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Research note

Ecological Strategies of Ornamental Invasive Tree and Shrub Species in Chernihiv's Green Infrastructure

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ABSTRACT

This study examined the ecological strategies of invasive tree and shrub species in the forests and forest parks of the city of Chernihiv in Ukraine through analysis of their adaptation and sustainability indicators. Natural and semi-natural forests and forest parks of Chernihiv form the green infrastructure of an average-sized Eastern European city in the continental biogeographic region. In total, 93 ornamental species of trees and shrubs are present in forests and forest parks of Chernihiv, 17 of which are classified as invasive, and most introduced in the second half of the 20th century. Sustainable approaches are needed to control the spread of alien plant species. To address this, the ecological strategies of invasive plant species were investigated. According to the classification of J.P. Grime (1988, 2001), invasive species of cultivated ornamental plants belong to three categories: competitors (C-strategists), stress tolerators (S-strategists) and ruderal plants (R-strategists). The ecological strategy of invasive ornamental tree and shrub species in natural and semi-natural ecosystems within the city's green infrastructure is characterized by their high tolerance to environmental gradients and adaptability to the natural and geographical conditions of the introduced area.

Keywords: environmental strategy, green infrastructure, forest, invasive plants, urban ecosystem

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研究簡報

烏克蘭Chernihiv城市綠色基礎設施中 觀賞性入侵樹木和灌木的生態策略

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摘　要

本研究透過適應性和持續性指標分析，評估烏克蘭Chernihiv這座中等規模東歐城市的城市森林及森林公園之綠色基礎設施，並探討入侵樹木與灌木物種的生態策略。本研究調查烏克蘭Chernihiv城市森林及森林公園中的觀賞性樹木與灌木，共計93種。其中，17種被歸類為入侵物種，且大多數是在20世紀下半葉被引進。為應對此問題，本研究分析入侵植物物種的生態策略，並提出可持續的管理方法，以控制外來植物物種的擴散。根據J.P. Grime(1988, 2001)的分類，入侵的觀賞性樹木和灌木物種可分為三類：競爭者(C型策略者)、耐逆者(S型策略者)和荒野植物(R型策略者)。在城市綠色基礎設施中的自然與半自然生態系統內，入侵性觀賞樹木和灌木物種的生態策略特徵表現在它們對環境梯度的高度耐受性，以及對引入區域自然與地理條件的良好適應能力。

關鍵詞：環境策略、綠色基礎設施、森林、植物入侵、城市生態系統

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Green infrastructure is a strategically planned network of natural and semi-natural areas, along with other environmental features, designed and managed to provide a wide range of ecosystem services. In cities, it is represented by green spaces. Green infrastructure spaces improve the quality of the environment, improve the condition and connectivity of natural areas, and contribute to citizens' health and quality of life (EUR-Lex 2013). The EU Green Infrastructure Strategy aims to halt biodiversity loss and enable ecosystems to continue to deliver vital services. Incorporating forests into green infrastructure means integrating nature into every facet of urban living.

Urban forests and forest parks of the city of Chernihiv, Ukraine are representative of the green infrastructure of an average-sized Eastern European city in the continental biogeographic region. The combined area of the natural, semi-natural forests and forest parks of Chernihiv is 7.946 km^2, accounting for 10.06% of the city's total area (CCC

2024). Protected forest areas within the city cover 0.567 km^2. Chernihiv's green infrastructure and are primarily composed of pine and birch forests of the *Vaccinio-Piceetea* class, typical of forest zones. However, these forests also include synanthropic species of the *Robinietea* Jurko ex Hadač et Sofron 1980 class. Mixed oak-pine and other deciduous forests belonging to *Querco-Pinetum* var. *coryletosum* J.Matuszkiewicz 1982 are less common within the city's green infrastructure.

