Morphological Changes of Leaves of Birch (*Betula pendula* Roth) During the Growing Season in the Conditions of Petrochemical Pollution of the Environment

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Abstract. The authors analyze their data on birch leaves (*Betula pendula* Roth) during the growing season of 2019. Studies were conducted on the territory of the Ufa industrial center near oil refineries. Model birch trees grow on permanent plots. Ten leaves are numbered on the trees. Photographs of each plate were taken during the growing season (June-July-August-September). The integral indicator of the stability of leaf development was calculated according to five criteria: (1) the wide of the left and right halves of the leaf; (2) the length of the second vein from the base of the plate; (3) the distance between the grounds of the bottom of the first and second veins of the second-order of the leaf; (4) the distance between the ends of the first and second veins of the second-order of the plate; (5) the angle between the central vein and the second vein of the second order from the base of the leaf. The research shows that under conditions of the hydrocarbon type of environmental pollution, there are deviations in the morphological development of birch leaves. The authors show that an individual trajectory of morphological development is characteristic of leaves. The phenomenon of adaptive polymorphism of birch leaves is noted. Moreover, the morphological and functional features of the plate are inextricably linked. Leaf asymmetry indicators can be used to characterize the state of birch trees in urban conditions.

Keywords: Birch (*Betula pendula* Roth) · Integral indicator · Leaf polymorphism · Industrial center

1. Introduction

One approach to assessing plants' resistance to their growth under extreme conditions is to determine developmental stability and asymmetry [1-2, 4, 7-8, 10, 13].

The formed leaf passes through four phases: 1) the formation of primordia; 2) the leaf; 3) laying of the plate of the leaf due to the lateral meristem; 4) leaf plate growth by stretching. Peculiarities of leaf growth during the growing season are not well understood [6]. The study of the morphological changes in leaves during the growing season should be considered when organizing monitoring studies [9, 11-12].

The investigation aimed to study the morphological changes of birch leaves (*Betula pendula* Roth) under environmental pollution during the growing season.

The subject of the research is birch plantations in the industrial zone of Ufa.
2. Materials and Methods
The research was conducted in the industrial zone on the territory of the Ufa Industrial Center. Plantings grow near oil refineries. The general characteristics of the stands have been presented previously [9].

Objects of studies – model trees of birch (*Betula pendula* Roth). The first tree is large-leaved; the second tree is small-leaved. In the crown of each tree, ten leaves are numbered. Each plate was photographed during the growing season (June-July-August-September). Used a Nikon D40 digital camera. Photographs of the leaves were computer-processed using standard programs.

A method was used to study the leaves' morphological characters [3, 14, 17]. The stability of the development of leaves of tree stands is estimated. The studies were carried out in 2019, characterized by average values of weather and climatic conditions.

The actual material for assessing the stability of development of birch leaves is the morphological characteristics of the right and left halves of the plate according to 5 signs [18]:

1st sign – the width of the left and right halves of the leaf;
2nd sign – the length of the vein of the second order from the base of the plate;
3rd sign – the distance between the grounds of the bottom of the first and second veins of the second-order of the leaf;
4th sign – the distance between the ends of the first and second veins of the second-order of the plate;
5th sign – the central vein's angle and the second vein of the second order from the leaf base.

Statistical processing of the research results was carried out in the programs: STATISTICA, GraphPad Prism, Microsoft Excel.

3. Results
Shown are changes in birch leaves during the growing season [15]. The integral indicator of the stability of leaf development (small-leaved tree and large-leaved tree) was calculated according to five criteria [16] (Fig. 1, Fig. 2, Fig. 3, Fig. 4, Fig. 5). The obtained data were statistically processed, 1-way ANOVA, ANOVA (table 1, table 2, table 3, table 4, table 5, table 6, table 7, table 8, table 9, table 10, table 11, table 12, table 13, table 14, table 15).

