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Dependence of Drooping Birch (*Betula pendula*) Phenological Indexes on the Intensity of Motor Traffic Pollution

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ABSTRACT

Dependence of phenological indexes such as emergence rate from winter dormancy (evaluated by share of blossom buds) and vegetation period termination (evaluated by share of fallen leaves) for birch (*Betula pendula* Roth) on the intensity of traffic pollution was studied. In 2011–2012, dependence of these parameters on pollution intensity was found using regression analysis. An increase in motor traffic led to a significant decrease in the studied phenological indexes in comparison with the control. The dependence of blossom bud share on traffic intensity was clearer in comparison with the same dependence of share of fallen leaves. In different years of observation, similarity in the studied dependencies was found; therefore, they can be used for bioindication.

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INTRODUCTION

It is known that environmental pollution causes a disturbance of phenological indexes of different plant species [1-3], including emergence from winter dormancy in the spring and autumn vegetation termination [4]. However, the suitability of these parameters for assessing the level of environmental pollution is insufficiently studied.

At the present time, evidence has accumulated in toxicology to show that, apart from classical monotonic dose-response dependences (S-shaped, exponential), non-monotonic responses, which include hormesis [5-6] and paradoxical effects [7-9], also occur rather often. Hormesis is a biphasic dose-response phenomenon characterised by low-dose stimulation and high-dose inhibition [10]. It is known that the manifestation of paradoxical effects consists of the following: as the dose or concentration of the toxic agent is reduced, its toxicity increases, and vice versa, such that with an increase in the dose, the toxic effect is reduced [8,11]. Therefore, it is necessary to study the phenological indexes of plants under the action of environmental pollution in a wide range of values to determine the pattern of this dependence.

Drooping birch (*Betula pendula* Roth) often grows in roadside forest strips of cities in Russia. This species is a bioindicator and many its parameters are used for bioindication [12-14]. Therefore, this species of woody plant was selected for this study. The aim of this study was to determine the dependence of emergence rate from winter dormancy in spring (using share of blossom buds) and vegetation period termination in autumn (using share of fallen leaves) of *B. pendula* on the intensity of motor traffic pollution in a wide range of values, over 2 years of observation.

MATERIALS AND METHODS

Study area and study sites:

Our research was carried out in 2011–2012. We studied phenological indexes in middle-aged generative trees of *B. pendula*. The trees grew in 9-10 model areas (plots) of tree stands planted along roadsides in the upland part of the city of Nizhni Novgorod, Russia (Table 1). Motor traffic is a major source of pollution in this part of the city.

All plots were characterised by similar soil conditions (light grey forest soils with anthropogenically mixed upper horizons) and a normal moistening regime. Their location was chosen so that traffic intensity varied within a wide range, with the minimum and maximum values differing by a factor of several tens. A conditionally clean area near the village of Kiselikha, 20 km north of Nizhni Novgorod, was chosen as the control plot for *B. pendula*. The control plot was located far from highways and other pollution sources.

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Table 1: Traffic intensity in studied areas of the city of Nizhni Novgorod where *B. pendula* grew.

#	Studied areas	Traffic intensity, vehicles per hour			
		In spring 2011	In autumn 2011	In spring 2012	In autumn 2012
1	Campus of Lobachevsky State University	-	-	6	7
2	Nizhni Novgorod Kremlin	81	67	102	114
3	Melnikova Street	96	94	-	-
4	Lomonosova Street	141	135	-	-
5	Nevzorovih Street	312	208	285	319
6	Nartova Street	822	662	663	743
7	Meditsinskaya Street	945	1,025	915	1,025
8	Timiryazeva Street	1,383	1,307	1,308	1,465
9	Belinskogo Street	2,850	2,356	2,487	2,785
10	Gagarina Prospect (Lebedeva Street bus stop)	3,792	3,978	3,762	4,214
11	Gagarina Prospect (University bus stop)	4,731	4,990	4,245	4,754

Estimation of motor traffic pollution:

Motor traffic pollution was estimated by the traffic intensity (vehicles per hour). The traffic intensity was the median of vehicles per hour, counted three times on a weekday: in the morning (from 8 until 10); in the afternoon (from 12 until 15); and in the evening (from 17 until 19) [15]. We previously demonstrated that the traffic intensity was correlated with the content of the main pollutants (oxides of sulphur, nitrogen, carbon, benzine, kerosene, benzopyrene, and formaldehyde) in the air along highways in Nizhni Novgorod ($r = 0.8–0.9$; $p < 0.05$).