In addition to native species, introduced species are used to enhance urban green infrastructure. The practical suitability of introducing a specific plant depends on its viability in new growing conditions. Introduced plant species exhibit varying ecological strategies as they adopt to new growing conditions. The impact of invasive plant species on biodiversity is both irreversible and immense as plant invasions can drastically impact the functioning of an ecosystem. These invasions can also negatively impact environmental health, economic stability and public wellbeing (Ratnayake 2014). As such, there is a need to develop sustainable approaches to control the spread of alien plants. To address this, the ecological strategies of invasive plant species were investigated.

The purpose of the study was to determine the ecological strategies of introduced tree and shrub plants used to optimize the green infrastructure of the city of Chernihiv, located in the Polesie region of the continental biogeographic zone, over the last 30 years, and to propose parameters for assessing the potential invasiveness of these introduced species.

The study was based on observations of introduced species of shrubs and trees that were used to enhance Chernihiv's green infrastructure, from 1993 to 2023. Our methodology followed assessment approaches for invasive alien plants, primarily the scoring system of Bartz and Kowarik (2019).

Scoring systems generate assessment results by adding or multiplying scores from various indicators. Plant activity indicators include degree of annual shoots maturation, habitus preservation, ability to form shoots, ability for generative development, reproduction through seeds and root shoots, preference for soil conditions, drought resistance, wind resistance, resistance to soil compaction, compatibility of the introduction environment (IE) with the natural habitat, resistance to pests of the IE, phenotypic plasticity in the IE, growth intensity in the IE, edificatory capacity in the IE, and ability to naturalize. These indicators were assessed using a point scale from 1 to 5: 5 – splendid (high), 4 – very good, 3 – good, 2 – satisfactory, and 1 – bad (low). Frost resistance and winter hardiness zone were determined using the "Ukraine Plant Hardiness Zone Map" (Plantmaps.com 2024). The native range of introduced tree and shrub plants was determined according to "Plant Atlas 2020" (PA 2020).

The minimum and maximum population separation of each invasive plant species was determined in accordance with the "Habitat-based plant element occurrence delimitation guidance" (NSE 2020).

In Yalivshchyna Forest Park, all areas invaded by introduced ornamental species were surveyed. To count the number of shoots from both seeds and shoots of invasive ornamental tree and shrub species, 5 sample plots (each measuring 25 m^2) were selected for each plant species in areas with 5 years of invasion.

J.P. Grime's publications (Grime 1988, 2001) were used to determine the ecological strategies of cultivated ornamental invasive plant species. According to the classification of J.P. Grime (Grime 1988, 2001), there are three categories of cultivated ornamental invasive plant species: competitors (C-strategists), stress tolerators (S-strategists) and ruderal plants (R-strategists).

The Statistica 13.3 software package (TIBCO Software, Palo Alto, CA, USA) was used for statistical analysis of areas of Yalivshchyna Forest infested with ornamental trees and shrubs. Results were expressed as means ± standard deviation and significant differences between the means were determined using a multiple-range test, with p-values < 0.05 considered significant.

This inventory of green spaces in Chernihiv identified 93 ornamental species and forms of trees and shrub plants used for urban landscaping, 17 of which are invasive to the green infrastructure. These invasive species can be divided into three groups according to the time of their introduction into Chernihiv's green infrastructure: 1) species introduced from the end of the 19th century through the middle of the 20th century, including *Acer negundo* L., *Acer saccharinum* L., *Robinia pseudoacacia* L.; 2) species that were introduced from the late 1940s through the late 1980s, including *Amorpha fruticosa* L., *Fraxinus pennsylvanica* Marshall, *Caragana arborescens* Lam., *Cotinus coggygria* Scop. *Gleditsia triacanthos* L., *Juglans mandshurica* Maxim., *Quercus rubra* L., *Physocarpus opulifolius* (L.) Maxim., *Prunus virginiana* L., *Prunus serotina* Ehrh., *Ptelea trifoliata* L. and *Ulmus pumila* L.; and 3) species that were introduced from the early 1990s through the early 2010s, including *Rhus typhina* L. and *Robinia viscosa* Michx. ex Vent.