![Figure 1](image-url)

**Figure 1.** Integral index of stability of leaf development (the 1st sign). A – Large-leaved tree, B – Small-leaved tree.
Table 1. Column statistics (the 1st sign).

| Month | June | July | August | September |
|-------|------|------|--------|-----------|
| Tree  | Large-leaved | Small-leaved | Large-leaved | Small-leaved | Large-leaved | Small-leaved |
| Number of values | 8 | 8 | 8 | 8 | 8 | 8 |
| Minimum | 0.023 | 0.007 | 0.012 | 0.007 | 0.015 | 0.021 | 0.006 | 0.005 |
| Maximum | 0.133 | 0.093 | 0.202 | 0.13 | 0.117 | 0.14 | 0.116 | 0.109 |
| Mean | 0.054 | 0.039 | 0.059 | 0.049 | 0.054 | 0.063 | 0.056 | 0.055 |
| Std. Deviation | 0.038 | 0.028 | 0.063 | 0.040 | 0.034 | 0.043 | 0.043 | 0.042 |
| Std. Error | 0.013 | 0.010 | 0.022 | 0.014 | 0.012 | 0.015 | 0.015 | 0.015 |
| Lower 95% CI of mean | 0.022 | 0.015 | 0.007 | 0.016 | 0.025 | 0.026 | 0.020 | 0.020 |
| Upper 95% CI of mean | 0.085 | 0.062 | 0.112 | 0.083 | 0.082 | 0.099 | 0.092 | 0.091 |
| Coefficient of variation | 70.04% | 72.08% | 106.43% | 63.32% | 69.35% | 77.57% | 75.99% |
| Sum | 0.430 | 0.310 | 0.476 | 0.394 | 0.430 | 0.501 | 0.448 | 0.443 |

Table 2. 1-way ANOVA (the 1st sign).

| Parameter | Value | Large-leaved tree | Small-leaved tree |
|-----------|-------|-------------------|-------------------|
| P value   |       | 0.994             | 0.658             |
| P-value summary | ns | ns |
| Are means signific. different? (P < 0.05) | No | No |
| Number of groups | 4 | 4 |
| F        | 0.027 | 0.541             |
| R squared | 0.003 | 0.055             |

Bartlett’s test for equal variances. Large-leaved tree: Bartlett’s statistic (corrected) 3.186; P value 0.364; P value summary ns; Do the variances differ signif. (P < 0.05) – No. Small-leaved tree: Bartlett’s statistic (corrected) 1.447; P value 0.695; P value summary ns; Do the variances differ signif. (P < 0.05) – No.

Table 3. ANOVA (the 1st sign).

| ANOVA Table | SS       | df  | MS        |
|-------------|----------|-----|-----------|
| Large-leaved tree |          |     |           |
| Treatment (between columns) | 0.0001742 | 3   | 0.00005806 |
| Residual (within columns) | 0.05926   | 28  | 0.002116 |
| Total       | 0.05944  | 31  |           |
| Small-leaved tree |          |     |           |
| Treatment (between columns) | 0.002451  | 3   | 0.000817 |
| Residual (within columns) | 0.04232   | 28  | 0.001511 |
| Total       | 0.04477  | 31  |           |
2nd sign – the length of the vein of the second order from the base of the leaf

Figure 2. Integral index of stability of leaf development (the 2nd sign). A – Large-leaved tree, B – Small-leaved tree

Table 4. Column statistics (the 2nd sign).

| Month       | June | July | August | September |
|-------------|------|------|--------|-----------|
| Tree        |      |      |        |           |
| Number of values | 8   | 8    | 8      | 8         |
| Minimum     | 0.002| 0.008| 0.001  | 0.012     |
| Maximum     | 0.125| 0.04 | 0.109  | 0.104     |
| Mean        | 0.035| 0.023| 0.031  | 0.023     |
| Std. Deviation | 0.040 | 0.013 | 0.033  | 0.022     |
| Std. Error  | 0.014| 0.005| 0.012  | 0.008     |
| Lower 95% CI of mean | 0.002 | 0.012 | 0.006  | 0.012     |
| Upper 95% CI of mean | 0.069 | 0.033 | 0.059  | 0.042     |
| Coefficient of variation | 114.32% | 57.80% | 107.49% | 95.18% |
| Sum         | 0.281| 0.180| 0.248  | 0.185     |

Table 5. 1-way ANOVA (the 2nd sign).

| Parameter          | Value        |
|--------------------|--------------|
|                    | Large-leaved tree | Small-leaved tree |
| P value            | 0.996        | 0.928          |
| P-value summary    | ns           | ns             |
| Are means signifi. different? (P < 0.05) | No          | No             |
| Number of groups   | 4            | 4              |
| F                  | 0.022        | 0.151          |
| R squared          | 0.002        | 0.016          |
Bartlett’s test for equal variances. Large-leaved tree: Bartlett’s statistic (corrected) 0.488; P value 0.922; P value summary ns; Do the variances differ signif. (P < 0.05) – No. Small-leaved tree: Bartlett’s statistic (corrected) 2.285; P value 0.515; P value summary ns; Do the variances differ signif. (P < 0.05) – No.