Estimation of phenological indexes:

We estimated phenological indexes such as share of blossom buds (in May or in April) and share of fallen leaves (in September or in October) in 10 trees of each plot. Earlier, we supposed using these parameters for woody plants to estimate the emergence rate from winter dormancy in spring (share of blossom buds) and vegetation period termination (share of fallen leaves) in autumn [16].

To estimate the share of blossom buds, we studied the state of 100 buds in the middle and lower parts of the crown of each tree from the motorway (20 buds in five different parts of the crown of the tree). A bud was considered a blossom bud if the leaf was outside it. Then, the share of blossom buds in the pooled sample of buds for all 10 trees of the plot was calculated (10 trees × 100 buds; $n = 1,000$).

To estimate the share of fallen leaves, we studied the state of 100 shoot nodes in the middle and lower parts of the crown of each tree from the motorway (20 shoot nodes in five different parts of the crown of the tree). Each node of shoot has only one leaf; therefore, using the number of nodes without leaves we determined the number of fallen leaves. Then, the share of fallen leaves in the pooled sample of nodes for all 10 trees of the plot was calculated (10 trees × 100 nodes; $n = 1,000$).

Statistical analysis:

Statistical analyses were carried out using the programs Statistica 6.0. and Primer of Biostatistics 4.03. The chi-squared test with Bonferroni correction was used for multiple comparisons of the studied parameters in trees of different plots. Regression analysis was used to evaluate the dependence of the studied parameters on traffic intensity. Sampling shares with standard errors were used for graphical data presentation.

RESULTS AND DISCUSSION

The results of regression analysis showed that the dependencies of share of blossom buds and share of fallen leaves on traffic intensity were most adequately described by line equations in 2011 (Figs. 1a,b). The increase in traffic intensity caused a significant decrease in the studied parameters of *B. pendula* in comparison with the control. There was a positive correlation between share of blossom buds and share of fallen leaves (Spearman's correlation: $r = 0.82$; $p = 0.004$) in 2011.

Regression analysis showed that share of blossom buds and share of fallen leaves in *B. pendula* depended on traffic intensity and were most adequately described by a monotone quadratic polynomial function in 2012 (Figs. 2a,b). An increase in traffic intensity caused a significant decrease in the studied parameters. At the same time, the dependence of share of fallen leaves on traffic pollution was significantly more difficult to detect in comparison with 2011. Two points of the dependence were outside the 95% confidence interval of values; therefore, they were excluded from the regression analysis in 2012 (Gagarin pr., Lebedeva St. bus stop; Nizhni Novgorod Kremlin). Exclusion of such points from regression analysis is an accepted procedure in statistics [17]. A positive correlation between share of blossom buds and share of fallen leaves (Spearman's correlation: $r = 0.91$; $p = 0.004$) was found in 2012.

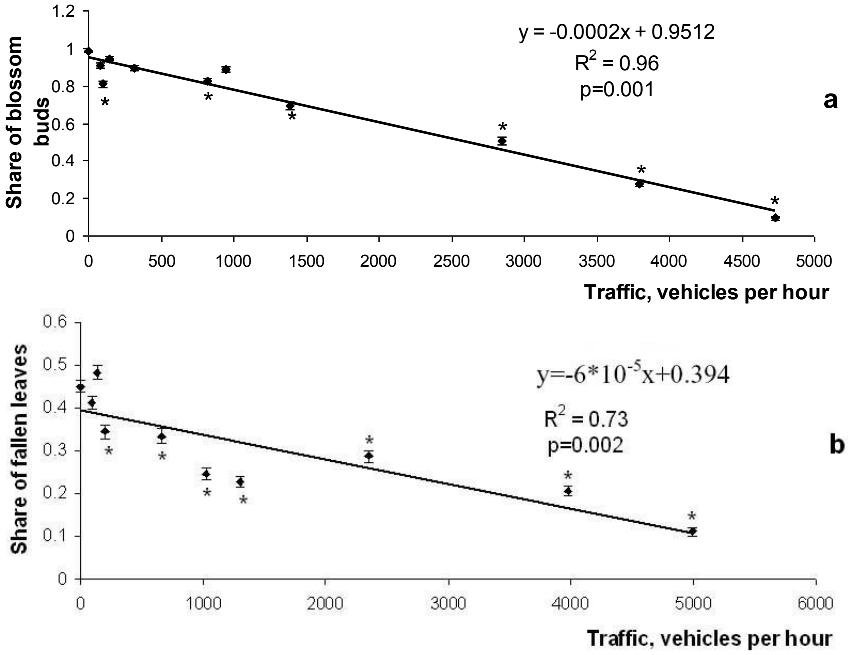

Fig. 1: Dependence of *B. pendula* share of blossom buds (a) and fallen leaves (b) on the motor traffic intensity in 2011.