Among the invasive plants found in the forest phytocenoses of Chernihiv's green infrastructure are *Quercus rubra*, *Robinia pseudoacacia*, *Prunus virginiana*, *Prunus serotina*, *Juglans mandshurica*, *Gleditsia triacanthos*, *Rhus typhina*, *Physocarpus opulifolius*, *Acer saccharinum*. Invasive species along forest outskirts and slopes include *Caragana arborescens*, *Cotinus coggygria* and *Ptelea trifoliata*. In the floodplain phytocenoses of Chernihiv's green infrastructure, several tree species exhibit varying degrees of invasiveness, in particular *Acer negundo*, *Amorpha fruticosa*, *Fraxinus pennsylvanica* and *Robinia viscose*, *while Ulmus pumila* is concentrated in forest strips along the railway tracks.

The environmental context within the actual or potential range of alien species, as well as the values incorporated into impact assessments may vary across different societies, and these contexts may change over time (Bartz and Kowarik 2019). Chernihiv's green infrastructure uses introduced species of trees and shrubs from natural habitats located outside the European continent, mainly in North America, such as: *Acer negundo* (North America), *Prunus virginiana* (North America), *Quercus rubra* (North America), *Robinia viscosa* (North America), *Prunus serotina* (Eastern North America), *Robinia pseudoacacia* (Southeastern North America), *Acer saccharinum* (Eastern North America), *Gleditsia triacanthos* (Central North America), *Fraxinus pennsylvanica* (Eastern North America from Florida and Texas north to Nova Scotia and Quebec), *Physocarpus opulifolius* (New York to Minnesota and South Dakota), *Ptelea trifoliata* (south to Florida, Arkansas and Kansas), *Rhus typhina* (Eastern North America), *Amorpha fruticosa* (from southern Canada through to Guatemala).

Cotinus coggygria is native to a large area extending from southern Europe, east across central to the Himalayas and northern China. *Caragana arborescens* is native to Siberia and parts of China, *Juglans mandshurica* is native to the Eastern Asiatic Region (China, Russian Far East, North Korea and South Korea). *Ulmus pumila* is native to northern China, eastern Siberia, Manchuria, and Korea.

The geographic origin of introduced species affects the degree of compatibility between the introduced environment (IE) and the natural habitat of the species (Table 1).

Table 1 also highlights the adaptation and resilience of invasive tree and shrub species introduced into the city's green infrastructure, which were analyzed to identify their ecological strategies.

Do introduced trees pose a threat of invasiveness? Invasive plant species are known for their success in colonizing new ecosystems due to their ability to tolerate a wide range of environmental conditions, grow and reproduce rapidly and gain a reproductive advantage, compete aggressively for resources, and benefit from the lack natural enemies or pests in the new ecosystem. Invasive species must not only be able to survive in a new area, but also replace native species to be successful. A key factor in the success of invasive alien species is their reproductive advantage, which allows them to produce sufficient fertile offspring to establish an effective population size. The species should have the ability to spread in a new habitat successfully. If a new species can disrupt the existing ecological equilibrium, this is an indicator of invasiveness. Once invasive alien species become established in an area, they are able to proceed to invade new habitats. These species harbor certain characteristics that can distinguish them from native species (Ratnayake 2014). Invasive species exhibit a particular ecological profile rather than a biological profile. Comparison of our data presented in Table 1 supports the conclusion that species traits determine their success or failure during the various stages of the invasion process.

Part of the challenge of assessing invasiveness lies in the fact that there may be multiple strategies that allow species to succeed in their new environment. P.M. Herron with co-authors (Herron et al. 2007) hypothesized that different growth forms (trees, shrubs) might use different strategies or use different niches, and that these would be associated with different traits. For most traits, including the dominant traits of evergreen-ness, growth rate, native range size, and invasive history, models showed that the traits bore the same relationship to invasiveness across all growth forms (Herron et al. 2007). It should be noted that the compatibility of the introduced environment with the natural habitat determines the plant's frost resistance.

