Use of morphometric and phenological indicators of *Betula pendula* Roth for environmental health assessment

Nina Turmukhametova*, and *Denis* Turmukhametov

Mari State University, 1 Lenin Square, Yoshkar-Ola, 424000, Russia

Abstract. The article presents the results of long-term biomonitoring of the quality of the environmental of the city of Yoshkar-Ola (Russia) based on the analysis of morphological and phenological indicators of *Betula pendula* Roth. The authors studied Betula pendula trees at various stages of ontogenesis in the generative period. The authors also found out the heterogeneity of ontogenetic groups of trees by morphological and phenological characteristics in different ecotopes of the city, differing in the degree of pollution by industrial and transport emissions, using principal component analysis A decrease in the morphometric parameters of the *Betula pendula* leaf blade and leaf damage by phyllophagous insects do not always indicate a deterioration in the quality of the habitat. Moderate doses of atmospheric toxicants can accelerate the growth of *B. pendula* leaves. However, in conditions of urban pollution, the stability of *B. pendula* development is disrupted, which is manifested in an increase in the leaf asymmetry index. There are the most informative indicators of the state of the environment in individuals *B. pendula*: morphometric – an indicator of fluctuating asymmetry of leaves, phenological – the timing and duration of phenophases. The young generative trees of *B. pendula* are most sensitive to habitat pollution.

1 Introduction

The problem of studying the variability of plants at the organism level and the search for signs-markers of ontogenetic states of individuals is important for the ecology of populations [1, 2]. On the other hand, when studying the variability of plants living in a built environment, it is necessary to identify signs that are indicators of the quality of the habitat.

Tree plantings are an important object of urban ecosystem formation as well as a valuable indicator of the state of the environment. Researchers more often use various morphometric indicators of vegetative and generative organs of plants as bioindicative signs, less often – changes in the rhythms of their seasonal development [3-10]. In the works of the population-ontogenetic direction [1, 11, 12] it is shown that the heterogeneity of the rhythms of seasonal development of individuals of one cenopopulation can be a mechanism of adaptation to changes in environmental conditions. The study of the rhythmological polyvariance of plant

* Corresponding author: bonid@mail.ru

ontogenesis can contribute to the identification of the most sensitive species and signs-markers of habitat quality.

The purpose of our study is to analyze the variability of individuals of the *Betula pendula* Roth of various biological ages according to a complex of morphometric and phenological signs.

2 Materials and methods

B. pendula have an average gas-protection and often used for greening cities [13]. We have obtained data on three ontogenetic systemic generative transition of ontogenesis – young (g1), middle-aged (g2) and old (g3) [14]. We conducted research in 1999-2002, 2020-2022 in the city of Yoshkar-Ola (Republic of Mari El, Russia) and selected ecotopes in various zones of pollution by industrial and transport emissions [15]: No. 1 on the territory of the protected forest park "Pine Grove" (the zone of least pollution), No. 2 - one of the residential areas of the city (the zone of low pollution), No. 3 – the central park of the city, No. 4 – the vicinity of the pharmaceutical plant (zone of moderate pollution). We conducted observations of the rhythm of seasonal development of 240 *B. pendula* trees of plots No. 1-4 in 1999-2002. During the growing season, a total of 15 phenophases of the development of vegetative and generative structures of trees were recorded. The frequency of observations was every 1-2 days in spring and every 6-7 days in summer and autumn [16, 17]. We studied the morphometric characteristics of the shoots [18] in 20-40 individuals of different ontogenetic states also in 1999-2002. In 2021 we redefined the area and percentage of leaf plates damage [19]. The study of fluctuation asymmetry (FA) of the trees leafs was completed in 2020-2022 with using standard methods. The measuring of the leaf blade was carried out according to 5 signs, the differences between the left and right halves of the leaf were averaged by the number of signs, as a result of which we obtained an index of fluctuating assimetry – IFA [20]. Statistical data processing was carried out in the Statistica 10 software package using factor ANOVA, Scheffe test and principal component Analysis (PCA) [21].

