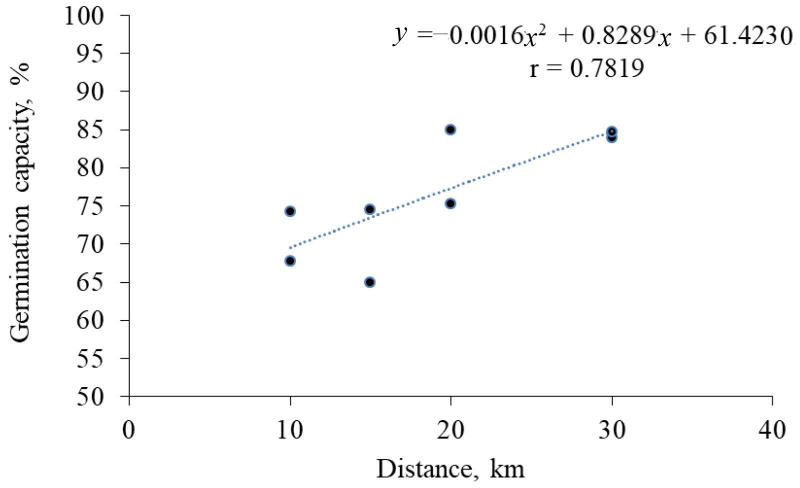
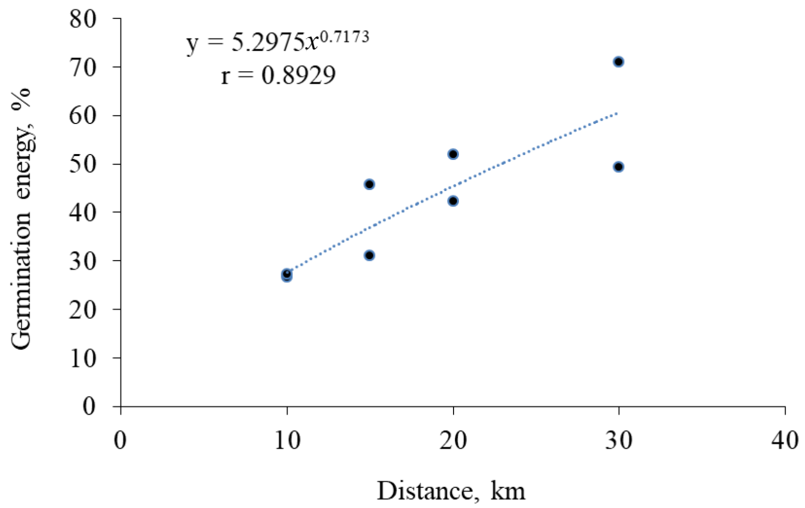


Fig. 4. Comparison of germination properties

In addition, we found an existing relationship between seed germination and distance from the source of pollution. In this case, seed germination (r = 0.7819) and energy (r = 0.8929) were strongly associated with an increase in distance from the source of pollution. This positive trend observed in seed quality showed that pollution sources have a negative impact not only on the quality of forest areas, but also on the ability to regenerate (fig. 5 *a*, 5 *b*).



a



b

Fig. 5. Relationship between distance from the source of pollution and seed germination properties

Consequently, the quality and weight of 1000 seeds tended to improve with distance from the city center. The existing relatively poor site classes and seed quality in nearby forest areas of Ulaanbaatar city might be associated with high concentrations of gases and dust, accumulation of heavy metals and other chemicals in forest soils and on tree surfaces, which have a strong negative impact on tree physiology, stand reproduction and site quality.

Conclusion

In conclusion, a number of pollutants transferred to forest ecosystems by air movement and wind activity have a strong negative impact not only on the site quality, but also on the forest reproductive capacity by deteriorating the quality of seeds. Moreover, the main wind direction, and remoteness from the pollution sources become a determining factor in the differentiation of the forest site quality and reproductive capacity in the surrounding forests of Ulaanbaatar city.

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ВЛИЯНИЕ РАССТОЯНИЯ ОТ ИСТОЧНИКОВ ЗАГРЯЗНЕНИЯ ДО ЛЕСОНАСАЖДЕНИЙ НА КАЧЕСТВО СЕМЯН *Larix sibirica* Ledeb. В ОКРЕСТНЫХ ЛЕСАХ ГОРОДА УЛАН-БАТОРА (МОНГОЛИЯ)

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Аннотация. Качество семян и их всхожесть являются главными показателями, определяющими успех восстановления и структуру естественных лесных экосистем. Основное внимание уделено проблемам, связанным с качеством семян лиственницы сибирской (*Larix sibirica* Ledeb.) и ее прорастанием в условиях загрязнения воздуха в окружающих лесных экосистемах города Улан-Батора. Цель работы – выявление влияния загрязнения воздуха на индекс участка и анализ взаимосвязи качества семян и расстояния от лесного участка до центра города (максимума загрязнения). Исследования проведены в естественных лиственничниках, произрастающих в окрестностях столицы Монголии. Всего было заложено восемь пробных площадей размером 100×100 м с использованием полностью рандомизированного плана отбора проб вдоль основного направления ветра. Удаленность от центра города составляла 10, 15, 20 и 30 км как на север, так и на юг. Обнаружены значительные различия средней высоты древостев ($p > 0{,}001$) и диаметра на высоте 1,3 м ($p > 0{,}001$). В целом все изученные лесонасаждения относились к III, IV и V классам бонитета, т. е. характеризовались относительно плохим состоянием с точки зрения индекса участка. Более высокие индекс участка и качество семян у *Larix sibirica* Ledeb. наблюдались в наиболее удаленных от центра города местах, и, наоборот, самые низкие по качеству семена были найдены недалеко от центра. Это позволяет утверждать: леса, произрастающие близко к источникам загрязнения, имеют потенциальный риск деградации, а их репродуктивные органы чувствительнее к воздействию вредных веществ, чем у деревьев, расположенных в экологически более благоприятных районах.

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Ключевые слова: лиственница сибирская (*Larix sibirica* Ledeb.), качество семян, всхожесть, индекс участка, загрязнение воздуха, Улан-Батор, Монголия.

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