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INVASIVE WOODY PLANT SPECIES ON CONSTRUCTION SITES IN RUSSIAN CITIES: SCALE, REGIONAL FEATURES, AND ECONOMIC ASPECTS OF COMPENSATION PAYMENTS

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ИНВАЗИОННЫЕ ВИДЫ ДРЕВЕСНЫХ РАСТЕНИЙ НА СТРОИТЕЛЬНЫХ ПЛОЩАДКАХ ГОРОДОВ РОССИИ: МАСШТАБЫ, РЕГИОНАЛЬНЫЕ ОСОБЕННОСТИ И ЭКОНОМИЧЕСКИЕ АСПЕКТЫ КОМПЕНСАЦИОННЫХ ВЫПЛАТ

Abstract. Based on tree-level data from engineering-environmental surveys at 9 construction sites in four Russian cities (Ufa, Dmitrov, Moscow, Birobidzhan), the distribution of invasive woody plant species was analyzed. A total of 27.418 trees of 57 species were recorded. The proportion of invasive species ranged from 0% in Birobidzhan to 46.8% in Moscow. The absolute dominant among invasives is *Acer negundo* L. (5.751 individuals, 21% of all trees). Regression analysis of the log-transformed compensation cost (calculated according to regional regulatory documents) showed that, all else being equal (diameter, height, condition, city), invasive trees have, on average, a 9.9% lower cost ($p < 0.001$), which is explained by the reduced species coefficients for box-elder maple already embedded in the existing valuation methods. However, this reduction is insufficient to cover the costs of subsequent invasion control and monitoring. For *A. negundo* L., significant inter-city differences were found: the highest proportion (9.9% of all trees) and the lowest average cost (1,106 RUB) were recorded in Ufa, due to a high number of small-diameter individuals on disturbed lands. In Moscow and Dmitrov, despite lower proportions, the average cost of invasive trees is much higher (6.836 and 6.085 RUB, respectively) due to larger tree sizes and better condition. Invasive herbaceous species (*Heracleum sosnowskyi* Manden., *Solidago Canadensis* L., *Ambrosia artemisiifolia* L., etc.) were also recorded at the survey sites, requiring special attention during post-project monitoring. We propose changes to the regulatory framework: introduction of an additional reduction factor (0.1–0.3) for invasive species when calculating compensation costs, mandatory inclusion of post-project monitoring (at least 5 years) with removal of invasive

Аннотация. На основе данных подеревных учетов, выполненных в ходе инженерно-экологических изысканий на 9 строительных объектах в четырёх городах России (Уфа, Дмитров, Москва, Биробиджан), проведён анализ распространения инвазионных видов древесных растений. Всего учтено 27 418 деревьев 57 видов. Установлено, что доля инвазионных видов варьирует от 0% в Биробиджане до 46,8% в Москве. Абсолютным доминантом среди инвазионтов является *Acer negundo* L. (5751 особь, 21% от общего числа деревьев). С помощью регрессионного анализа логарифма компенсационной стоимости (рассчитанной по региональным нормативным документам) показано, что при равных таксационных показателях (диаметр, высота, состояние, город) инвазионные деревья имеют в среднем на 9,9% более низкую стоимость (p<0,001), что объясняется заложенными в методиках пониженными породными коэффициентами для клёна ясенелистного. При этом существующее снижение недостаточно для покрытия расходов на последующую борьбу с инвазией и мониторинг. Для *A. negundo* L. выявлены существенные межгородские различия: максимальная доля (9,9% от всех деревьев) и минимальная средняя стоимость (1106 руб.) зафиксированы в Уфе, что связано с высокой долей мелкомерных особей на нарушенных землях. В Москве и Дмитрове, несмотря на меньшую долю, средняя стоимость инвазионных деревьев значительно выше (6836 и 6085 руб. соответственно) за счёт более крупных размеров и лучшего состояния. На участках изысканий зафиксированы также инвазионные травянистые виды (борщевик Сосновского, золотарник канадский, амброзия полыннолистная и др.), требующие особого внимания при послепроектном мониторинге. Предложены изменения в нормативную базу: введение понижающего коэффициента (0,1–0,3) для инвазионных видов при расчёте компенсационной стоимости, обязательное включение в проекты

seedlings, and priority use of native fast-growing species in compensatory plantings on reclaimed sites.
Keywords: invasive species, *Acer negundo*, urban ecosystems, engineering and environmental surveys, compensation cost, urban forest management.
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послепроектного мониторинга (не менее 5 лет) с удалением самосева инвазионтов и приоритетное использование аборигенных быстрорастущих пород в компенсационных посадках.
Ключевые слова: инвазионные виды, *Acer negundo*, урбоэкосистемы, инженерно-экологические изыскания, компенсационная стоимость, управление городскими насаждениями.
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Introduction

Invasive woody plant species represent a pressing problem in urban green space management [2; 11]. The most aggressive alien species that has spread widely across disturbed habitats in the European part of Russia is box-elder maple *Acer negundo* L. [13; 15; 16]. Its high seed production, rapid growth, and tolerance to pollution allow it to dominate synanthropic communities, displace native species, and transform vegetation cover [9; 16].

