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Analysis of the structure of flora of artificial phytocoenosis and assessment of its competitiveness against invasion of alien plants and their suitability for the creation introduction populations of rare species of the Caucasian flora

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The flora and its immigration groups in the plot "Caucasus" in M.M. Gryshko National Botanical Garden (Kyiv) were studied. Their compositions and stability of formed artificial phytocoenoses were analyzed. During 70 years of directed job on the phytogeographical plot "Caucasus" a number of flora complexes have been successfully formed, in which the vegetation of the Caucasus has been modeled. Those artificial phytocoenoses in which the share of plant species of the Caucasian flora is high and predominates over the share of other plant ˢpecies, the authors consider as mature. The prevalence of specially introduced species among the edificators is especially important for the full-fledged modeling of a plant group under *ex situ*. These in the studied plot "Caucasus" include forest stands, they were the most resistant to phytoinvasions. Artificial florocomplexes of sparse forests, steppes, and meadows also have a high species diversity of introduced species, but in this, they are significantly inferior to the corresponding phytocoenoses of the Caucasus. In general, there is a tendency that in the conditions of the botanical garden artificial phytocoenoses with the formed coenotic structure are resistant to the settlement of local plants and weeds and in their composition grows mainly a high proportion of rare plant species. Those artificial phytocoenoses in the plot "Caucasus", in which the share of introducers is less than 30%, should not be considered as formed, as such plantings are unstable to the spread of weeds and invasive plants. A tendency was found that mature artificial phytocoenoses are the most suitable for the successful formation of populations of rare species of Caucasian flora.

Keywords: National Botanical Garden, biodiversity, artificial phytocoenoses

Introduction

At the current stage of the development of biological sciences, the invasion of alien organisms, which leads to phytopollution and a decrease in the diversity of native taxa, is an urgent problem (Mashhadi and Radosevich, 2004; Burda et al., 2015; Pyšek et al., 2020; Baquero et al., 2021; Szumańska et al., 2021; Vrabič-Brodnjak and Možina, 2022). It is important to develop management to reduce the negative impact of invasive organisms on local ecosystems and cultivated plants (Prabakaran et al., 2019; Baquero et al., 2021). In this connection, the issues of monitoring and studying the acclimatization and naturalization of alien plants in the scientific centers of their introduction – Botanical

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Gardens (Burda et al., 2015; Konaikova and Peregrym, 2023).

Currently, the importance of research on the spontaneous diversity of vascular plants in Botanical Gardens is growing (Galera and Sudnik-Wojcikowska, 2004; Atha et al., 2016). Due to significant work on the introduction of new plants, the spontaneous flora of vascular plants in botanical gardens are extremely diverse and dynamic; their inventory is often reduced to compiling lists of recorded taxa and draws attention to the need to monitor invasive species (Heywood and Sharrock, 2013). At the same time, the study of the structure of phytocoenoses in botanical gardens is little practiced, because artificial ecosystems in culture are rare, but the study of the resilience of ecosystems to the impact of invasive species is important (Burda et al., 2015; Vainoriene, 2021; Rakhmetov and Zaimenko, 2022). Therefore, a detailed study of the taxonomic composition of artificial phytocoenoses in botanical gardens and their resistance to biological invasion is relevant.

The leading and one of the largest scientific institutions of Ukraine, which studies the acclimatization of alien plants *ex situ*, is the M.M. Gryshko National Botanical Garden of the National Academy of Sciences of Ukraine (NBG) (Zaimenko et al., 2018; Rakhmetov and Zaimenko, 2022; Zaimenko and Rakhmetov, 2022). Currently on the territory of this institution stable artificial phytocoenosis, which are integral landscape elements of the NBG and to some extent model the vegetation of several regions of the temperate zone of Eurasia are presented. The species composition of phytocoenoses requires constant monitoring in order to rationally care for the plots, project formation of plantings, and scientifically sound replenishment of collections. When inventorying the flora of collection plots, as a rule, the establishment of the full species composition is not targeted, and wild (native and alien) plant species are often ignored. Instead, the ratio of introduced plants in the artificial phytocoenosis can be an indicator of the success of its formation, maturity, and stability. It is well known that natural communities show the highest resistance to phytoinvasions, and their anthropogenic disturbance leads to the loss of horizontal and vertical coenotic connections, penetration of invasive species, and gradual transformation (Bulakh, 2010; Burda et al., 2015). Resistance to phytoinvasions is one of the integral features of a mature natural phytocoenosis.

