Ekológia (Bratislava) Vol. 39, No. 4, p. 322–332, 2020
DOI:10.2478/eko-2020-0026

THE ALIEN FRACTION OF THE WOODY FLORA OF YELANETSKYI STEP NATURE RESERVE, SOUTHERN UKRAINE

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Abstract

Konaikova V.O., Vakarenko O.V.: The alien fraction of the woody flora of Yelanetskyi Step Nature Reserve, southern Ukraine. Ekológia (Bratislava), Vol. 39, No. 4, p. 322–332, 2020.

Results of investigations on the patterns of distribution and dispersal of alien species of trees and shrubs in the territory of a steppe protected area, Yelanetskyi Step Nature Reserve (Mykolaiv Region, southern Ukraine), are presented. We registered within this protected area 10 alien woody species. For the most widespread ones (*Ulmus pumila* L., *Gleditsia triacanthos* L., *Elaeagnus angustifolia* L., *Robinia pseudoacacia* L.), we carried out ecological analyses. In order to establish the scope of impact of ecological factors upon these species, their specificity, and interdependence between ecological factors, the phytoindication method was applied (Didukh, 2012). The results of our analysis conducted on 12 main ecological factors (as outlined by Didukh, 2011), such as soil water regime (Hd), variability of damping (Fh), soil aeration (Ae), soil acidity (Rc), nitrogen content (Nt), salt regime (Sl), carbonate content in soil (Ca), thermoregime (Tm), climate humidity (Om), continentality (Kn), cryoregime (Cr), and light intensity (Lc), show that dispersal of model alien species does not have ecological limitation. However, *E.angustifolia* and *R.pseudoacacia* have the strongest capacity to penetrate the steppe communities, especially disturbed ones. Further dispersal of these alien species in the studied area and adjacent territories is hampered only by the integrity of the structure of steppe communities.

Key words: invasions, forestation, steppe, phytoconenoses.

Introduction

The Ukrainian steppe region is the second largest steppe region in Europe in terms of its area, following only the Russian European steppes. Because of that, the Ukrainian steppes are of exceptional importance for the conservation of steppe biodiversity. However, only 1% of the Ukrainian steppe region is covered at present by natural vegetation, while most of its territory is used for agriculture. Despite this, current estimates (Burkovskiy et al., 2013) indicate that even this 1% contains habitats of almost 30% of plants and animals listed in the Red Data Book of Ukraine (Didukh, 2009). This is the main reason why special attention should be paid to the protection of these territories.

The steppe flora complexes are most severely affected by anthropogenic influence, which often leads to the irreversible loss or degradation of steppe plant communities. The extremely fragmented steppe ecosystem is represented by small "islands" usually surrounded by stands of synanthropic vegetation. Following agricultural activities, afforestation, overgrazing, recreational activities, industry, fires, and climate changes have the greatest impact on steppe ecosystems. All these factors make a strong negative effect on the stable plant communities' structure,which leads to favorable conditions for the alien species. Even without anthropogenic impact, restoration of the aboriginal steppe complex is often slowed down for a long time because of competition with invasive species. Rare feathergrass (*Stipa* spp.) formations and fragments of steppe shrublands formed by *Caragana frutex* (L.) K. Koch and *Amygdalus nana* L. disappear not only because of overgrazing, but also due to the presence of synanthropic plants, including alien species, in the vegetation.

This cumulative effect of a large number of synanthropic species inhibits the restoration of the natural floristic composition of communities and leads to complete disappearance of the steppe flora (Protopopova et al., 2002). Besides, areas of artificial afforestation can act as sources of these alien species. Non-native species such as *Ulmus pumila* L., *Gleditsia triacanthos* L., *Elaeagnus angustifolia* L., and *Robinia pseudoacacia* L. are commonly used in forestry in the Ukrainian steppe region because of their high adaptability to the climate of the area and the high rates of growth and recovery,though in order to improve the zonal chernozems' state and fertility in the conditions of the steppe zone of Ukraine, it is more expedient to use nature flora species, for example, *Quercus robur* (Gorban et al., 2020).

The present research aimed to compile a list of alien species of trees and shrubs, in order to determine the distribution patterns of the model species within the study area,conduct their ecological analysis, and establish the amplitudes of ecological factors for these species, their specificity, and interdependence between ecological factors.

