Vitality structure of *Acer negundo* populations in an urban environment

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Abstract. The results of a comparative analysis of the vitality structure of *Acer negundo* populations during ontogenetic development in an urban environment are presented. The vitality structure of *A. negundo* populations is changing from prosperous to depressive, with the changing living condition of individuals and the quality of populations in urban conditions. The quality index of *A. negundo* populations was in the amplitude from 0.5 to 0.166 along the urbanization gradient. High plasticity and variability of *A. negundo* in combination with the dynamic vitality structure on the background of anthropogenic impacts provide active colonization of this invasive species in the city.

1. Introduction

The expansion of invasive species is currently a global ecological problem [1, 2, 3]. An urban environment provides invasive species with maximum opportunities due to the high degree of its disorderliness, unoccupied ecological niches, as well as the availability of possible regeneration niches. The intensity of the invasion process in cities increases due to the biological characteristics of the plants, which make up the invasiveness complex of a species. The basis of the species invasiveness syndrome is the parameters of the reproductive sphere of plants (type of pollination, seed productivity), peculiarities of vegetative reproduction, life form, plasticity and variability, ecological-cenotic strategy and attitude to phytophages [3].

*Acer negundo* L. is one of the widespread urban species included in the “blacklist” of invasive plants in Russia, whose natural range is in North America. The plant penetrated Europe in the 17th century, and by the end of the 19th century spread in Russia. In 1950-1960 *A. negundo* was widely cultivated in the cities of the Russian Far East, where it quickly naturalized.

In an urban environment, *A. negundo* forms self-renewing introductory populations. The combination of high ecological tolerance, pronounced allelopathic properties, and the peculiarities of mycorrhiza formation give *A. negundo* competitive advantages over local species. The ability to spread quickly is associated with abundant seed production, high germination of seeds, their spread over relatively long distances, as well as the ability to quickly recover from damage due to the germination of dormant buds [2]. The reasons for its successful invasion in an urban environment is its active regeneration, both under its own canopy and under the canopy of other trees, which allows *A. negundo* to maintain its leadership in urban plantings.
The successful growth of *A. negundo* throughout the city indicates a high invasive potential of the species, which is realized already at the early stages of development. The distribution of *A. negundo* in urban cenoses, due to its high seed productivity and seed germination, allows the species to quickly acclimatize to free ecological niches.

The aim of the study was to study the life state of *A. negundo* and do a comparative analysis of the vitality structure of its populations during ontogenesis in different conditions of an urbanized environment (for example, Khabarovsk) for organizing population monitoring.

2. Object and Methods
The determination of the relative life state of *A. negundo* in different ontogenetic states was carried out according to the following categories: 1 – healthy tree without signs of weakening (the highest class of vitality); 2 – weakened, reduction in crown density by 30% (intermediate class of vitality); 3 – strongly weakened, with signs of oppression, a decrease in density by 60% (the lowest class of vitality); 4 – dead wood (dead). The assessment of the vital state of adult plants was carried out with continuous counting in plantings in different urban ecotopes. For plants of an immature ontogenetic state, the size of counting plots was 1 m², which were laid in four replicates along the gradient of ecotopes. The names of vascular plants, the surnames of the authors of taxa are given in accordance with the Plant List database.

The gradient of urbanized ecotopes was the following: 1 – parks; 2 – boulevards; 3 – sections along highways; 4 – sections in the right-of-way of the main city roads; 5 – in residential areas of the city (low-rise building area).

The vitality structure of *A. negundo* populations was studied within the framework of the population-demographic approach [2]. The assessment of the vital state of local populations of *A. negundo* was carried out using the integral indicator of the quality of populations

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Q = \frac{1}{2} (a + b) < c
\]

estimated by the ratio of individuals of the lowest (c), intermediate (b), and highest (a) vitality classes, the quality of populations (Q). 1338 specimen of *A. negundo* were analyzed from 5 urban ecotopes in different ontogenetic states. All received materials were subjected to statistical analysis using special software within the packages Excel, Statistica (version 7) and Vital [4].