The artificial phytocoenosis is an artificial ecosystem, but depending on the purpose of its formation, it may have the same characteristics as native phytocoenosis: tiered, complex structure, mosaic, etc. It is natural that in the case of successful selection of the species composition of the introduced artificial phytocoenosis will be quite resistant to the negative impact of alien species, and therefore will acquire the maturity inherent in the native phytocoenosis.

This study was aim to conduct a comprehensive inventory of the plant species composition both in individual exposition sections and the plot as a whole; to analyze the resistance of artificial phytocoenoses to the spread of invasive plants depending on the immigration structure of the species composition of their flora.

Material and methodology

Location of the study

The research was conducted during the last decade (2010–2020) based on the phytogeographical plot "Caucasus" of the M.M. Gryshko National Botanical Garden, National Academy of Sciences of Ukraine (NBG). Information on the species composition of the collection in the plot "Caucasus", the structure of individual exposition sections, as well as rare plant species in the collection and introductory populations, have already been given earlier (Didenko, 2016; Didenko, 2018; Shynder, 2015, 2019).

Objects of research

The plot "Caucasus" currently has a heterogeneous vegetation and consists of about 20 individual sections and dendrogroups. Artificial phytocoenoses representing different geographical regions of the Caucasus were formed in these sections. 8 main sections have the largest areas and high presentability: beech forests, deciduous forests, Talysh, woodland, maple grove, birch grove, meadows, and steppes (Figure 1 and 2). In 1950–1960, hardy plants imported from the Caucasus were specially planted on these flora complexes to create artificial phytocoenoses in Kyiv. Now these 8 sections are the models of vegetation of the Caucasian region. Also, the structure of artificial plantations of plane tree alley is compared – this artificial phytocoenosis is not a model of natural vegetation, but is an ornamental park plantation. An artificial phytocoenosis with the participation of Caucasian plants spontaneously formed in the alley of plane trees.

