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Ecological strategies of decorative invasive tree and shrub plant species in the city's green infrastructure †

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Abstract: Natural and semi-natural areas of Chernihiv (Ukraine) represents the green infrastructure of an average-sized Eastern European city in the continental biogeographical region. In total, 93 decorative species and forms of tree and shrub plants are used for the city landscaping, and 17 of them are invasive in green infrastructure. As such there is a need to develop sustainable approaches to control the spread of alien plants. For this purpose, the invasive plant species ecological strategies were investigated. According to the classification of J.P. Grime (1988, 2006), the decorative cultivated plants of invasive species belong to three categories: competitors (C-strategists), stress tolerators (S-strategists) and ruderal plants (R-strategists).

Keywords: alien species; continental biogeographical region; green infrastructure; plant invasions; plant strategy; urban ecosystem.

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1. Introduction

Green infrastructure is a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. In cities it is represented by green spaces. Green infrastructure spaces improves the quality of the environment, the condition and connectivity of natural areas, as well as improving citizens' health and quality of life [1]. The EU Green Infrastructure Strategy aims to help stop biodiversity loss and enable ecosystems to deliver their services to people.

Natural and semi-natural areas of Chernihiv (Ukraine) represent the green infrastructure of an average-sized Eastern European city in the continental biogeographical region. Not only natural species of plants, but also introducers are used to optimize plantings of green infrastructure. The practical expediency of introducing a specific plant is determined by its viability in new growing conditions. Introduced plant species used to optimize urban green infrastructure exhibit different ecological strategies in new growing conditions. The impact of invasive plant species on biodiversity is irreversible and enormous because plant invasions can alter the functioning of an ecosystem dramatically. They also have a negative impact on environmental, economic and public wellbeing [10]. As such there is a need to develop sustainable approaches to control the spread of alien plants. For this purpose the invasive plant species ecological strategies were investigated.

The purpose of the study was to establish the ecological strategies of introduced tree and shrub plants that have been used to optimize the green infrastructure of Chernihiv (the Polesie district of the continental biogeographical region) over the last 30 years, and to propose parameters for assessing the potential invasiveness of introduced tree species.

2. Materials and Methods

The study is based on observations of introduced species of shrubs and trees that were used to optimize Chernihiv green infrastructure, for the period 1993 – 2023. Plant activity indicators (degree of annual shoots maturation, habitus preservation, ability to form shoots, ability to generative development, seeds and root shoots reproduction, pickiness to 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, ability to naturalize) were assessed using a point scale: 5 – splendid (high), 4 – very good, 3 – good, 2 – satisfactory, 1 – bad (low). Frost resistance and winter hardiness zone were determined according to "Ukraine Plant Hardiness Zone Map" [9]. The native range of introduced tree and shrub plants was determined according to "Plant Atlas 2020" [8]. J.P. Grime's publications [4, 5] were used to determine the ecological strategies of the decorative cultivated plants of invasive species. According to the classification of J.P. Grime [4, 5] there are three categories of the decorative cultivated plants of invasive species: competitors (C-strategists), stress tolerators (S-strategists) and ruderal plants (R-strategists).

3. Results

As a result of the inventory of green spaces in Chernihiv, it was found that 93 decorative species and forms of tree and shrub plants are used for the city landscaping and 17 of them are invasive in green infrastructure.

Among the invasive plants of the green infrastructure forest phytocenoses the following species were found: *Quercus rubra* L., *Robinia pseudoacacia* L., *Prunus virginiana* L. *Prunus serotina* Ehrh., *Juglans mandshurica* Maxim., *Gleditsia triacanthos* L., *Rhus typhina* L. *Physocarpus opulifolius* (L.) Maxim., *Acer saccharinum* L. Forest outskirt and slopes plant species are *Caragana arborescens* Lam., *Cotinus coggygria* Scop. and *Ptelea trifoliata* L. In the floodplain phytocenoses of the Chernihiv city's green infrastructure number of trees show invasiveness of varying intensity, in particular *Acer negundo* L., *Amorpha fruticosa* L., *Fraxinus pennsylvanica* Marshall, *Robinia viscosa* Michx. ex Vent. The *Ulmus pumila* L., is concentrated in forest strips along the railway track.

Green infrastructure of Chernihiv uses introduced species of trees and shrubs with a natural habitat, which are located outside the European continent, mainly in North America: *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 Scop. is native to a large area from southern Europe, east across central Asia and the Himalayas to northern China. *Caragana arborescens* Lam. is native to Siberia and parts of China, *Juglans mandshurica* Maxim. is native to the Eastern Asiatic Region (China, Russian Far East, North Korea and South Korea). *Ulmus pumila* L. is native to northern China, eastern Siberia, Manchuria, and Korea.