Conventional control measures (mechanical removal, chemical treatment) require substantial resources and are often ineffective without a systematic approach [2; 10]. At the same time, large infrastructure projects preceded by engineering-environmental surveys involve complete clearing of woody vegetation within the right-of-way, creating an opportunity for the large-scale elimination of invasive species. To date, however, no comprehensive quantitative estimates have been available on the presence of invasive woody plants at construction sites across different regions of Russia, nor has an analysis been conducted on the economic consequences of their removal under the existing regulatory framework.

In the Russian Federation, the compensation cost for cutting down urban green spaces is calculated according to regional methodologies, which, as a rule, do not differentiate between native and invasive species [1; 8]. Tree-level inventory data contained in engineering-environmental survey reports remain an under-utilized resource for monitoring invasion processes and informing management decisions (Khorun, Martynyuk, 2016).

The aim of this study is to quantitatively characterize the distribution of invasive woody plant species, identify regional features, and assess the economic aspects of compensation payments for their removal, based on tree-level inventories at nine construction sites in four Russian cities (Ufa, Dmitrov, Moscow, Birobidzhan).

Materials and Methods

Study sites. The initial data were obtained during engineering-environmental surveys at nine construction sites located in four cities: Ufa (three sites: Sipailovskaya St., Kuznetsovskii Zaton micro-district, Nizhegorodka micro-district), Dmitrov (two sites: a bridge on Rogachevskaya St., Tatishcheva St.), Moscow (one site: METK), and Birobidzhan (three sites: BUL, a bridge over the Bira River, and an additional plot). The total sample comprised 27,418 trees.

Table 1

Characteristics of the study objects

City	Natural zone	Sites (number)	Right-of-way area, ha	Main land type	Share of disturbed land
Ufa	Forest-steppe	3	~120	Residential, industrial	High
Dmitrov	Mixed forest zone	2	~45	Urban and suburban	High
Moscow	Mixed forest zone	1	~25	Urban	High
Birobidzhan	Broadleaved–Korean pine forests of the Russian Far East	3	~70	Urban, floodplain	Medium

The sites represent typical disturbed urban and suburban territories (highway shoulders, vacant lots, power-line corridors, garage cooperatives, private sector, clear-cuts). These sites cannot be considered representative of the entire territory of the cities; however, they characterize the most typical habitats where invasive species find optimal conditions for expansion.

Field methods. Fieldwork was carried out by the authors in 2020–2025. At each site, a complete inventory of all woody plants with a trunk diameter at breast height (1.3 m) ≥ 8 cm was conducted. For each tree, the following parameters were determined: species identity, trunk diameter (to the nearest 1 cm), height (to the nearest 0.5 m), and condition category (“good”, “satisfactory”, “poor”, “hazardous”). The absence of plant species listed in the Red Data Book of the Republic of Bashkortostan [6] and the federal Red Data Book was also recorded.

Species classification. Invasive status was assigned based on the “Black Data Book of the Flora of Central Russia” [16] and regional “Black Books”, taking into account current data on species distribution [12; 15]. The main invasive species in the sample is *A. negundo* L.; isolated individuals of *Populus alba* L. (3 trees) and *Ulmus pumila* L. (1 tree) were also recorded, which does not affect the general patterns.

Non-woody invasive species. During the surveys, invasive herbaceous plants were recorded at all sites. The most frequent were *Heracleum sosnowskyi* Manden., *Solidago canadensis* L., *Reynoutria sachalinensis* (F.Schmidt) Nakai, *Impatiens glandulifera* Royle, *Echinocystis lobata* (Michx.) Torr. & A.Gray, *Bidens frondosa* L., *Conyza canadensis* (L.) Cronquist, as well as *Ambrosia artemisiifolia* L. in Birobidzhan. These species were not included in the quantitative analysis of woody vegetation but were taken into account when assessing the overall invasive potential of the territories.

