The State of the Ash-Leaved Maple (*Acer negundo* L.) in the Barnaul Ribbon Pine Forest

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Abstract. Ash-leaved maple is one of the most aggressive alien species in most Russian regions. It was first brought to the Altai Krai in 1933. For a long time, maple had been used in the urban and village greenery planting and tree belt areas. Nowadays, it is actively settling along riverbanks, roadsides, abandoned lands, etc. Ash-leaved maple is a danger as a transformer species, preventing the pine’s reproduction in the unique natural communities – ribbon pine forests. We studied the state of the *Acer negundo* L. populations as a transformer species in the Barnaul ribbon pine forest. The maple population status was assessed by the transect method at the selected registration sites. The age of plants was determined by the method of T. A. Rabotnov. The first ordered branches were used for a more detailed characterization of the maple populations. The introduction of maples into the *Pinus sylvestris* L. communities is associated with a significant anthropogenic impact on the natural communities of the ribbon pine forest. There are pure maple communities formed in some places in the northern part of the ribbon pine forest. Throughout the Barnaul ribbon pine forest, the maple populations are normal and invasive only in the south part. The first-ordered maple branches in the southern part of the ribbon pine forest have signs of apex change associated with adverse ecological factors. The development indicators of maple trees along the entire ribbon pine forest were evaluated for the first time. The results indicate the high adaptability of maple to various ecological factors.

Keywords: *Acer negundo* L. · Transformer species · Transect method · Populations · Development indicators · Tree cover

1. Introduction

The ash-leaved maple (*Acer negundo* L.) occupies the leading place among the aggressive alien species in most Russian regions. It was first brought to the Altai Krai in 1933. Maple populates disturbed habitats (wastelands, roadsides, slopes of railways, yards, etc.) and invades native communities. The degradation processes are currently observed in unique ribbon pine forests due to path and road networks and cuttings. These cases contribute to the penetration of maple into the ribbon pine forests. The ash-leaved maple begins expanding from the forest edge and actively penetrates the small and recreationally weakened forest areas. The ash-leaved maple’s aggressiveness, combined with its shade endurance and ability to withstand high recreational loads, suppresses the natural reproduction of native forest-forming species [12, 13].

The forests’ fragmentation by roads, railways, and paths, which serve as particular corridors for the distribution of two-winged achenes of maple, is one of the conditions for a successful maple invasion into the forests. This aspect of a successful introduction of invasive species into the woods was
pointed out by A. P. Gusev [5]. *Acer negundo* can quickly form multilayered thickets with a high canopy density, which prevents the reproduction of native plant species [7].

The physiologically active substances in the soil under the crown of *A. negundo* act mainly as growth inhibitors and may affect the formation of vegetation in the under-tree space [4]. From the age of 7 (1–6), *Acer negundo* L. gives self-seeding near and far from mother plants (from 5 to 15–20 plants per m²), forms abundant perennials, and root shoots [10].

2. Materials and Methods

The data on the absolute age of the invasive *Acer negundo* transformer species of different ontogenetic groups and vitality provides valuable additional information that allows us to address the sustainability and periodicity of generational changes. The assessment of the coenocytic structure states of the *Acer negundo* populations was carried out at the outlined registration sites and laid transects. The ontogenetic stage and the level of vitality were determined at each site of maple. The determination of these parameters for the plants of early ontogenetic stages (seedlings, juvenile, and juvenile-to-adult phase of the first subgroup) was performed on sites of 100 m².

According to the works of M. V. Kostina [6, 7], the ontogenetic state of maple includes three periods:

- Pre-reproductive period. It is divided into four ontogenetic stages: (1) seedlings (pl), (2) juvenile plants (j), (3) immature plants (im), (4) late vegetative plants (v).
- Reproductive period. It is divided into three ontogenetic stages: (1) young reproductive trees (g1), (2) middle-aged reproductive trees (g2), (3) old reproductive trees (g3).
- Post-reproductive (senile) period – Senile trees (s).

To characterize the vitality composition of populations by the method of Yu. A. Zlobin [14, 15], we distinguished three levels of vitality: normal, reduced, and low.

The assessment of the absolute age of *Acer negundo* was carried out by cutting the trunks (at the height of 1.3 m) and the trunks’ base in the undergrowth individuals. Based on the obtained data, it is possible to determine an individual population according to the ontogenetic state (invasive, normal, regressive).