Table 6. ANOVA (the 2nd sign).

| ANOVA Table | SS           | df  | MS      |
|-------------|--------------|-----|---------|
|             | Large-leaved tree |     |         |
| Treatment (between columns) | 0.00008159   | 3   | 0.0000272 |
| Residual (within columns)     | 0.0353       | 28  | 0.001261 |
| Total              | 0.03538      | 31  |         |
|             | Small-leaved tree |     |         |
| Treatment (between columns) | 0.00013      | 3   | 0.00004321 |
| Residual (within columns)     | 0.00802      | 28  | 0.000286 |
| Total              | 0.00815      | 31  |         |

3rd sign – the distance between the bases of the first and second veins of the second-order of the leaf

Figure 3. Integral index of stability of leaf development (the 3rd sign). A – Large-leaved tree, B – Small-leaved tree

Table 7. Column statistics (the 3rd sign).

| Month     | June  | July | August | September |
|-----------|-------|------|--------|-----------|
| Number of values | Large-leaved | Small-leaved | Large-leaved | Small-leaved | Large-leaved | Small-leaved | Large-leaved | Small-leaved |
|           | 8     | 8    | 8      | 8         | 8          | 8            | 8            | 8            |
| Minimum   | 0.045 | 0.028| 0.037  | 0.005     | 0.032      | 0.005        | 0.049        | 0            |
| Maximum   | 0.223 | 0.264| 0.261  | 0.143     | 0.256      | 0.1          | 0.235        | 0.143        |
| Mean      | 0.155 | 0.093| 0.165  | 0.058     | 0.137      | 0.051        | 0.136        | 0.057        |
| Std. Deviation | 0.057  | 0.075| 0.074  | 0.049     | 0.076      | 0.033        | 0.061        | 0.047        |
| Std. Error | 0.020 | 0.027| 0.026  | 0.017     | 0.027      | 0.011        | 0.021        | 0.017        |
Lower 95% CI of mean: 0.107, 0.030, 0.102, 0.017, 0.073, 0.024, 0.085, 0.017
Upper 95% CI of mean: 0.203, 0.156, 0.227, 0.099, 0.200, 0.079, 0.187, 0.096
Coefficient of variation: 36.98%, 80.65%, 45.21%, 84.45%, 55.59%, 63.25%, 44.64%, 82.87%
Sum: 1.243, 0.747, 1.316, 0.466, 1.093, 0.411, 1.088, 0.452

Table 8. 1-way ANOVA (the 3rd sign).

| Parameter | Value Large-leaved tree | Value Small-leaved tree |
|-----------|-------------------------|-------------------------|
| P value   | 0.790                   | 0.389                   |
| P-value summary | ns                     | ns                     |
| Are means signif. different? (P < 0.05) | No                    | No                     |
| Number of groups | 4                     | 4                     |
| F         | 0.35                    | 1.043                   |
| R squared | 0.036                   | 0.101                   |

Bartlett’s test for equal variances. Large-leaved tree: Bartlett’s statistic (corrected) 0.779; P value 0.855; P value summary ns; Do the variances differ signif. (P < 0.05) – No. Small-leaved tree: Bartlett's statistic (corrected) 4.687; P value 0.196; P value summary ns; Do the variances differ signif. (P < 0.05) – No.

Table 9. ANOVA (the 3rd sign).

| ANOVA Table | SS   | df | MS   |
|-------------|------|----|------|
| Large-leaved tree |      |    |      |
| Treatment (between columns) | 0.0048 | 3  | 0.0016 |
| Residual (within columns) | 0.128  | 28 | 0.004572 |
| Total       | 0.1328 | 31 |      |
| Small-leaved tree |      |    |      |
| Treatment (between columns) | 0.008868 | 3  | 0.002956 |
| Residual (within columns) | 0.07938  | 28 | 0.002835 |
| Total       | 0.08824 | 31 |      |
4th sign – the distance between the ends of the first and second veins of the second-order of the leaf

![Graph showing Integral indicator for plant leaf number across different months and tree types.]