To incorporate the environment-related context of invasion impacts, assessments should consider information regarding the (potential) distribution of alien species and of (potentially) affected environmental resources (Bartz and Kowarik 2019). Therefore, in Yalivshchina Forest Park, which spans 83 hectares, and is experiencing an invasion of all 17 species of trees and shrubs under study, the areas where these species have naturalized was calculated (Table 2).

As can be seen from Table 2, *Robinia pseudoacacia* is present in only three areas, but each area covers about 3 ha, where this species exhibits active invasion. In the case of areas infested by six species (*Acer negundo*, *Amorpha fruticosa*, *Prunus virginiana*, *Prunus serotina*, *Robinia viscosa*,and *Ulmus pumila*), the coverage does not exceed 1 ha. For other species, more localized invasions were noted. It should be noted that different

Table 1. Scoring of various indicators of adaptation and resilience of invasive tree and shrub species introduced into Chernihiv's green infrastructure

Plant species [1]	Rp	As	Ca	Cc	Gt	Fp	Jm	Po	Pt	Qr	Rt	An	Af	Pv	Ps	Rv	Up
Compatibility of the IE with the natural habitat	4	4	3	4	4	4	3	4	4	4	4	4	4	4	4	4	3
Degree of annual shoots maturation	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Frost resistance; winter hardiness zone	frost resistant (WH 1-6); 5a (from -28,8℃ to -26,1℃)																
Habitus preservation	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Ability to form shoots	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Regularity of growth	constant																
Ability for generative development	4	2	4	2	3	2	4	3	2	4	3	4	4	3	4	4	3
Seed reproduction	5	2	2	1	1	1	3	2	2	4	2	5	4	4	4	1	3
Root shoots reproduction	5	1	2	1	1	1	1	2	1	1	3	1	5	1	1	5	5
Sensitivity to soil conditions	1	2	2	2	2	2	2	2	2	2	2	1	2	2	2	1	1
Drought resistance	5	4	4	5	4	3	4	4	4	4	4	4	3	4	4	4	5
Wind resistance	5	2	5	5	5	3	3	5	5	5	4	4	5	2	2	2	5
Resistance to soil compaction	5	4	4	4	4	1	3	4	4	2	1	4	4	4	3	3	5
Resistance to pests of the IE	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Phenotypic plasticity in the IE	5	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3
Growth intensity in the IE	5	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3
Ability to naturalize	5	2	2	2	2	2	3	2	2	4	2	4	3	3	3	3	3
Edificatory capacity in the IE	5	1	1	1	1	1	1	1	1	1	1	3	2	2	2	2	2
Minimum population separation, km	0,5	4,0	3,5	5,5	2,5	3,0	7,0	3,5	4,0	2,5	3,0	2,5	6,5	13,0	13,0	7,0	7,0
Maximum population separation, km	2,0	11,0	10,0	12,5	11,0	9,5	10,5	11,5	12,0	13,0	9,0	7,0	9,5	13,0	13,0	12,0	10,0

[1] Rp – *Robinia pseudoacacia*, As – *Acer saccharinum*, Ca – *Caragana arborescens*, Cc – *Cotinus coggygria*, Gt – *Gleditsia triacanthos*, Fp – *Fraxinus pennsylvanica*, Jm – *Juglans mandshurica*, Po – *Physocarpus opulifolius*, Pt – *Ptelea trifoliata*, Qr – *Quercus rubra*, Rt – *Rhus typhina*, An – *Acer negundo*, Af – *Amorpha fruticosa*, Pv – *Prunus virginiana*, Ps – *Prunus serotina*, Rv – *Robinia viscosa*, Up – *Ulmus pumila*.