* indicates significant differences between parameters of trees growing in contaminated and control areas at $p < 0.05$.

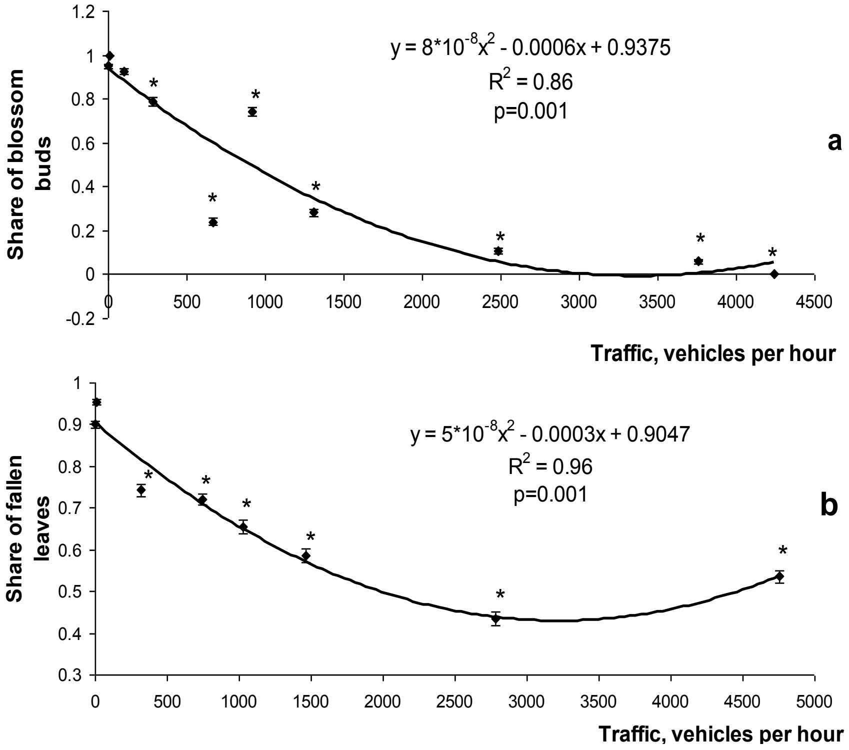

Fig. 2: Dependence of *B. pendula* share of blossom buds (a) and fallen leaves (b) on the motor traffic intensity in 2012.

* indicates significant differences between parameters of trees growing in contaminated and control areas at $p < 0.05$.

Thus, share of blossom buds and share of fallen leaves depended on the intensity of motor traffic pollution in 2011–2012. An increase of motor traffic caused a significant reduction in these plant parameters in comparison with the control. This fact indicated that *B. pendula* started and finished vegetation later in the polluted plots in comparison with control. Our data are consistent with the results of other authors who have shown a decrease in emergence rate from winter dormancy for other species of birch upon exposure to environmental pollution [4].

Apparently, the observed effects of pollution were caused by more drying of the tree crown under an increased traffic load. We found a positive Pearson's correlation between the percentage of crown drying and traffic intensity (in 2011: $r = 0.91$ $p = 0.001$; in 2012: $r = 0.83$ $p = 0.003$). Crown drying of the trees induced the intensive growth of shoots for crown regeneration; therefore, vegetation period termination started later in contaminated plots in autumn in comparison with the control. Apparently, intensive growth of shoots also induced a shortage of resources needed to resist low temperatures during winter dormancy and as a result death of shoots in winter. Therefore, we found significant crown drying of trees in contaminated plots in May after blossoming of buds when we evaluated percentage of crown drying.

Conclusion:

We can draw the following conclusions based on this study:

1. *B. pendula* emergence rate from winter dormancy (estimated by share of blossom buds) and vegetation period termination in autumn (estimated by share of fallen leaves) depended on the intensity of motor traffic pollution over 2 years of observation. An increase in motor traffic caused a significant reduction of these plant parameters in comparison with the control.
2. The share of blossom buds of *B. pendula* was more dependent on traffic intensity than the share of fallen leaves.
3. The studied dependencies of phenological indexes of *B. pendula* did not vary significantly between the different years of observation (in 2011–2012). Therefore, the share of blossom buds and share of fallen leaves of *B. pendula* can be used for bioindication.

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