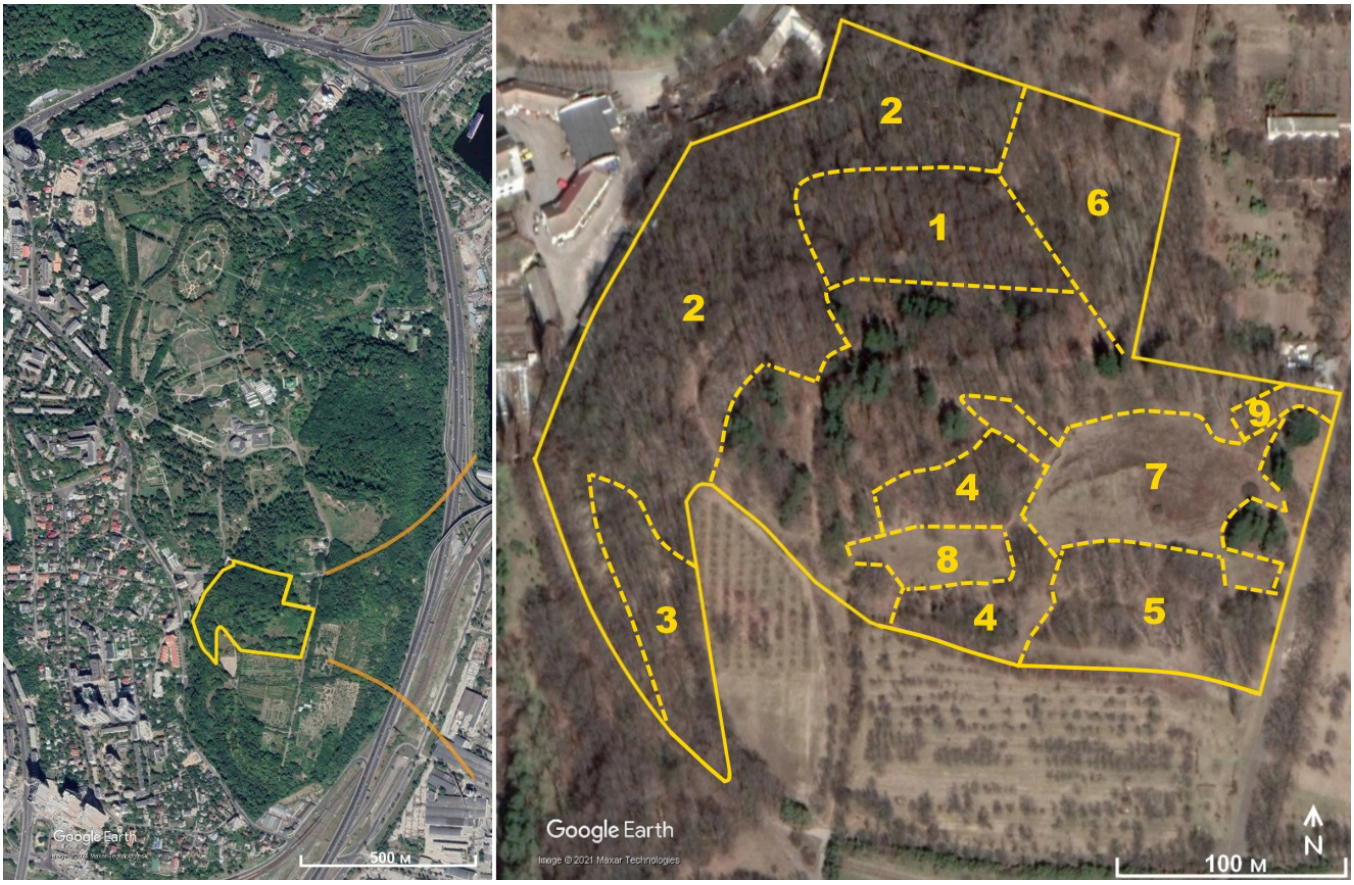

Figure 1 Map of the plot "Caucasus" on the territory of the National Botanical Garden (left) and the scheme of its division into individual sections (right)
1 – Beech Forests; 2 – Deciduous Forests of the Great Caucasus; 3 – Talysh; 4 – Woodland; 5 – Maple Grove; 6 – Birch Grove; 7 – Meadows; 8 – Steppe; 9 – Platans Alley

Immigration groups of plants

Plants in the artificial phytocoenoses of the plot "Caucasus" for analysis purposes were divided into 5 immigration groups:

1. species that are within the native flora of the Caucasus region;
2. other introduced species that are not native in the Caucasus but have been planted for various reasons;
3. native species, absent in the natural flora of the Caucasus;
4. alien species, xenophytes;
5. alien species, escaped plants (ergasiophygophytes).

Species of the first two groups are part of the cultivated plants of the NBG, although they often grow spontaneously. Species from other immigration groups form a spontaneous flora of the botanical plot and are not subject to collection monitoring. The structure and formation of the spontaneous flora of the NBG are revealed in detail in a special series of articles (Shynder, 2019).

Results and discussion

The first plants from the Caucasus were brought to the NBG in 1946. In that period, up to 1600 types of vascular plants of the Caucasian flora were introduced into the plantation. Most of them were first introduced in Ukraine. The florocomplexes formed on the plot had a wide ecological range – from coastal to semi-desert. The results of the introduction and acclimatization of many species of Caucasian flora are highlighted in the works of Kharkevych (1966). It should be noted that the author took into account the negative experience of predecessors in the establishment and formation of plant communities in terms of introduction outside their range. Kharkevych emphasized that it is practically impossible to protect artificial phytocoenosis of the phytogeographical plot from invasions of alien and native plant species (Kharkevych, 1966). But artificial plant communities in the botanical garden can be very close to natural phytocoenoses in species and coenotic structure (Shynder, 2015; Didenko & Shynder, 2020). Namely, a well-formed and complex structure of the

Figure 2 Artificial phytocoenosis on plot "Caucasus" of the M.M. Gryshko National Botanical Garden
1 – Beech Forests; 2 – Deciduous Forests; 3 – Talysh; 4 –Woodland; 5 – Birch Grove; 6 – Meadows; 7 – Steppe; 8 – Platans Alley

phytocoenosis is the best natural barrier against the penetration of invasive plants (Elton, 1958; Protopopova et al., 2002).