1. *Invasive type* – the population consists only of pre-reproductive plants; occasionally, young generative plants can occur as an exception;
2. *Standard type* – the spectrum consists of plants of all ontogenetic groups; the range is left-sided;
3. *Regressive type* – the spectrum consists only of senile plants; occasionally, old generative plants can occur as an exception.

The *invasive populations*, i.e., communities with the invasive type of ontogenetic spectrum, are in the nascent stage. Depending on the ontogenetic composition, the abundance of the plants, and the ecological and coenobitic conditions, there is a more or less possible chance for transformation into normal *populations*, i.e., capable of long spontaneous self-maintenance in seeds and vegetative way. The *regressive people* are at the stage of extinction because old plants lose their seed production ability, such conditions in the community inhibit the development of the undergrowth [9].

In the morphological analysis of *Acer negundo*, we used the system developed by I. G. Serebryakov [11]. The natural regeneration registration was carried out by continuous recounting in an area of 100 m²: regeneration of up to 10 plants is considered single, up to 20 – moderate, more than 20 – plentiful. For each studied plant of *Acer negundo*, the age state was determined by the T. A. Rabotnov method [9] with the A. A. Chistyakova additions for woody plants [3] using first-order model branches, which were cut and analyzed in detail by several parameters.

The abundance of flowering and seed production was assessed by a one-to-five scale developed by V. G. Privateer. This scale was developed based on the Swedish school and is recommended for use in forestry: 0 – seed production failure, 1 – abysmal seed production, 2 – low seed production, 3 – medium seed production, 4 – good seed production, 5 – excellent seed production [8].
3. Results and Discussion

In the ash-leaved maple population of the forest near the Kirova settlement (table 1), the trees’ average height was 2.6 m, the age was 3–4 years (determined by the diameter of the shoot and the amount of growth). The distance to the first branching was only 15 cm. Vitality did not exceed two points, i.e., all maple plants were of reduced spirit. They grew and developed more slowly than the plants of average energy. Their sizes in each ontogenetic stage were smaller than the dimensions of the plants of normal vitality. Out of three, two plants were female, and one plant was male. Two- or three-trunked trees prevailed, which also testified to reduced life.

The maple in the forest near the Bulygino settlement reached an average height of 3.7 m, being about three years of age. The first branching began at the height of 48.3 cm. The vitality of the maple plants was high. There were two trees in a reproductive state (male and female); four trees failed to determine the gender. A large ten-year-old tree of up to 6.5 m high was likely male. In general, in the forests of the urban area, the maple population can be classified as usual since there were all age-related maple states (table 1). Figure 1 shows the map of the study area in the Altai Krai.

Male maples are predominant in the maple population on the outskirts of the Mokhnatushka village. These trees are prevalently located in the center of the thicket. Female trees grow on the periphery. The number of female plants is three times lower than that of the males. All trees from the studied population belong to the reproductive ones (table 1).

Table 1. The development of the ash-leaved maple in the Barnaul ribbon pine forest.

| Height, m | Age, years | Trunk diameter, cm | Distance to the first branching site, cm | The abundance of flowering and seed production | Vitality level | Ontogenetic state |
|-----------|------------|--------------------|-----------------------------------------|-----------------------------------------------|---------------|------------------|
| Kirova settlement (1***) |
| 2.6* (2.5–3.0) | 3.4 (2.0–6.5) | 1.2 (0.5–2.2) | 15.0 (10–20) | 1-0 | 2 | g1 male 2 female |
| Bulygino settlement (1) |
| 3.7 (6.5–2.3) | 3.1 (10.3–0.5) | 1.05 (0.5–3.5) | 48.3 (15–80) | 2-0 | 2-1 | 4 im 1 v g2 female, g1 male |
| The outskirts of the Mokhnatushka village (1) |
| 11 (4.0–20.0) | 16.1 (36.3–5.7) | 5.6 (2.2–14.0) | 62.5 (20–150) | 0–3 | 1–2 | 7g1 1 g2 1 female:3 male |
| The outskirts of the Kostin Log village, Novichikhinsky district (2) |
| 20.1 (3.0–30.0) | 12.8 (25.6–4.4) | 5.6 (1.4–54.1) | 67.7 (0–150) | 1–4 | 1–3 | 5 male g1 1 male g2 1 female g2 8 im 4 female g1 v |
| The outskirts of the Krugloev village, Uglovsky district (3) |
| 5.0 (2.5–6.5) | 11.4 (6.8–19.0) | 5.0 (3.0–8.6) | 65.4 (38–104) | 0 | 2 | 5 v 1 im |

Note: * average value (in parentheses are indicators of the range of variation).
** – long-term monitoring sites.
Source: Compiled by the authors.
Figure 1. The map of the study area in the territory of the Altai Krai. Source: Compiled by the authors.