**Figure 4.** Integral index of stability of leaf development (the 4th sign) A – Large-leaved tree, B – Small-leaved tree.

**Table 10.** Column statistics (the 4th sign).

| Month       | June | July | August | September |
|-------------|------|------|--------|-----------|
| Tree        |      |      |        |           |
| Number of values | 8 | 8 | 8 | 8 |
| Minimum     | 0.004 | 0.003 | 0.006 | 0.006 | 0.027 | 0.019 | 0.023 | 0.005 |
| Maximum     | 0.224 | 0.136 | 0.184 | 0.168 | 0.207 | 0.189 | 0.232 | 0.153 |
| Mean        | 0.079 | 0.068 | 0.066 | 0.072 | 0.094 | 0.071 | 0.091 | 0.064 |
| Std. Deviation | 0.070 | 0.056 | 0.058 | 0.062 | 0.062 | 0.064 | 0.072 | 0.059 |
| Std. Error  | 0.025 | 0.020 | 0.021 | 0.022 | 0.022 | 0.023 | 0.025 | 0.021 |
| Lower 95% CI of mean | 0.021 | 0.021 | 0.017 | 0.020 | 0.042 | 0.017 | 0.031 | 0.015 |
| Upper 95% CI of mean | 0.138 | 0.115 | 0.115 | 0.125 | 0.146 | 0.125 | 0.151 | 0.113 |
| Coefficient of variation | 88.62% | 82.50% | 88.26% | 86.42% | 65.97% | 90.45% | 79.09% | 91.27% |
| Sum         | 0.634 | 0.544 | 0.528 | 0.578 | 0.754 | 0.568 | 0.725 | 0.514 |

**Table 11.** 1-way ANOVA (the 4th sign).

| Parameter                      | Value  |
|--------------------------------|--------|
|                                | Large-leaved tree | Small-leaved tree |
| P value                        | 0.825  | 0.994  |
| P-value summary                | ns     | ns     |
| Are means signif. different?   | No     | No     |
| Number of groups               | 4      | 4      |
| F                              | 0.300  | 0.028  |
| R squared                      | 0.031  | 0.003  |
Bartlett’s test for equal variances. Large-leaved tree: Bartlett’s statistic (corrected) 0.383; P value 0.944; P value summary ns; Do the variances differ signif. (P < 0.05) – No. Small-leaved tree: Bartlett’s statistic (corrected) 0.147; P value 0.986; P value summary ns; Do the variances differ signif. (P < 0.05) – No.

Table 12. ANOVA (the 4th sign).

| ANOVA Table          | SS      | df | MS   |
|----------------------|---------|----|------|
| Large-leaved tree    |         |    |      |
| Treatment (between columns) | 0.003895 | 3 | 0.001298 |
| Residual (within columns) | 0.1213  | 28 | 0.004332 |
| Total                | 0.1252  | 31 |      |
| Small-leaved tree    |         |    |      |
| Treatment (between columns) | 0.000305 | 3 | 0.000102 |
| Residual (within columns) | 0.1023  | 28 | 0.003652 |
| Total                | 0.1026  | 31 |      |

5th sign – the angle between the central vein and the second vein of the second order from the base of the leaf

Figure 5. Integral index of stability of leaf development (the 5th sign) A – Large-leaved tree, B – Small-leaved tree.

Table 13. Column statistics (the 5th sign).

| Month   | June | July | August | September |
|---------|------|------|--------|-----------|
| Tree    |      |      |        |           |
| Large-leaved | 0.005 | 0.006 | 0.009 | 0.004 | 0.001 | 0.002 |
| Small-leaved | 0.124 | 0.062 | 0.092 | 0.055 | 0.12 | 0.056 | 0.132 | 0.075 |
| Number of values | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| Minimum | 0.005 | 0.006 | 0.009 | 0.004 | 0.001 | 0.002 |
| Maximum | 0.124 | 0.062 | 0.092 | 0.055 | 0.12 | 0.056 | 0.132 | 0.075 |
| Mean    | 0.048 | 0.027 | 0.041 | 0.019 | 0.054 | 0.030 | 0.065 | 0.030 |
| Std. Deviation | 0.039 | 0.018 | 0.031 | 0.018 | 0.047 | 0.019 | 0.046 | 0.025 |
| Std. Error | 0.014 | 0.006 | 0.011 | 0.007 | 0.017 | 0.007 | 0.016 | 0.009 |
### Lower 95% CI of mean

| Value | Large-leaved tree | Small-leaved tree |
|-------|-------------------|-------------------|
| 0.015 | 0.004             | 0.015             |
| 0.012 | 0.014             | 0.027             |
| 0.015 | 0.004             | 0.009             |