Much later, in the phytogeographical plots of Gryshko National Botanical Garden, sociological studies of rare plants and their populations became important. The inventory period began in 2003. 218 introduced species of flora of the Caucasus, which grow in the plot "Caucasus", were noted. In addition, the study of the status of introduced populations of rare species of Caucasian plants has been started. Little attention was paid to the study of artificial phytocoenosis and its structure. From 2010 to 2014, an inventory of the species composition of the flora and vegetation of this area was carried out (Shynder, 2014; Shynder and Kruglyak, 2015). According to the results, it was established that a total of 406 plant species from 89 families grow on this site; of them, there are 350 species of Caucasian flora from 83 families.

Since 2014 the collection of living plants in the plot has been significantly supplemented by newly introduced species from the Caucasus (Didenko, 2016, 2019), and many previously lost taxa have been restored. Given this, the species composition of the collection needs to the monitoring, and the database needs in the adjustment.

According to the results of the inventory of the collection and spontaneous flora of the main allotments in the plot "Caucasus", modern information on their species diversity was obtained (Table 1) (Didenko and Shynder, 2020).

Consider in more detail the taxonomic composition of plants in individual phytocoenoses in the plot "Caucasus". The floristic section "Beech forests" covers an area of 0.5 ha and has a fully formed structure of tree and grass tiers. The shrub layer is quite sparse due to significant shading. Within the allocation, 62 species of plants grow, of which 39 species are introduced from the Caucasus, that is the majority, including woody – 7, shrubby – 5, and herbaceous perennials – 25. The share of alien plants is very indicative, which is only 3.33% of xenophyte species (*Impatiens parviflora* DC. and *Oxalis stricta* L.) do not pose a threat to the formed populations of perennial plants of Caucasian origin. In this section, relatively few (10) native perennials are represented. Thus, in the composition of beech artificial phytocoenosis alien species play almost no role, which indicates its maturity and resistance to invasion.

The deciduous forests unite the tree stands of the former lowland non-flooded forests, tugai forests, and deciduous forests of the Greater Caucasus. During long-term acclimatization, some of the tree species that were planted as edificators of these allotments fell out of the plantations, so it is now advisable to combine these stands into one prefabricated forest allotment with an area of about 1.5 ha. Its stand is formed by *Carpinus betulus* L., *C. orientalis* Mill., *Fraxinus excelsior* L., and species of the genera *Acer* and *Ulmus* with the participation of many other tree species. In total, 114 species of plants were recorded in this floristic section, 67 of which were introduced from the Caucasus. The shrub layer is sparse and represented by only 6 Caucasian introducers, and there are 46 introducers of the flora of Caucasus in the composition of the herbage.

The share of alien plants is slightly more than 5% and currently, they do not pose a significant threat

Table 1 The correlation of immigration groups of the species in individual sections of the plot "Caucasus"

Sections	Immigration groups of the species					Total
	cultivated plants of the Caucasian flora	cultivated plants of other floras	native plants	xenophytes	escaped plants from other plots of the Botanical Garden	
Beech Forests	39 (62.9%)	3 (4.8%)	18 (29.0%)	2 (3.2%)	–*	62 (100.0)
Deciduous Forests	67 (58.8%)	10 (8.8%)	31 (27.2%)	3 (2.6%)	3 (2.6%)	114 (100.0)
Talysh	36 (49.3%)	6 (8.2%)	21 (28.8%)	4 (5.5%)	6 (8.2%)	73 (100.0)
Woodland	62 (43.4%)	3 (2.1%)	54 (37.8%)	12 (8.4%)	12 (8.4%)	143 (100.0)
Maple Grove	22 (36.7%)	5 (8.3%)	21 (35.0%)	4 (6.7%)	8 (13.3%)	60 (100.0)
Birch Grove	14 (30.4%)	–*	25 (54.3%)	4 (8.7%)	3 (6.5%)	46 (100.0)
Meadows	63 (37.7%)	2 (1.2%)	70 (41.9%)	17 (10.2%)	15 (9.0%)	167 (100.0)
Steppe	34 (39.1%)	1 (1.1%)	43 (49.4%)	6 (6.9%)	3 (3.4%)	87 (100.0)
Platans Alley	19 (31.1%)	2 (3.3%)	30 (49.2%)	8 (13.1%)	2 (3.3%)	61 (100.0)

to introductory populations. In contrast to the beech floristic section, the phytocoenose of which is actually represented by one forest group, the stand of deciduous forests is polydominant. According to the ratio of immigration groups in its species composition, this floristic section is also stable and mature.