Calculation of compensation cost. The compensation cost of each tree was determined according to regional regulatory documents.

– For Ufa: Decision of the Council of the City District of Ufa of the Republic of Bashkortostan No. 23/19 of 26.02.2010 "On the Rules for the Protection, Conservation and Reproduction of Forests and Maintenance of Green Spaces…" with amendments.

– For Dmitrov and Moscow: "Methodology for Calculating the Fee for Cutting Down Green Spaces and Determining the Amount of Damage Caused by Their Destruction or Damage on the Territory of Municipalities of Moscow Region" (approved by Protocol No. 53 of the Commission for Administrative Reform in Moscow Region of 29.01.2018).

– For Birobidzhan: Rules of Improvement of the Territory of the Municipal Formation "City of Birobidzhan" (Decision of the City Duma No. 224 of 23.12.2021).

All methodologies are based on multiplying the base cost (or the unit rate per volume of wood) by coefficients that account for diameter, height, condition, and species composition of the tree. For *A. negundo* L., the Moscow Region methodology sets a reduced species coefficient of 0.3 (i.e., the cost is reduced by 70% relative to the most valuable species); the Ufa and Birobidzhan methodologies also include species coefficients that vary depending on the region and land category.

For comparative analysis, the cost of each tree was also calculated using the unified Moscow Region methodology but without applying the species coefficient (species coefficient = 1), which made it possible to assess the influence of this coefficient on the final cost.

Statistical analysis. Data were aggregated by city and project, calculating: total number of trees, proportion of invasive species, mean values of diameter, height, and compensation cost. To identify factors influencing the logarithm of compensation cost, a linear regression model was constructed:

$$\ln(\text{Compensation cost}) = \beta_0 + \beta_1 \cdot D + \beta_2 \cdot H + \beta_3 \cdot V + \beta_4 \cdot \text{Invasive} + \beta_5 \cdot \text{Cond} + \beta_6 \cdot \text{City} + \varepsilon$$

where:

D – trunk diameter, cm;

H – height, m;

V – stem wood volume, m^3;

Invasive – binary variable (1 – invasive species, 0 – native);

Cond – condition (1 – good … 4 – hazardous);

City – categorical variable for city (reference – Birobidzhan).

Coefficients were exponentiated to interpret the percentage change in cost. All calculations were performed in the R environment (version 4.5.3) using the dplyr and ggplot2 packages.

Results

1. General characteristics of the sample. In the sample of 27,418 trees, 57 species were recorded. Native species constitute the vast majority (98.2%). Invasive species are almost exclusively represented by *A. negundo* L. (5,751 individuals, 99.9% of all invasive trees). The proportion of invasive species varies sharply among cities (Table 2): the maximum is in Moscow (46.8%), followed by Dmitrov (34.7%) and Ufa (23.8%); in Birobidzhan, invasive woody species are entirely absent (0%). This reflects both climatic constraints for *A. negundo* L. in the Russian Far East and the different history of development and landscaping.

Table 2

General characteristics of the sample by city

City	Total trees	Number of species	Invasive trees	Invasive proportion,%	Mean diameter, cm	Mean height, m
Moscow	3807	24	1783	46.83	22.6	9.8
Dmitrov	3603	29	1249	34.67	18.7	11.9
Ufa	11461	25	2722	23.75	22.6	13.8

2. Species composition and distribution of *A. negundo* L. *A. negundo* L. occurs in three cities: Moscow (1,783 individuals), Dmitrov (1,246 individuals), and Ufa (2,722 individuals). In Ufa, the species is the most numerous but is represented predominantly by young, small-diameter individuals (median diameter 11 cm, average cost 1,107 RUB; Table 3), indicating ongoing active expansion on disturbed lands. In Moscow and Dmitrov, the trees are larger (mean diameter 17.9 and 15.0 cm, respectively), reflecting a longer invasion history, and have a higher average cost. The distribution of compensation cost for *A. negundo* L. by city is shown in Fig.