### Upper 95% CI of mean

| Value | Large-leaved tree | Small-leaved tree |
|-------|-------------------|-------------------|
| 0.081 | 0.066             | 0.093             |
| 0.042 | 0.034             | 0.046             |
| 0.066 | 0.034             | 0.104             |
| 0.066 | 0.046             | 0.050             |

### Coefficient of variation

| Value | Large-leaved tree | Small-leaved tree |
|-------|-------------------|-------------------|
| 81.38% | 66.86%           | 82.84%           |
| 76.46% | 97.21%           | 70.54%           |
| 88.45% | 62.29%           | 70.54%           |
| 76.46% | 97.21%           | 70.54%           |
| 62.29% | 70.54%           | 82.84%           |

### Sum

| Value | Large-leaved tree | Small-leaved tree |
|-------|-------------------|-------------------|
| 0.384 | 0.218             | 0.297             |
| 0.218 | 0.324             | 0.428             |
| 0.324 | 0.152             | 0.242             |
| 0.152 | 0.428             | 0.521             |
| 0.428 | 0.242             | 0.237             |

### Table 14. 1-way ANOVA (the 5th sign).

| Parameter                        | Value  |
|----------------------------------|--------|
|                                  | Large-leaved tree | Small-leaved tree |
| P value                          | 0.683              | 0.667              |
| P-value summary                  | ns                 | ns                 |
| Are means signif. different? (P < 0.05) | No             | No                 |
| Number of groups                 | 4                  | 4                  |
| F                                | 0.504              | 0.528              |
| R squared                        | 0.051              | 0.054              |

Bartlett’s test for equal variances. Large-leaved tree: Bartlett's statistic (corrected) 1.382; P value 0.710; P value summary ns; Do the variances differ signif. (P < 0.05) – No. Small-leaved tree: Bartlett's statistic (corrected) 0.865; P value 0.834; P value summary ns; Do the variances differ signif. (P < 0.05) – No.

### Table 15. ANOVA (the 5th sign).

| ANOVA Table                       | SS      | df  | MS    |
|-----------------------------------|---------|-----|-------|
|                                  | Large-leaved tree |     |       |
| Treatment (between columns)       | 0.002581| 3   | 0.00086|
| Residual (within columns)         | 0.04784 | 28  | 0.001709|
| Total                             | 0.05042 | 31  |       |
|                                  | Small-leaved tree |     |       |
| Treatment (between columns)       | 0.000645| 3   | 0.000215|
| Residual (within columns)         | 0.01141 | 28  | 0.000408|
| Total                             | 0.01206 | 31  |       |

### 4. Discussion

Using the Bartlett test, an approximate criterion is determined for assessing the dispersion homogeneity for equal deviations according to measured the leaves’ five criteria standards. Whether these deviations differ significantly leaf development, the answer is received – there are no differences.

Using ANOVA analysis of variance, it was shown that there are no differences between the average values of the compared groups on five signs of leaf development.

However, the figures show that unique individual marked by a particular development pathan individual development path represents each leaf. The leaves' adaptive response to extreme growing conditions (environmental pollution) is manifested in this case. The phenomenon of adaptive polymorphism of birch leaves is noted. Moreover, the morphological and functional features of the plate are inextricably linked.
5. Conclusion
In the Ufa industrial center, with a predominance of the hydrocarbon type of environmental pollution, mixed reactions of woody plants are noted. This is manifested in a deviation of leaf development during the growing season. It is shown that leaf asymmetry indicators can characterize the state of birch trees (*Betula pendula* Roth) in urban conditions. The need to monitor the state of the stands and the timely detection of violations and changes in individual trees' shape is associated with the development of measures for the shelves' care and the reconstruction of the frames.

6. Acknowledgments
The studies were carried out as part of the program of the Scientific and Educational Center Dendroecology and Environmental Management and using the equipment of the Center for Collective Use Agidel of the Ufa Federal Research Center of the Russian Academy of Sciences.

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