In the southern part of the plot "Caucasus" is a section of the Talysh relict forest. This section has great scientific value as a well-formed model of the Talysh forest and on quantity of rare and endemic species. In total, 73 species grow in this section; almost half of them (36 species) were introduced from Talysh. The share of native species is slightly more than a quarter, and alien – more than 13%. This immigration structure indicates that the vegetation cover on the plot is less stable compared to the other forest sections discussed above. This can be explained by the depleted structure of tree and shrub tiers in this section due to the mismatch of climatic conditions of Talysh and Kyiv. Therefore, the artificial model of forest coenosis from this remote Caucasus region now has a lot of free ecotones in the phytocoenotic structure, and therefore is quite prone to settlement by native and alien plants. Among the latter, there are a number of expansive, in particular: *Berberis aquifolium* Pursh, *Celtis occidentalis* L., *Lonicera tatarica* L., *Parthenocissus inserta* (A. Kern.) Fritsch, which increases the need for control of vegetation in this section.

Woodlands include the artificial phytocoenosis of oak crooked forest and arid sparse forest and are presented mainly in the form of ecotonic band groups around the steppe section. Under the tent of trees, a large number of shrubs and woods outskirt species of plants have found shelter here. Among them are 14 mostly low-growing trees, such as *Prunus mahaleb* L., *Crataegus pentagyna* Waldst. & Kit., *Juniperus foetidissima* Willd., *Quercus macranthera* Fisch. & C.A.Mey. etc., 12 shrubs, 34 herbaceous perennials. A significant share (37.76%) of the species composition belongs to native species, among which herbaceous perennials predominate, and a fairly significant share (16.78%) is occupied by alien plants. This artificial phytocoenosis was favorable for the settlement of aboriginal plant species, many of which in the conditions of NBG are confined to such habitats. The formed artificial floristic groups have rather steady and mature structures of wood and bush tiers, but the grass stand on the structure is heterogeneous. In general, the modeling of ecotone groups on the plot was quite successful, because the more long-lived tree and shrub tiers, which are a kind of phytocoenotic framework, were resistant to phytoinvasions.

The stands of the maple grove in the plot "Caucasus" were formed by species of the genus *Acer* with the participation of *Fraxinus angustifolia* Vahl subsp. *oxycarpa* (M.Bieb. ex Willd.) Franco & Rocha Afonso. High proportions of native (35.0%) and alien (20%) species of flora indicate that this phytocoenosis is far from mature and not resistant to phytoinvasions. Many years of experience in keeping the plot shows that the artificial phytocoenosis in the maple grove is under the constant influence of successions, in particular, due to the abundant undergrowth of *Acer* spp., *Cornus sanguinea* L. subsp. *australis* (C.A.Mey.) Jáv. C.A.Mey, *Celtis occidentalis* L., etc. Therefore, its existence in a state of a grouping of the park type, most suitable for the successful growth of introductory populations of rare species here, is possible only with the periodic clearing of undergrowth.

The basis of the birch grove is the stand *Betula pubescens* Ehrh. var. *litwinowii* (Doluch.) Ashburner & McAll. and *B. pendula* Roth. This section presents only 14 species that were introduced from the Caucasus, ie less than a third of the total species composition, and native flora species predominate in the floristic composition (54.35%). Currently, this artificial phytocoenosis is in a state of degradation and needs artificial support and rejuvenation. The meadow section presents various groups of meadow vegetation of the Caucasus, for example: mountain tall grass and steppe-meadow grass. In total, there are 167 species in the area of 0.6 ha, including 63 introduced from the Caucasus. The shares of native (41.92%) and alien (19.16%) species of flora are relatively high here. It should be noted that among perennial grass species in the area, Caucasian introducers make up about 46% and are slightly inferior to native species. Therefore, this artificial phytocoenosis, although marked by high representativeness, but is not mature enough and not sufficiently resistant to the influence of primarily native and alien plant species of flora. However, among the latter, there are almost no edificators and dominants, and high phytocoenotic positions in this species have introducers from the Caucasus. Of the undesirable species, only the invasive alien species *Solidago canadensis* L. has a significant effect in the late aspect.