Table 3

Population parameters of *A. negundo* L. by city

City	Number of individuals	Proportion of all trees,%	Mean cost, RUB	Total wood volume, m^3	Mean diameter, cm	Mean height, m
Dmitrov	1246	4.54	6085	346.6	15.0	10.6
Moscow	1783	6.50	6836	437.9	17.9	6.9
Ufa	2722	9.93	1107	444.3	12.4	7.8

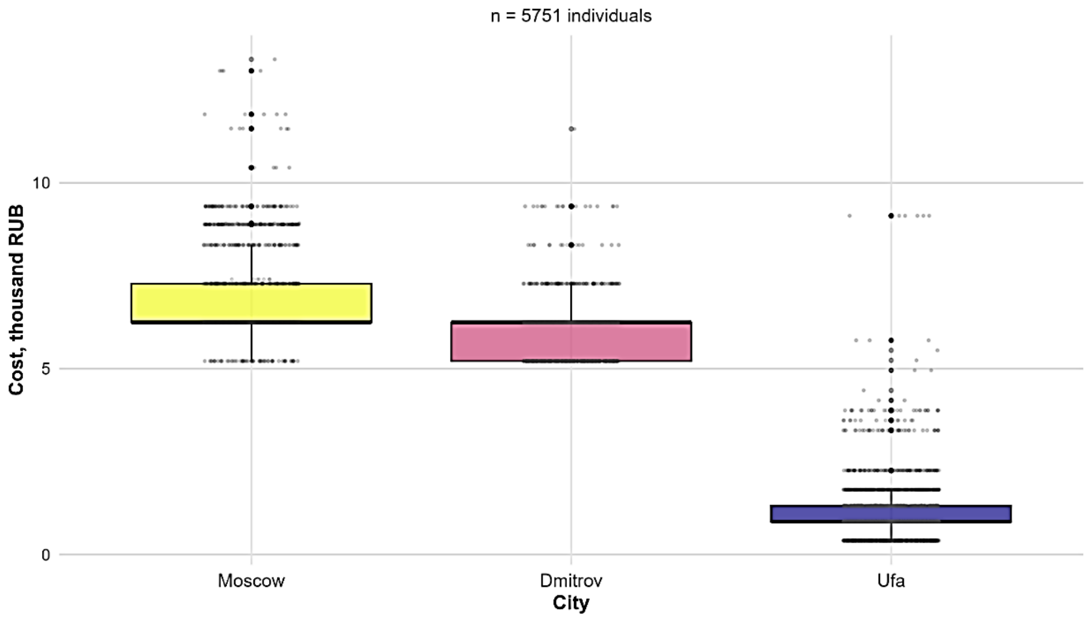

Fig. Distribution of compensation cost of *A. negundo* L. by city

3. Regression analysis of compensation cost. Linear regression of the log-transformed cost showed high explanatory power ($R^2 = 0.74$). With fixed inventory parameters and city, invasive status leads to an average cost reduction of 9.9% (exp(–0.1043) = 0.901; $p < 0.001$) (Table 4). The negative coefficient for the is_invasive variable is explained by the fact that regional methodologies assign lower species coefficients to *A. negundo* L. compared to most native species.

Table 4

Regression coefficients (dependent variable – log compensation cost)

Predictor (variable in model)	Coefficient	Std. Error	t value	*p* value	exp(coef)	95% CI for exp
Intercept	7.220	0.015	476.4	<0.001	1365.9	1325.9–1407.1
Trunk diameter, cm	0.055	0.0005	116.3	<0.001	1.0567	1.0557–1.0577
Tree height, m	0.036	0.0006	55.1	<0.001	1.0364	1.0351–1.0377
Wood volume, m³	–0.210	0.003	–69.7	<0.001	0.8106	0.8059–0.8154
Invasive species (1 – yes, 0 – no)	–0.104	0.010	–10.13	<0.001	0.9010	0.8830–0.9193
Tree condition (1 – good … 4 – emergency)	–0.198	0.008	–26.35	<0.001	0.8200	0.8080–0.8322
City: Dmitrov (city_name Dmitrov)	0.641	0.013	50.55	<0.001	1.8991	1.8524–1.9469
City: Moscow (city_name Moscow)	0.665	0.013	51.82	<0.001	1.9437	1.8955–1.9932
City: Ufa	–0.892	0.009	–94.07	<0.001	0.4099	0.4024–0.4176

Note: Reference city – Birobidzhan; the model explains 74% of the variance ($R^2 = 0.74$).

4. Economic aspects of compensation payments. The total compensation cost of invasive species in the sample amounted to 22.78 million RUB (16.1% of the total payments for all surveyed trees). Regression analysis showed that, for identical inventory characteristics, the cost of *A. negundo* L. is, on average, 9.9% lower than that of native species (Table 4). This difference reflects the reduced species coefficients already embedded in the regulatory methodologies. However, such a reduction does not compensate for the costs of targeted eradication of invasive thickets and subsequent monitoring.