1 – places of descriptions, 2 – forest type of vegetation. Numbers 1, 2, and 3 indicate long-term monitoring sites.

There were two female trees with green seeds. One of them preserved the last year’s two-winged achenes. Half of all maple trees in this population had 2–4 trunks. The average height of the plants is 11 m (4–20). The vitality level was 1–2 points, i.e., some plants show a slight decrease in vitality. On average, the branching began at the height of 62.5 (20–150) cm.

In general, ash-leaved maple populations in the urban forest and the immediate outskirts of the settlements (Mokhnatushka village) can be attributed to the normal and fully formed ones with a fairly high vitality level and the presence of plants of all ages. However, maple often has a system of 2–4 trunks. Single-trunked trees were also found in a ratio of about 1:1. Thus, the spectrum of age-related states of maple in this population looks as follows: v – 6.3%; im – 18.8; g1 – 68.8%; g2 – 6.3%.

Maple plants in the Costin Log population (table 1) are 20 (3–30) meters high. The height of the immature plants did not exceed 7 m. The trees in a reproductive state were much higher. A multi-stemmed male maple tree with a height of about 30 m is located on the discussed territory. There were nine immature, one late vegetative, and six male and female trees out of 22 plants. The female plants bore seeds; there were occasional dry inflorescences on the male trees. The plants of two vitality points prevailed, i.e., the ones having leaves damage and dry branches. There was a lower number of plants with the first level of vitality. There were mainly reproductive and immature plants.

Excessive humidity was often observed on this soil profile in the plant communities, which contributed to the active growth of maple trees. Thus, the spectrum of age-related states of maple in this population looks as follows: v – 4.5%; im – 41%; g1 – 45.5%; g2 – 4.5%; g3 – 4.5%. This is the population of a familiar type with the shift to the right.

In the Krugloye village (table 1), all measured maple trees vegetated; their average height was 5.0 m. The age of the trees was 11.4 (6.8–19.0) years. The vital state was mainly at the second level since some of the studied branches were dry. All five plants did not reach a reproductive state. Therefore, this population may be invasive.

The first-order branches were cut off from immature maple plants at a height that did not exceed 3–4 m. The following parameters evaluated such components as the entire length of the branch (cm), the size of the annual growth (cm), the weight of air-dried leaves and shoots, the diameter at the base of the shoot, the diameter of a young part (cm), the number of leaves, and the age of the branch.
Table 2. The parameters of the development of first-order branches in maple trees in the plant communities of the Barnaul ribbon pine forest.

| Statistics Parameters | Mean, the error of the mean | Coefficient of variation, % |
|-----------------------|-----------------------------|-----------------------------|
| The entire length of the first ordered branch, cm | 124.6±6.8 | 33.56 |
| Length of growth on the branch of the first order, cm | 14.1±2.2 | 97.4 |
| Base diameter on the branch of the first order, cm | 1.1±0.06 | 31.9 |
| The diameter of young growth, cm | 0.4±0.03 | 44.9 |
| Weight of dry leaves, g | 4.0±0.5 | 75.9 |
| Weight of dry shoots, g | 8.4±1.2 | 91.0 |
| The number of all leaves, pcs. | 93.0±10.1 | 67.0 |
| The number of leaves in the young growth of first-order branches, pcs. | 6.0±0.9 | 80.7 |

*Source:* Compiled by the authors.

The length of the first ordered branch of the ash-leaved maple in the Barnaul ribbon pine forest averages to 124.6 cm (table 2). However, the fluctuations were very significant for all 17 sampling points from north to south. The coefficient of variation was 33.5%. The maximum branch length exceeded 200 cm. The annual growth on these branches (figure 2) averaged 14.1 cm. The variation coefficient reached almost 100% due to the large variability of the growth length and its complete absence.

![Figure 2](image1.png) **Figure 2.** The length of the first ordered branch of ash-leaved maple in the Barnaul ribbon pine forest conditions from north to south, cm. *Source:* Compiled by the authors.

![Figure 3](image2.png) **Figure 3.** The diameter of the first ordered branch of ash-leaved maple in the Barnaul ribbon pine forest conditions from north to south, cm. *Source:* Compiled by the authors.
Figure 4. The weight of dry leaves and the first ordered branches of ash-leaved maple in the conditions of the Barnaul ribbon pine forest from north to south, g (air-dried). Source: Compiled by the authors.