The Caucasian steppe section with an area of 0.2 ha is located on the slope of the southern exposition. Vegetation is represented by meadow-steppe phytocoenosis. Of the 87 plant species, only 34 species were introduced from the Caucasus. Interestingly, the flora of this section is almost twice as rich as the meadow section, and the migratory structures of the

flora in both these sections are very similar. The share of local plant species in the steppe section (49.4%) is significantly higher, and alien plants (10.4%) is much lower, which indicates a higher overall resistance of the heterogeneous phytocoenoses formed here to invasions of alien species. As part of the coenotic framework – a group of perennial grasses as in the meadow section, the shares of introducers from the Caucasus (46.8%) and native species (50.0%) are almost equal. Thus, the steppe artificial phytocoenosis turned out to be quite mature and resistant to the influence of alien plants, and to a large extent, this resistance is provided by a successful combination of populations of native and introduced meadow-steppe plant species.

As part of the artificial phytocoenosis of the dendrogroup – Platans Alley 61 species of plants were noted, of which only 19 were introduced. Half (49.18%) are native forest species of flora and a fairly high share of alien plants (over 16%). This artificial phytocoenosis is not a model of aboriginal phytocoenosis, so the migratory structure of its flora can be compared with other artificial phytocoenoses that have been specially formed.

Based on the comparison of the share of rare species in the composition of phytocoenoses, the sozological value of individual sections in the plot "Caucasus" was established. The largest number of rare species of flora of the Caucasus is represented in the artificial phytocoenosis in the Beech Forests 58.1% (Table 2). The species structure of this phytocoenosis is characterized by the largest share of Caucasian plants, and the share of weeds and native species is minimal. Thus, the section on Beech Forests is an example of the successful formation of an artificial coenosis in the Botanical Garden, which is resistant to alien species and has great sozological value. This became possible due to the successful selection and acclimatization in the Botanical Garden of the main tree species of beech forests, which have now formed the coenotic structure of natural communities.

In other sections, where the share species of flora of the Caucasus in the structure of the phytocoenosis is high, the share of rare species is 17.8–26.7% (Table 2). On this sections predominate in a small proportion of weeds and this also indicates the high phytocoenotic stability of artificial phytocoenoses in the botanical garden and their high sozological value. In the section Steppe, the share of species of flora of the Caucasus is only 40.2%, but more than half of them are rare. Dominant in this artificial phytocoenosis is mainly local meadow and steppe plants, therefore, it is not stable enough in the Botanical Garden, but its sozological value is high.

Finally, the vegetation in Birch Grove, Meadows, and Platans Alley was the least resistant to native plant species and weeds. The share of species of flora of the Caucasus here is 30.4–38.9%, and rare species among them are very few – only 4.3–8.2% (Table 2). Thus, in general, there is a tendency that fully formed phytocoenoses in the Botanical Garden are more resistant to the settlement of local plants and weeds and in their composition grow the mostly high proportion of rare plant species. Instead, unformed artificial phytocoenosis are not resistant to the penetration of local plants and weeds, and their sozological value is low.

Such a regularity is characteristic of natural ecosystems. It is widely known that invasive plant species are the fastest to expand on ruderal and disturbed phytocoenoses, and in native phytocoenoses alien plants are mostly unable to successfully take root and compete with a large number of native plants and their grouping (Elton, 1958; Protopopova et al., 2002, 2014; Burda et al., 2014; Miroshnik, 2016). Empty

Table 2 Rare plants in individual sections of the plot "Caucasus"

Section	Total species	Caucasian flora species	%	Rare species	%
Beech forests	62	42	67.7	36	58.1
Deciduous forests	114	77	67.5	25	21.9
Talysh	73	42	57.5	13	17.8
Woodland	143	65	45.5	28	19.6
Maple grove	60	27	45.0	16	26.7
Birch grove	46	14	30.4	2	4.3
Meadows	167	65	38.9	11	6.6
Steppe	87	35	40.2	19	21.8
Platans alley	61	21	34.4	5	8.2

Niche Hypothesis and Species Richness Hypothesis – both hypotheses are among the main theories that explain the phenomenon of phytoinvasions (Mosyakin, 2009). However, the taxonomic richness of vegetation of specific phytocoenoses is not always a guarantee of their resistance to the spread of foreign plants (Stohlgren et al., 2001, 2003). To date, all aspects of this process have not been fully explored. But, obviously, at different stages of development of phytocoenoses their stability is provided by different levels of species richness (Mosyakin, 2009).