3 Results and discussion

The analysis of the variability of 8 morphological features of *B. pendula* allowed us to establish that the first principal component (PC) mainly reflects the metric parameters of the shoot system. The I PC accounts for 34% of the variability. The II PC covers 30% of the variance, IFA is positively correlated with it, and the number of shortened shoots is negatively correlated with it. The III PC can be characterized as a component of the size of the infructescence, it accounted for 20% of the variability (Table 1).

Table 1. Factor loading for morphological features *B. pendula.*

Variable	**Principal components**		
	I	**II**	**II**
Long shoot length	**0.87**[a]	0.07	-0.15
Number of metamers	**0.90**[a]	-0.15	-0.09
Number of short shoots	-0.06	**-0.81** [a]	0.31
Number of long shoots	**0.82**[a]	0.32	0.04
IFA of leaf from short shoots	-0.03	**0.90**[a]	0.20
IFA of leaf from long shoots	-0.41	**0.82**[a]	0.17
Infructescence length	0.12	0.27	**-0.89**[a]
Infructescence diameter	-0.50	-0.20	**-0.75**[a]
Dispersion	*33.59*	*29.95*	*19.56*

[a]$p< 0.01$.

 https://doi.org/10.1051/e3sconf/202344305011

G3 individuals have the polyvariance of shoots: an increase in the growth of long shoots (P<0.01-0.05), the number of long shoots, with the same number of metamers and short shoots. Consequently, the intensive growth of shoots of g3 individuals of *B. pendula* in unfavorable conditions is determined by a more significant stretching of internodes in the process of visible shoot growth. In urban conditions in individuals of different ages *B. pendula* shows an ambiguous reaction to a complex of urban factors, which leads to the activation of growth processes. This phenomenon can be explained both by elevated temperatures and increased carbon dioxide content in the air, and by the use of pollutants by trees as additional elements of mineral nutrition [10, 22, 23].

According to the II PC, there is a clear division of urban ecotopes into 2 parts: ecotopes No. 1 and No. 2, ecotopes No. 3 and No. 4 (Figure 1). Unfavorable conditions of ecotopes No. 3 and No. 4 affected the morphostructure of *B. pendula* – these trees have high IFA values and longer shoots.

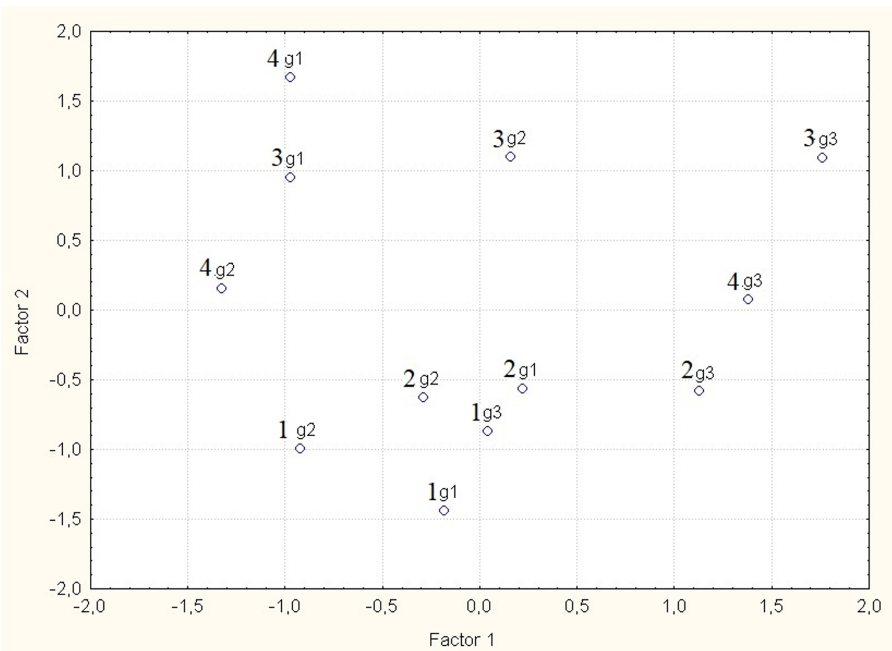

Fig. 1. Ecotope distribution along the significant factors: g1, g2, g3 – ontogenetic states of *B. pendula.*