3. Research results and their discussion
The greening system of Khabarovsky was formed over more than a century and a half of the city’s development. In the greening of Far Eastern settlements, *A. negundo* was actively planted in 1950 – 1960; therefore, at present, the species is one of the most widespread urban plants. The practice of preferring fast-growing tree species led to the fact that *A. negundo*, together with introduced poplar species, was widely used as an ornamental plant in landscaping. Until now, five tree species dominate in the structure of Khabarovsky’s landscaping: *Populus simonii Carrière, Populus balsamifera L., Ulmus pumila L., Fraxinus mandshurica Rupe.* and *A. negundo*. Rapid growth, high dust-holding capacity of the species, undemanding soil conditions and the availability of planting material determined the massive use of *A. negundo* in green building. *A. negundo* was most actively used in the greening of city streets, boulevards, parks, courtyards, and sanitary protection zones of enterprises. The species is common in intra-block landscaping, often found in intra-urban recreational forest park zones, in old gardens and small parks. In the absence of competition with other species, *A. negundo* actively assimilates weedy places, dumps, wastelands and residential areas. The species integrates into cenotically open communities of parks, penetrates into plant groups in damaged technogenic areas, where the number of its local populations increases, and competes with seed undergrowth of *F. mandshurica* and *U. pumila* along roadsides, tramways, and railways.

Within the secondary range, the species is highly invasive and capable of naturalization, showing a tendency to dispersal [1]. *A. negundo* has a wide range of adaptations to habitats due to its high tolerance to soil moisture deficiency and soil fertility, is moderately resistant to flooding, has a high growth rate, is light-loving, unpretentious to soil conditions, adapted to low temperatures [2], which makes possible

\(^1\) See http://www.theplantlist.org (accessed: 12.02.2021).
an active expansion of its range. In cities, the plant actively populates parks, wastelands, abandoned arable fields, roadsides, railroad slopes, landfills; seed germination is often observed in accumulations of fine earth on sheds and roofs of buildings.

The participation of A. negundo in the greening of Khabarovsk city boulevards varies from 8.1 to 10.6% of the total number of trees; in the structure of linear plantations of highways, its share ranges from 4.2 to 5.4%, slightly decreasing at the periphery of the city, and along the main drives in the city its participation increases to 12.3%. In the past, the plant was actively used for intra-block gardening; at present, on average, up to 13% of trees are represented by A. negundo. In the park cenoses of Khabarovsk, A. negundo is among the dominant species along with P. simonii, P. balsamifera, U. pumila, F. mandshurica and accounts for about 7.11% of all growing woody plants. Moreover, there has been a steady increase in its participation in parks. For example, in the period from 2006 to 2016 in the Dynamo Park (a local specially protected natural area of Khabarovsk), the number of A. negundo increased by 1.5 times due to the active natural reproduction of the population, where the share of young plants of seed origin was about 54.0%.

The plant is embedded in urban phytocenoses and plant groups in parks, being a weed among street plantings, and forms spontaneous thickets in wastelands, dumps, abandoned roads and man-made areas. The highest density of growth of self-renewing populations of A. negundo was noted on the slopes of highways, where the number of seedlings and young plants was 100 pcs/m². In urban parks (areas without systematic mowing), active natural regeneration of A. negundo is also observed, being on average up to 75 pcs/m². On the railroad slopes with gravelly flooring on the technical right-of-way, almost pure thickets of the species are formed, and the density of its populations is 40 pcs/m². In residential areas of the city, where ruderal communities are formed on unkempt lawns with the participation of Poa annua L., Festuca pratensis L., Bromopsis inermis (Leyss.) Holub, Achillea asiatica Serg., Polygonum aviculare L., T. officinale, the density of A. negundo is on average up to 20 pc/m².

On the territory of cities, there are many free ecological niches, but their occupation requires special properties from plants – a high plasticity and variability, i.e. the ability to grow in adverse conditions. Plant survival in such an unstable environment, where abiotic environmental factors and stresses are highlighted, is possible on the basis of effective ontogenetic adaptations. The totality of private adaptations and species-level adaptive complexes constitutes a strategy for plant protection, ensuring the survival of their populations under the influence of urbanization. Phenotypic plasticity is the main component of success of the invasion of species due to a high adaptability of plants in comparison with local species and it determines the differentiation of the population structure of a species.