If an additional reduction factor of 0.3 were introduced for invasive species (i.e., the cost would be reduced to 30% of its current level), payments for their removal would decrease by approximately 15.95 million RUB (11.3% of the total compensation sum). These released funds are proposed to be directed specifically to finance post-project monitoring and measures to prevent secondary invasion, which are currently not provided for in project budgets. Such an approach would allow the financial burden to be redistributed toward specialized environmental works without increasing the overall estimated project cost.

The existing system of compensation payments thus already contains elements that take invasive status into account, but their economic effect is insufficient to stimulate active control of invasive species. The proposed adjustment of the regulatory framework would strengthen this incentive and create a permanent source of funding for mandatory post-project monitoring.

Discussion

The obtained results confirm that *A. negundo* L. is the dominant invasive species in urbanized landscapes of the European part of Russia, especially on disturbed lands [14; 15]. The high proportion of invasive species in Moscow (46.8%) and Dmitrov (34.7%) reflects the long history of anthropogenic transformation of the territory and, probably, milder climatic conditions compared to Ufa. In Ufa, despite a lower proportion of invasive species in the total number of trees (23.8%), the absolute abundance of *A. negundo* L. is the highest, and the population is characterized by a predominance of young individuals a typical picture of active expansion against the background of ongoing land development [3; 4].

The absence of *A. negundo* L. and other invasive woody species in Birobidzhan is explained by the harsh climatic conditions, geographic isolation, and a different history of introduction [14]. At the same time, invasive herbaceous species (*A. artemisiifolia*, *I. glandulifera*, *Helianthus tuberosus*, etc.) were recorded at the Birobidzhan sites, indicating the need for post-project monitoring regardless of the presence of woody invaders [5].

Regression analysis showed that, for identical inventory characteristics, the compensation cost of *A. negundo* L. is, on average, 9.9% lower than that of native species. This is explained by the effect of reduced species coefficients established in regional methodologies (especially in the Moscow Region methodology) [8]. Consequently, the regulatory framework already indirectly recognizes the lower economic value of box-elder maple; however, this reduction is insufficient to make the targeted removal of invasive thickets and subsequent monitoring economically justified. It should be borne in mind that *A. negundo* L. is capable of forming a persistent soil seed bank [13]; therefore, a one-time removal of adult individuals does not guarantee eradication of the species. The proposed introduction of an additional reduction factor (0.1–0.3) would release funds that should be purposefully directed toward post-project monitoring (at least 5 years) and control of invasive seedlings, rather than remaining at the disposal of the developer.

Large infrastructure projects can serve as a powerful, albeit unintentional, tool for the local suppression of invasive species [2; 10]. However, to consolidate the effect, mandatory measures that are currently not provided for are necessary: post-project monitoring with removal of self-seeding, and priority use of native species in compensatory plantings. For formal street and highway landscaping, species from the standard assortment (small-leaved lime, Norway maple, European rowan) should be used [7]. Fast-growing pioneer species (silver birch, goat willow) are appropriate on reclaimed and buffer sites, where the main task is the rapid formation of a closed canopy that impedes the secondary spread of invaders.

Conclusion

1. Invasive woody plant species at the surveyed construction sites in four Russian cities are almost exclusively represented by *A. negundo* L. (5,751 individuals, 21% of the total number of trees). The proportion of invasive species varies from 0% in Birobidzhan to 46.8% in Moscow, reflecting the climatic and historical characteristics of the regions.

2. Regression analysis showed that, for equal inventory parameters, the compensation cost of *A. negundo* L. is, on average, 9.9% lower than that of native species, which is explained by the reduced species coefficients embedded in the valuation methods. The existing reduction is insufficient to fund invasion control measures.

3. The population of *A. negundo* L. in Ufa is characterized by the highest abundance but the lowest average cost (1,107 RUB) due to the predominance of small-diameter individuals; in Moscow and Dmitrov, the cost is significantly higher (6,836 and 6,085 RUB, respectively) due to the larger tree sizes.

4. Invasive herbaceous species were recorded at all sites, which necessitates the mandatory inclusion of measures for their control in post-project monitoring programs.

5. To improve the effectiveness of invasive species management, we propose:

– introducing an additional reduction factor (0.1–0.3) for invasive species in compensation cost calculation methodologies, with the saved funds purposefully directed to monitoring;

– requiring developers to include post-project monitoring (at least 5 years) with removal of invasive seedlings in project designs;

– differentiating compensatory plantings: native ornamental species for street landscaping, fast-growing pioneer species for buffer and reclaimed zones.

The conducted study demonstrates the high potential of engineering-environmental survey data for the scientific substantiation of management decisions in the field of biodiversity conservation and optimization of the regulatory framework.

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