In Botanical Gardens and Arboretums, the impact of invasive plant species is very noticeable, as most of the plantations are artificial, and therefore they are not resistant to the impact of aggressive alien plants. For example, in the M.M. Gryshko National Botanical Garden conducted experiments on the effect of invasive alien plants on artificial steppe phytocoenoses and it was confirmed that the greatest resistance to the spread of some foreign plants has formed phytocoenoses of perennial steppe grasses (Maryushkina, 2002). To date, in Botanical Gardens and Arboretums, the most invasive activity is mainly naturalized wood escaped plants, in particular, vines. They often begin to spread uncontrolled in ruderal areas where there is no natural vegetation (Kovtoniuk, 2019; Doiko et al., 2021). The experience of studying invasive plants in the M.M. Gryshko National Botanical Garden and Syretsky Dendrological Park of national importance shows that most foreign plants are found in open grassy areas, and in shaded forest areas such species are few (Shynder, 2019; Glukhova et al., 2020). 55 invasive plants have been marked in the In the park-monument of landscape art "Feofania" (Kyiv) and most of them are spreading uncontrollably in artificial plantations and ruderal phytocoenoses (Hubar and Konyakin, 2020). Monodominant plantations of introduced shrub and perennial herbaceous plants also have high resistance to the influence of invasive plants (Didenko, 2014, 2017; Shynder and Kruglyak, 2014). This is largely due to the fact that the indigenous vegetation in the city of Kyiv is forest and therefore plantations of trees and shrubs are generally more resistant, especially to the influence of herbaceous alien plants.

Thus, the phytogeographical plot "Caucasus" is represented by a whole complex of sections, which simulated the Caucasian vegetation. Currently, the most mature and resistant to phytoinvasions were forest phytocoenoses, primarily beech and deciduous. They are dominated by introducers, and the participation of alien plants is minimal. Thus, these artificial phytocoenosis are successful models of forest ecosystems of the Caucasus. Instead, birch and maple groves have proved to be unstable and require constant intervention to maintain their condition. Artificial phytocoenoses of woodlands, meadows and steppes also proved to be stable.

In those sections where the share of native and alien plant species is high, it is necessary to conduct a purposeful introduction of Caucasian flora species to fill the habitats and increase the overall competitiveness of the artificial phytocoenosis. For those formed by artificial phytocoenosis that model natural ecosystems, the desired share of introducers in the total species composition should be at least 40–50%. This is especially important for the main tier (sub-tier) – wood tier in forest phytocoenoses, shrub-tree tier – in shrub vegetation, and dominant sub-tier of perennial grasses in meadows and steppes. That artificial phytocoenosis in the plot «Caucasus», in which the share of introducers is less than 30%, should not be considered as formed. The identified patterns of stability of phytocoenoses depending on the immigration structure of their species composition can be successfully used not only in the introduction of plants into botanical gardens but also in predicting the consequences of the introduction process.

Conclusions

According to the results of the inventory of the taxonomic composition in the plot "Caucasus" in M.M. Gryshko National Botanical Garden, the artificial phytocoenoses that model the forest vegetation of the Caucasus region are mature. Artificial phytocoenoses of sparse forests, steppes, and meadows also have a great variety of introduced plants of the Caucasian flora, but in this, they are significantly inferior to the natural plant communities of the Caucasus region. Those artificial phytocoenoses, in which the share of introduced species is less than 30%, it is inexpedient to call formed. In general, there is a tendency that in the conditions of the botanical garden mature artificial phytocoenoses are the most resistant to the penetration of unwanted native plants and weeds. In the composition of such plant communities are usually found many rare plants that form stable populations.

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