The diameter of the first ordered branch at its base averaged 1.1 cm. Nevertheless, there were several branches with the diameter at the bottom, reaching almost 2 cm. The coefficient of variation is 31.9% (table 2).

The diameter of the young growth averaged to 0.4 mm. However, according to figure 3, it could reach almost 0.8 cm in optimal growth conditions.

The weight of dry leaves of the first ordered branches (figure 4) in most plants did not exceed 5 g; the coefficient of variation did not exceed 75.9%. The air-dry weight of the first-order branches averaged 9.1 g. The coefficient of variation exceeded 90% (table 2).

Figure 6. Schematic structure of the first ordered branch of the ash-leaved maple tree:

a) Novichikhinsky district, 6 km south-west of the Novichikha village, green moss–reed grass pine forest, branch length 106 cm;

b) Novichikhinsky district, Melnikovo village, graminaceous–sedge pine forest, branch length 111 cm. Source: Compiled by the authors.

Figure 7. Schematic structure of the first ordered branch of the ash-leaved maple tree:

a) Uglovsky district, sagebrush–junegrass pine forest, branch length 80 cm;

b) Barnaul, 0.4 km from Bulygino, pine forest, wild strawberry–reed grass, branch length 122 cm. Source: Compiled by the authors.
The number of leaves on the maple branches averaged 93.0, with the coefficient of variation equal to 67.0%. The number of leaves was significantly higher (200–220) (figure 5). The number of leaves on the current year shoots averaged to six. Nevertheless, in some projections, it equaled 2–8. Thus, we can note that the main development indicators of first-order branches are not relatively consistent with the state of the maples in the Barnaul ribbon pine forest. As an example, we note that the skeletal branches of the first order often bear traces of apex changes with reduced vitality, which is visible in the maple trees of the Uglovsky district. In this case, the maple suffers from frost (figures 8–9). The dependence is associated with the specific environmental and climatic conditions of the maple plant habitats.

Thus, when moving from north to south along the Barnaul ribbon pine forest, the maple’s abundance and its role in forming the lower tree layer decrease. Maple populations are typical throughout the Barnaul ribbon pine forest, except for the extreme south (Uglovsky district), where the maple population is invasive.

In the outskirts of Barnaul, maple populations are represented in communities at various stages of succession associated with the penetration of this invasive species. We observed the final stages of the series in (1) the outskirts of the Yuzhny tract and the Lentochny Bor highway intersection and in (2) the Yuzhny settlement at the junction of Belinsky and Dzerzhinsky streets, where the maple – equisetum – sweetroot and maple – dead cover associations were formed.

Some forest communities in the outskirts of the Kостин Log and Melnikovo villages, Novichikhinsky district, did not have reproductive maple trees but had many young plants, which indicates a further southwards expansion of the maple.

A high coefficient of variation rate in maple populations by the degree of its development, including the development parameters of the first-order branches, indicates the remarkable plasticity of the maple and its adaptability to various ecological factors.

The most unfavorable ecological and climatic conditions for maple invasion were noted in the southern part of the Barnaul ribbon pine forest. This was reflected in the structure of the first ordered branches – the death of the apical meristem and subsequent repeated changes of the top.

The active settlement of ash-leaved maple occurs throughout the Barnaul ribbon pine forest. However, it occurs with different frequency and abundance in different parts marked with various ecological conditions and anthropogenic transformation of initial communities. During the observation period, pure maple communities appeared in different parts of the ribbon pine forest in 5.8 ha.
Considering the information from all forest districts over ten years, the maple and mixed forest area with the participation of ash-leaved maple in the Barnaul ribbon pine forest has increased almost six times (from 54.1 ha to 311.1 ha).

4. Conclusion
The following factors determine the phytocenotic conditions of the ash-leaved maple introduction in the Barnaul ribbon pine forest:

1. The anthropogenic transformation of phytocenoses in the ribbon pine forest. Maple invasion is facilitated by cutting, littering, mechanical destruction of soil and vegetation cover, and the change of light and mineral regimes. The plant species usual for initial communities disappear. Pure maple communities are formed in some habitats, prevalently in depression. The pine forest, which is not exposed to the pronounced impact, creates its special hydroclimate, more or less restricting the penetration of alien plants.

2. An extensive network of roads in the ribbon pine forest becomes a corridor, especially near cities and villages. The invasive transformer species Acer negundo moves from populated areas and forest borders to clearings. There, depending on the degree of soil and vegetation covering disturbance, and the degree of habitat humidity, it becomes a dominant or an edifier of an invasive or transformed community, changing the course of natural and anthropogenic restoration succession in the ribbon pine forests of the Altai Krai.