Table 2. Areas of Yalivshchyna Forest Park infested with ornamental trees and shrubs

Plant species	Number of plots	Average plot area ± SE, ha	Skew
Robinia pseudoacacia	3	2.921 ± 0.071	0.081
Acer saccharinum	9	0.042 ± 0.001	-0.005
Caragana arborescens	8	0.061 ± 0.001	-0.004
Cotinus coggygria	3	0.009 ± 0.002	-0.02
Gleditsia triacanthos	2	0.001 ± 0.000	0.001
Fraxinus pennsylvanica	3	0.026 ± 0.002	0.003
Juglans mandshurica	6	0.081 ± 0.003	0.001
Physocarpus opulifolius	18	0.068 ± 0.001	0.021
Ptelea trifoliata	8	0.002 ± 0.000	0.001
Quercus rubra	7	0.045 ± 0.028	0.027
Rhus typhina	4	0.016 ± 0.002	0.001
Acer negundo	9	0.615 ± 0.011	0.003
Amorpha fruticosa	7	0.464 ± 0.021	-0.011
Prunus virginiana	11	0.702 ± 0.047	0.042
Prunus serotina	19	0.639 ± 0.033	0.004
Robinia viscosa	2	0.232 ± 0.012	0.001
Ulmus pumila	1	0.237 ± 0.018	-0.003

species differ in their performance and thus need to be assessed individually. Intraspecific differentiation should also be considered in assessment approaches, as this can lead to varying environmental impact. Infertile varieties of an invasive alien species might be ‘safe’, but not necessarily so (Bartz and Kowarik 2019).

The ability to naturalize and edificatory capacity of species in the introduced environment largely depends on reproductive efficiency under the conditions of the introduced green infrastructure phytocenoses. This is supported by the results of counting the number of shoots of seed (Fig. 1) and shoots (Fig. 2) originating among the ornamental invasive tree and shrub species. As can be seen from the diagrams (Fig. 1 and 2), *Robinia pseudoacacia* produces the largest number of shoots, closely followed by maple (*Acer negundo*) in terms of the number of shoots of seed origin. Studies have shown that for *Robinia pseudoacacia* seed and stump shoot reproduction, spreading distance increases with increased light availability and decreases with tillage (Carl et al. 2019).

Emerging from high and low combinations of stress and disturbance are three life strategies commonly used to categorize plants based on their environment: 1) C-competitors, 2) S-stress tolerators, and 3) R-ruderals (Grime 1988, 2001).

Competitors (C-strategists) survive in stable and productive habitats thanks to their ability to monopolize resources efficiently, especially through their spatial dynamics (large individuals and organs). Stress tolerators are plant species that live in areas of high intensity stress and low intensity disturbance. Species that have adopted this strategy generally have slow growth rates, long-lived leaves, high rates of nutrient