The contribution of three PCs to the total variance of 6 phenological features of *B. pendula* was 82%. The I PC accounts for 38.5% of the total variability; it is positively correlated with leaf lifespan and vegetation duration. II PC covers 35% of variability, it is negatively correlated with the duration of leaf deployment and positively with the duration of leaf yellowing and leaf fall. The III PC accounts for 18.5% of variability, it includes a feature – the duration of flowering (Table 2).

According to PC II, there is a division of trees in the zone of moderate pollution into phenorhythmogroups. We obtained that g2 individuals have acceleration seasonal development and g1, g3 – delayed (P<0.01–0.05). As a rule, middle-aged generative individuals of *B. pendula* are characterized by earlier periods of the beginning of phenophases, rapid unfolding of leaves, prolonged flowering, yellowing of leaves and, in general, the growing season, compared with young and old generative trees. In trees in ecotope No. 1, a similar dependence was also recorded, but there were no statistically significant differences over all the years of the study (P>0.05). In addition, phenophases of *B. pendula* trees in the urban environment begin earlier, their duration and the duration of the general vegetation are reduced (P<0.01–0.05). There is large heterogeneity in phenorhythmogroups in the conditions of the urban system, it can be caused by the action of air toxicants as asynchronizers of the rhythms of growth and development and the different sensitivity of trees of different ages to them.

Table 2. Factor loading for phenological features *B. pendula.*

Variable	Principal components		
	I	II	III
Duration of leaf deployment	-0.32	**-0.77**[a]	0.24
Duration of flowering	-0.06	-0.14	**0.96**[a]
Duration of yellowing of leaves	-0.47	**0.85**[a]	0.04
Leaf lifespan	**0.90**[a]	0.31	0.13
Vegetation duration	**0.86**[a]	0.38	0.22
Leaf fall duration	-0.65	**0.71**[a]	0.23
Dispersion	*38.49*	*34.97*	*18.52*

[a]p< 0.01.

Analysis of leaf samples by morphometric indicators revealed that medium-aged generative *B. pendula* trees form larger leaves in urban ecotopes. A statistically significant difference in the length, width and area of the leaf has been proved (P<0.05). A warmer microclimate of urban ecotopes, emissions from motor vehicles and industrial enterprises contribute to stimulating leaf growth processes. A similar trend was recorded by other authors on the example of various urban ecosystems [22]. By the end of the growing season , the largest area of *B. pendula* leaf damage by insects was observed in ecotopes No. 1 and No. 2, smaller – in ecotopes No. 3 and No. 4 (P<0.05).

The IFA of birch leaves ranged from 0.036 to 0.039 on the territory of ecotope No. 1 in 2020-2022 years [23]. During this period the state of model trees is assessed on the ontogeny stability scale [20] as optimal. The IFA of *B. pendula* of urban ecotopes No. 2-4 on the scale of development stability varies from 0.040 to 0.051 (p<0.05-0.001) and indicates the unfavorable quality of the habitat. However, in the same *B. pendula* trees, the linear growth of shoots was increased and abundant annual fruiting was noted.

4 Conclusions

PCA by morphological and phenological features showed that fragments of *B. pendula* populations are mainly divided into 2 groups: more (ecotopes No. 1 and No. 2) and less (ecotopes No. 3 and No. 4) favorable zones within the city. In the PC plane, the ontogenetic groups in the more favorable zone are located close to each other, and in the less favorable zone they are scattered, which indicates their heterogeneity in the morphostructure of organs and phenorhythms.