3. In the southern part of the Barnaul ribbon pine forest in the dry steppe area, in the most unfavorable conditions for maple invasion, Acer negundo develops in deep roadside ditches with accumulated water or in the road slopes close to the edge of the shrub swamps. Additionally, freezing of the branches and the apex change effect are observed. In most cases, the maple is represented by a multi-stemmed life form.

The biological and structural assessment of the Acer negundo populations formed in the ribbon pine forests of the Altai Krai allowed to point out the following features. From north to south along the Barnaul ribbon pine forest, the maple’s abundance and role in forming the lower tree layer decrease. The maple populations almost throughout the whole Barnaul ribbon pine forest are normal, except for the extreme south (Uglovsky district), where they are invasive.

It was concluded that in the outskirts of Barnaul, maple populations are represented in communities at various stages of succession associated with the penetration of this invasive species. We observed the final stages of the series in (1) the outskirts of the Yuzhny tract and the Lentochny Bor highway intersection and (2) in the Yuzhny settlement at the junction of Belinsky and Dzerzhinsky streets, where the maple – equisetum – sweetroot and the maple – dead cover associations were formed.

Some forest communities in the outskirts of the Kostin Log and Melnikovo villages, Novichikhinsky district, did not have reproductive maple trees but had a significant number of young plants in the undergrowth, which indicates a further southwards expansion of the maple.

A high coefficient of variation rate in the maple population with its development, including the parameters of the first-order branches, indicates this remarkable plasticity of the maple and its adaptability to various ecological factors.

The most unfavorable ecological and climatic conditions for maple invasion were noted in the southern part of the Barnaul ribbon pine forest, which was reflected in a particular structure of the first-ordered branches: the death of the apical meristem and subsequent repeated apex changes.

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References
[1] Borisova E A 2010 Features of the invasive plant species spread throughout the territory Russian Journal of Biological Invasions 4 pp 2-9
[2] Borisova E A 2016 Invasions of woody plants into the natural communities of the Upper Volga region
Russian Journal of Biological Invasions 1 pp 24-30

[3] Chistyakova A A 1988 Life forms and their spectra as indicators of a species’ state in a census (by the example of broad-leaved trees) Bull. MOIP. Sep. Biol. 93(6) pp 93-105

[4] Eremenko Yu A 2014 Allelopathic activity of invasive tree species Russian Journal of Biological Invasions 2 pp 33-39

[5] Gusev A P 2016 Alien transformer species as a reason for blocking restoration processes (on the example of the southeast of Belarus Russian Journal of Applied Ecology 3 pp 10-14

[6] Kostina M V, Minkova N O, and Yasinskaya O I 2013 On the biology of ash-leaved maple in the green spaces of Moscow Russian Journal of Biological Invasions 4 pp 32-43

[7] Kostina M V, Yasinskaya O I, Barabanshchikova N S, and Orlyuk F A 2015 To the question of the invasion of ash-leaved maple (Acer negundo L.) in the Moscow Region forests Russian Journal of Biological Invasions 4 72-80

[8] Lavrenko E M Ed. 1964 Field geobotany (Moscow, USSR: Publishing house of the Academy of Sciences of the USSR)

[9] Rabotnov T A 1987 Experimental phytocenology (Moscow, USSR: Publishing House of Moscow State University)

[10] Saxonov S V, Rakov N S, Vasyukov V M, and Senator S A 2017 Alien plants in forest communities of the Middle Volga: Methods of dissemination and degree of naturalization Samara Scientific Bulletin 6(2) pp 78-83

[11] Serebryakov I G 1962 Ecological morphology of plants (Moscow, USSR: Higher School)

[12] Vasyukov M M, and Theodoronsky V S 2015 Some issues of the formation of green spaces during the establishment of ecological paths (protected areas “Tushinskaya Chasha,” “River Kotlovka,” Moscow). Vestnik MGUL - Lesnoy Vestnik 5 pp 113-119

[13] Zhukov R S 2020 Ash-leaved maple in the urban forests of Moscow Dendrology and tree care in an urban environment Available at http://econf.rae.ru/article/9786

[14] Zlobin Yu A 1984 Coenopopulation analysis in phytocenology (Vladivostok, USSR: Publishing House of the Academy of Sciences of the USSR)

[15] Zlobin Yu A 1989 Principles and methods for studying coenobitic plant populations (Kazan, USSR: KSU Publishing House)