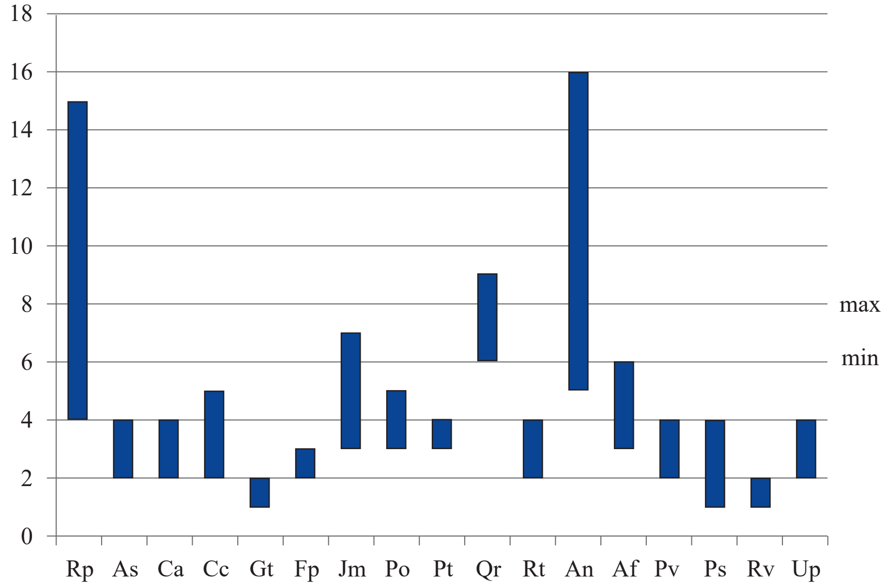

Fig. 1. Maximum and minimum numbers (ordinate) of the seed-origin shoots of ornamental invasive tree and shrub species per 25 m^2. Abbreviations (abscissa) for plant species names are given in Table 1.

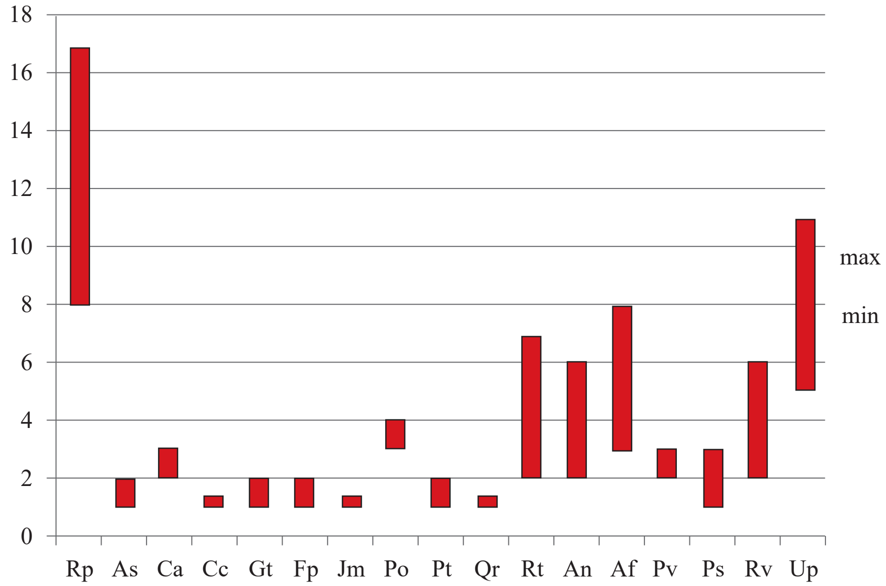

Fig. 2. Maximum and minimum number (ordinate) of root-origin shoots of ornamental invasive tree and shrub species per 25 m^2. Abbreviations (abscissa) for plant species names are given in Table 1.

retention, and low phenotypic plasticity. Ruderal plants (R-strategists) are pioneer species in disturbed areas—for example urban environments, wastelands, roadsides, agricultural fields—with rapid growth, high reproductive rates, and long-distance dispersal. Fig. 3 shows the distribution of plant species depending on their ecological strategy. The teeth of the gears symbolize the indicators of adaptation and resistance of invasive tree and shrub species.

Robinia pseudoacacia (C-strategist) poses the greatest danger to the phytodiversity of green infrastructure. Invasion of black locust leads to black locust-pine and black locust-birch phytocenoses in anthropogenically disturbed forests, which differ in structure and species composition. The process of infestation of indigenous crops by *Robinia pseudoacacia* progresses through several stages. Initially, seedlings appear in phytocenoses disturbed by logging and recreational pressure. Recent research by Tang et al. (2024) found that *R. pseudoacacia* exhibits varying water use patterns and physiological and morphological adaptations as a plantation ages. While *R Robinia pseudoacacia* exhibited relatively consistent water uptake through different ages, it mainly took up water from middle and deep soil layers in both dry and wet periods (Tang et al. 2024).