The specific microclimate of the urban environment, pollution of the atmosphere and soil by industrial and transport emissions leads to the population biodiversity of *B. pendula*. The heterogeneity of the generative fraction of trees is manifested in the variability of morphometric features of the shoot system and the rhythms of tree development. The stability of the number of shoot metamers, the high intensity of fruit formation, and the asynchrony of seasonal development are adaptive mechanisms of *B. pendula* individuals to various conditions of the urban environment. The most labile quantitative signs of individuals are B. pendula are IFA, as well as the timing and duration of phenophases, therefore it is advisable to use these signs for bioindication work, and in the most sensitive young generative trees.

Mari State University Strategic Academic Leadership Program (PRIORITY-2030) funded this research.

References

1. A.A. Notov, L.A. Zhukova, Biology Bulletin **46**, 47 (2019)
2. G.O. Osmanova, L.A. Zhivotovsky, Biology Bulletin, **47**, 141 (2020)
3. F.H. Meyer, *Bäume in der Stadt* (EDP Verlag Ulmer, Stuttgart, 1982)
4. H.-G. Dässler, *Einfluss von Luftverunreinigungen auf die Vegetation* (EDP Reihe Umweltforschung Gustav Fischer Verlag, Jena, 1991)
5. F. Lakatos, S. Mirtchev, *Manual for Visual Assessment of Forest Crown Condition* (EDP Food and Agriculture Organization of the United Nations, Pristina, Kosovo, 2014)
6. N.B. Khondhodjaeva, K.B. Ismillaeva, N.T. Ruzimbayeva, Europ. Sci. **4**, 68 (2018)
7. E.A. Erofeeva, B.N. Yakimov, Symmetry **12**, 727 (2020)
8. A.A. Minin, I.E. Trofimov, V.M. Zakharov, Biology Bulletin **47**, 149 (2020)
9. V.M. Zakharov, I.E. Trofimov, Emerging Topics in Life Sciences **6**, 295 (2022)
10. E. Shadrina, V. Soldatova, N. Turmukhametova, Symmetry **15**, 700 (2023)
11. L.A. Zhukova, Russian Journal of Ecology **32**, 151 (2001)
12. T.A. Polyanskaya, M.A. Polyanskaya, Bulletin of Tver State University. Series: Biology and Ecology **24**, 105 (2011)
13. G.M. Il'kun, *Air Pollutants and Plants* (EDP Naukova Dumka, Kiev, 1978)
14. *Diagnoses and Keys of Age States of Forest Plants: Trees and Shrubs* (EDP Mosk. Gos. Pedagog. Inst.Moscow, 1989)
15. *Report on the ecological situation in the Republic of Mari El for 2022* (EDP Prin, Izhevsk, 2023)
16. N.E. Bulygin, *Phenological observations on deciduous woody plants* (EDP Forestry Academy, Leningrad, 1979)
17. A.A. Minin, Proceedings of the Russian Academy of Sciences of the Russian Academy of Sciences. Geographical series **3**, 75 (2000)
18. I.G. Serebryakov, *Morphology of vegetative organs of higher plants* (EDP Soviet Science, Moscow, 1952)
19. A.I. Fedorova, A.N. Nikol'skaya, *A Practical Course in Ecology and Environmental Protection* (EDP Vlados, Moscow, 2003)
20. V.M. Zakharov, A.S. Baranov, V.I. Borisov, A.V. Valetskii, N.G. Kryazheva, E.K. Chistyakova, A.T. Chubinishvili, *Health of the Environment: Metodology Evaluation* (EDP Tsentr Ekologicheskoi Politiki Rossii Russia Moscow, 2000)
21. R.R. Sokal, F.J. Rohlf, *Biometry* (EDP Freeman, New York, 1995)
22. I.L. Buharina, A.A. Dvoeglazova, *Bioecological Features of Herbaceous and Woody Plants in Urban Ecosystems* (EDP Udmurtskii universitet, Izhevsk, 2010)
23. N.V. Turmukhametova, D.B. Turmukhametov, IOP Conf. Series: Earth and Environmental Sc. **1076**, 012082 (2022)