The structure of the species population and its change are indicators of plant resistance under stressful environmental conditions [5]. Urbanization leads to the differentiation of the population structure and changes the ratio of plants of different vitality groups. The division of the continuum of plants of different vitality [4] into three size classes (higher, intermediate, lower) also showed a high informative value of this approach for studying the responses in invasive plants of other life forms to the effect of a complex urbanized gradient.

The assessment of the vital state of individual specimen made it possible to identify the vitality structure of A. negundo populations at each stage of the complex urbanized gradient in the course of ontogenesis. The vitality composition of introduced A. negundo in different ontogenetic states turned out to be different and was influenced by ecological-cenotic factors. The quality index of A. negundo populations ranged from 0.5 to 0.166, varying along the gradient of urban ecotopes by a factor of 2.9.

The species has high indicators of vitality in different ecological and cenotic conditions of the city. At the early stages of ontogenetic development [im], prosperous populations of A. negundo were formed in all variants of the urbanized gradient; the population quality index varied from 0.500 to 0.381. The prosperous type of populations remained in the immature state for all populations of the studied species along the gradient of ecotopes, with the exception of the A. negundo population in the park. Here, under conditions of strong shading and competition with other species, a depressive type of population was noted, which persisted, starting from the virginal to the old generative ontogenetic state. In the authors’
opinion, this indicates a high plasticity of the species, a combination of different life strategies, depending on the conditions of the habitat.

Under anthropogenic loads (linear main tree plantations) in virginal (Q = 0.379) and young generative states, the prosperous type of *A. negundo* populations (Q = 0.388) is preserved, while in the middle-aged generative state, the vitality of populations decreased (Q = 0.333), and the equilibrium type populations were formed. The depressive type populations of *A. negundo* in the old generative state were of low quality (0.167).

The change in the quality of the *A. negundo* population in plantings along the main city drives is generally similar to the pattern of changes in the vitality of the *A. negundo* population in main plantings. The population quality index changed as follows: in the immature state being 0.422 (prosperous type) – in the young generative state being 0.352 (prosperous type) – in the mature generative state being 0.333 (equilibrium type) – in the old generative state being 0.166 (depressive type).

In the urban greening of the city, where the share of recreational loads on vegetation is high, the quality of *A. negundo* population rapidly decreases with age. In the immature and young generative states, the populations retain a relatively high vital state, the type of their populations belonged to the prosperous type (population quality index 0.472 and 0.374, respectively); at later stages of ontogenesis, depressive populations are formed (0.285 and 0.3, respectively).

On city boulevards, under conditions of single and group growth, *A. negundo* shows high characteristics of vitality. From immature to mature generative state, the populations of the species belonged to the prosperous type of vitality and showed high quality. At the later stages of ontogenesis (old generative), the depressive populations of the species were formed.

Of the five studied ecotopic populations of *A. negundo*, three (on boulevards, main plantings, and plantings along the main city drives), in accordance with the results of a vitality analysis, can be considered as existing under conditions of relative ecological optimum. In intra-block plantings and in conditions of shading in the park, the trees had a depressed appearance (the crowns being sparse, foliage decreasing, inclined forms of trees), the quality of their population decreased.

In general, the species showed a high level of adaptation to the urbanized environment, maintaining the level of plasticity and variability in ontogenesis in a wide range, which helps it to actively maintain its positions in the urban environment and stably populate new territories.

4. Conclusion
Under the conditions of increasing anthropogenic load, it becomes urgent to study the adaptations of plants of various life forms to the conditions of an urbanized environment. Invasive plants, showing high stress-resistant properties, reacted to the deterioration of growing conditions by changing the vitality structure of the population during ontogenesis. The quality index of *A. negundo* populations ranged from 0.5 to 0.166, varying along the urbanization gradient by a factor of 2.9. According to the vitality analysis, the populations of *A. negundo* growing on city boulevards, in main plantings and plantings along the main city drives can be considered as existing under conditions of an ecological optimum. The population research methods should be recommended for inclusion in programs for monitoring the state of vegetation in urbanized areas.

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