According to our data (Table 1), *R. pseudoacacia* has the highest rate of adaptation and resistance to environmental conditions. The reproduction strategies of

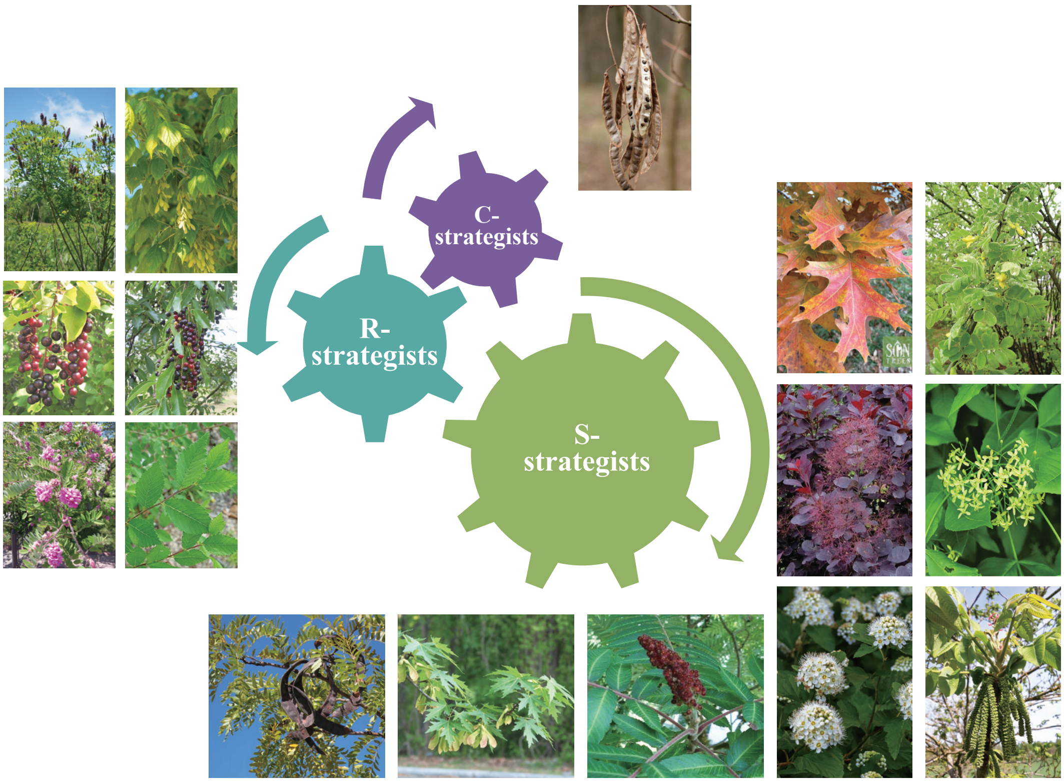

Fig. 3. Distribution of invasive plant species based on their ecological strategies.

Robinia pseudoacacia, both generatively by seeds and vegetatively by stump shoots and root sprouts, plays an important role in the active spread of this species in forests and forest parks of urban green infrastructures. In addition, the introduction of all species of the genus *Robinia* L. requires a number of phenotypic and ontogenetic adaptations. The most important of these is a change in life form, from tree to shrub, or from single-trunk to a multi-trunk tree, as well as a decrease in growth rates and a decrease in the total height of plants depending on soil fertility, moisture supply and the damaging effect of low winter temperatures (Lazarev 2020).

The S-strategists are: *Acer saccharinum*, *Caragana arborescens*, *Cotinus coggygria*, *Gleditsia triacanthos*, *Fraxinus pennsylvanica*, *Juglans mandshurica*, *Physocarpus opulifolius*, *Ptelea trifoliata*, *Quercus rubra*, *Rhus typhina*. These species are distinguished by their satisfactory phenotypic plasticity, growth intensity and ability to naturalize, despite poor edificatory capacity in the introduced environment (Table 1). S-strategists do not reduce the biodiversity value of the forest ecosystems, either by reducing the amount of phytodiversity and abundance of native plant species, or through degrading the visual appearance of the green infrastructure. They play an important role in preventing erosion in sloping areas.