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

Table 1. Indicators of adaptation and resistance of the tree and shrub invasive plant species under conditions of introduction into Chernihiv 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	2
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 °C to -26,1 °C)																
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 to generative development	4	2	4	2	3	2	4	3	2	4	3	4	4	3	4	4	3
Seeds 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
Pickiness 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	4	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
Edificatory capacity in the IE	5	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2
Ability to naturalization	5	2	2	2	2	2	3	2	2	4	2	4	3	3	3	3	3

[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 1 also shows the adaptation and resistance of the tree and shrub invasive plant species under conditions of introduction into the city's green infrastructure, which were analyzed to determine the ecological strategy of plants.

3. Discussion

An invasive species must be able to survive successfully and replace native plant species to be successful in a new area. Primarily invasive alien species should have reproductive advantage and produce sufficient amount of fertile offspring to initiate next generation (effective population size). The species should have the ability to spread in a new habitat successfully. If a new species can attack the existing ecological equilibrium, that would be a sign 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 the native species [10]. Invasive species exhibit a particular ecological profile rather than a biological profile. Comparison of our data presented in Table 1 allows us to agree that the species' traits determine their success or failure in the transition between different stages of the invasion process [10].

Emerging from high and low combinations of stress and disturbance are three life strategies commonly used to categorize plants based on the environment: 1) C-competitors, 2) S-stress tolerators, and 3) R-ruderals [4, 5].

Competitors (C-strategists) survive in stable and productive habitats thanks to their ability to monopolise 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 adapted this strategy generally have slow growth rates, long-lived leaves, high rates of nutrient retention, and low phenotypic plasticity. Ruderal plants (R-strategists) are pioneer species in disturbed areas (e.g., urban environments, wasteland, roadsides, agricultural fields) with rapid growth, a high reproductive rate, and long-distance dispersal.

Part of the challenge of assessing invasiveness lies in the fact that there may be multiple successful strategies that allow species to succeed in their new environment. P.M. Herron with co-authors [3] hypothesized that different growth forms (trees, shrubs) would 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 [3]. It should be noted that the compatibility of the introduced environment with the natural habitat determines the plant frost resistance.

Robinia pseudoacacia (C-strategist) causes the greatest danger to the phytodiversity of green infrastructure. Black locust–pine and black locust–birch phytocenoses are formed as a result of black locust's invasion in anthropogenically disturbed forests. They differ in structure and species composition. The process of infestation of indigenous crops by *Robinia pseudoacacia* goes through several stages. At the first stage of the distribution of black locust, seedlings of this species appear in phytocenoses disturbed by logging and recreational pressure. As proven by the latest research [12], different water use patterns and physiological and morphological adjustments were adopted by *R. pseudoacacia* as plantation age increased. The *R. pseudoacacia* exhibited a relative equal water uptake pattern and absorbed water at different ages. However, this species exhibited an exclusive water uptake pattern and mainly took up water from middle and deep soil layers in both dry and wet periods [12]. According to our data (Table 1), *R. pseudoacacia* has the highest rates of adaptation and resistance to environmental conditions.

S-strategists do not pose a threat to the city's green infrastructure biodiversity. They play an important role in preventing erosion processes in sloping areas. The S-strategists are: *Acer saccharinum*, *Caragana arborescens*, *Cotinus coggygria*, *Gleditsia triacanthos*, *Fraxinus pennsylvanica*, *Juglans mandshurica*, *Physocarpus opulifolius*, *Ptelea trifoliate*, *Quercus rubra*, *Rhus typhina*. They are distinguished by satisfactory phenotypic plasticity, growth intensity and ability to naturalize and bad edificatory capacity in the introduction environment (Table 1).

Classifying *Quercus rubra* (red oak) as an S-strategist can only be applied in the conditions of the studied green infrastructure of Chernihiv. At the same time, it is known that *Quercus rubra* is 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 [6]. Researchers [2] have found that *Q. rubra* made a negative influence mostly on the cover and species richness of the native understory vegetation, especially rare and protected plant species. The changes in the properties of soil and vegetation caused by invasive *Q. rubra* testify that this species may change both the structure and function of forest ecosystems. The differences, both in species composition and functional diversity, testified by the obtained results, are the effects rather of the habitat requirements of all the species present in forests than the influence of the red oak [11]. Considering the *Q. rubra* short-distance spread to the cultivation areas, it is hard to exactly indicate the ability of the red oak to invade habitats, or the invasiveness of the red oak.

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 introduction environment (Table 1).

For comparison, in regions located to the south of Chernihiv, some R-strategists reveal the 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 Danube Biosphere Reserve. *Acer negundo* plays a similar role in floodplain forests of the forest-steppe zone [7].

3. Conclusions

Our research confirmed the results of the previous studies that demonstrated that significant tolerance to the environmental gradients (temperature, soil moisture and salinity, light availability, resistance to pests), high reproductive ability, growth rate and native latitudinal range determine the ecological strategy of invasive plants. In addition, the ecological strategy of decorative invasive tree and shrub plant 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. There is a need to develop sustainable approaches to control the spread of alien plants.

Supplementary Materials: The following supporting information can be downloaded at: https://sciforum.net/paper/view/17579, Conference Poster: Ecological strategies of decorative invasive tree and shrub plant species in the city's green infrastructure.

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