Quercus rubra (red oak), though classified as an S-strategist under the specific environmental conditions of the studied green infrastructure of Chernihiv, is regarded as one of the most common invasive tree species in temperate European forests. It has been found in 34 and recognized as a naturalized species in 19 European regions (Lambdon et al. 2008). D. Chmura (2020) found that *Q. rubra* negatively affects both the cover and species richness of native understory vegetation, especially for rare and protected plant species. Changes in the properties of soil and vegetation caused by invasive *Q. rubra* suggest that this species may alter both the structure and function of forest ecosystems. The noted differences, in both species composition and functional diversity are more likely due to the habitat requirements of all the species present in forests rather than the direct influence of red oak (Stanek 2020). Considering the short-distance spread of *Q. rubra* into cultivation areas, it is difficult to precisely determine its invasiveness or ability to invade new habitats.

R-strategists are characterized by rapid growth, rather high generative and vegetative productivity, and the ability to spread over long distances. The following plant species were included in the group of R-strategists: *Acer negundo*, *Amorpha fruticosa*, *Prunus virginiana*, *Prunus serotina*, *Robinia viscosa*, *Ulmus pumila*. They are distinguished by good phenotypic plasticity, growth intensity and ability to naturalize, and satisfactory edificatory capacity in the introduced environment (Table 1).

For comparison, in regions located to the south of Chernihiv, some R-strategists express a C-strategy. For example, *Amorpha fruticosa* forms mixed *A. fruticosa – Populus nigra* communities in riparian parts of river valleys in the forest-steppe and steppe zones of Ukraine. This highly invasive species in the lower reaches of the Danube forms monodominant communities and also is a component of the associations *Hippophae rhamnoides* + *A. fruticosa*, *Salix alba* + *A. fruticosa*, and some others, and poses a serious threat for the unique tree and shrub vegetation complex of the Danube Biosphere Reserve. *Acer negundo* plays a similar role in floodplain forests of the forest-steppe zone (Lupu and Covaliov 2021).

As can be seen from Table 1 (data on minimum and maximum population separation), artificial territorial isolation from natural plant communities in the urban green infrastructure of Chernihiv (with population separations of 2.5 and 13.0 km) limits the ability of S- and R-strategists to actively express invasive traits. Additionally, most S-strategists and *Robinia viscosa* have a low generative potential, and reproductive by seed propagation is difficult due to the hard seed coats, which require pre-treatment for germination.

In the process of optimizing urban green infrastructure, the potential invasiveness of tree species should be taken into account, which can be predicted by a combination of a number of parameters, beginning with intensity of growth in the introduced environment, edifying capacity in the introduced environment, the ability to naturalize, as well as resistance to the action of extreme environmental factors.

Our research confirmed the results of previous studies that demonstrated that significant tolerance to environmental gradients (temperature, soil moisture and salinity, light availability, resistance to pests), high reproductive ability, growth rate and native latitudinal range, growth intensity, ability to naturalization and edificatory capacity in the introduced environment determine the ecological strategy of invasive plants. In addition, the ecological strategy of ornamental invasive tree and shrub species in natural and semi-natural ecosystems of the city's green infrastructure is determined by the natural and geographical conditions of the territory where the plants are introduced. Several indicators of successful introduction, such as frost resistance, regularity of growth, ability for generative development and various methods of reproduction also reflect the degree of species invasiveness. There is a need to develop sustainable approaches to control the spread of alien plants. The findings of this study on the ecological strategies of invasive tree and shrub species should be taken into account when developing effective ways to optimize green infrastructure, prevent the undesirable consequences of invasions.

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