Material and methods

For the analysis, we used relevés made by the authors within the territory of the nature reserve in May 2019. We used 41 relevés made by the authors to estimate the ecological amplitudes of invasive species. The plot sizes for relevés were from 25 to 100 m^2. All relevés were compiled in TURBOVEG (Hennekens, Schaminee, 2001) database. Floristic data were processed using JUICE (Tichý, 2002; Roleček et al., 2009). Calculation of environmental parameters was performed according to standardized scales of synphytoindication ecological amplitudes developed by Didukh (Didukh, 2000). Using the synphytoindication method (Didukh, 2012), we conducted our analysis of12 factors (Didukh, 2011): soil water regime (Hd), variability of damping (Fh), soil aeration (Ae), soil acidity (Rc), nitrogen content (Nt), salt regime (Sl), carbonate content in soil (Ca), thermoregime (Tm), climate humidity (Om), continentality (Kn), cryoregime (Cr), and light intensity (Lc). The method of Determined Correspondence Analysis (DCA)-ordination (Hill, Gauch, 1980) based on the computer language R (Venables, Smith, 2009) integrated into the JUICE software package was used in order to identify the main environmental factors of the plant communities' differentiation.

The classification of the alien species according to Kornaś (1968), as modified by Protopopova (1991) was followed;morphological types of plants in relation to moisture were determined following Didukh et al. (2000), and invasive species and transformers were determined following Richardson et al. (2000). The nomenclature of species mainly followedthe checklist of vascular plants of Ukraine (Mosyakin, Fedoronchuk, 1999), with necessary amendments. The high-rank syntaxa (class, order, union) were considered according to the European classification of vegetation (Mucina et al., 2016).

Study area

At present, the Yelanetskyi StepNature Reserve is the first and still the only steppe reserve in the Right-bank part, Ukraine (i.e., in the territory west of the Dnipro [Dnieper] River). It is located in the Yelanets and Nova Odesa districts (raions in Ukrainian) of Mykolaiv Region (oblast in Ukrainian). The territory belongs to the steppe zone of the North-steppe subzone. The natural conditions within the reserve are rather variable. The vegetation of the nature reserve includes the communities belonging to classes *Festuco-Brometea*, *Rhamno-Prunetea*, *Phragmo-Magnocaricetea*, *Agropyretea*, and *Robinietea* (Kolomiychuk et al., 2012).

The Yelanetskyi StepNature Reserve consists of two nature conservation research departments (branches). The first Yelanets department was established in 1996 to protect the largest array of virgin steppes in the Northwestern Black Sea region. In 2016, the reserve's area was expanded by the accession of the territory near Mykhailivka village of Nova Odesa District. Now, the total area of the reserve is 3002 ha, with 1667 ha in the Yelanets department and 1335 ha in the Mykhailivka department (Derkach, 2011; Kolomiychuk et al., 2012). We carried out our research in this new part of the reserve because almost no information on alien species was available for that location. So, we began the phytocoenotic monitoring to identify the initial state of vegetation in this territory.

The topography of the Mykhailivka department is gently rolling;it is represented by the system of the ravines Velyka Divchyna and Kemlycha, which belong to the basin of the South Buh (*Pivdennyi Bug*) river. It is characterized by the presence of the rocky slopes, with outcrops of Pontic limestones.

The studied area is located close to agricultural lands and artificial forest plantations and outlined by the forested field protection beltsthatare mainly formed by alien woody species. Also, a large part of the Mykhailivka department is affected by illegal grazing.

Results

We found 10 alien woody specieswithin the territory of investigation. By their life form, eight of them are trees (*Acer negundo, Ailanthus altissima, Fraxinus pennsylvanica, Gleditsia triacanthos, Morus alba, Prunus armeniaca, Robinia pseudoacacia, Ulmus pumila*) and two species can grow as trees or shrubs (*Amorpha fruticosa, Elaeagnus angustifolia*). All species in our list are kenophytes, but the time of their introduction is very different. For example, *Prunus armeniaca* L. is known in this territory since the fourth millennium BC, but most of these species were introduced in the 18th–19th century. Most of the analyzed species are ergasiophytes (species escaped from cultivation), except *Acer negundo* L., which is an ergasio-ksenophyte. By their adaptations to humidity conditions, six species are xero-mesophytes (*Ailanthusaltissima, Elaeagnus angustifolia, Fraxinus pennsylvanica, Gleditsia triacanthos, Morus alba, Robinia pseudoacacia*), two are mesophytes (*Acer negundo* and *Amorpha fruticosa*), and two are meso-xerophytes (*Prunus armeniaca* and *Ulmus pumila*). By their degree of naturalization, three species are agrio-epoecophytes (*Acer negundo, Ailanthus altissima, Amorpha fruticosa*), two are epoecophytes (*Robinia pseudoacacia* and *Ulmus pumila*), two are ergasiophygophytes (*Morus alba* and *Gleditsia triacanthos*), one is an agriophyte (*Elaeagnus angustifolia*), one is an ephemerophyte (*Prunus armeniaca*), and one is a colonophyte (*Fraxinus pennsylvanica*). Five of 10species are considered to be invasive for Ukraine (*Acer negundo, Ailanthus altissima, Amorpha fruticosa, Elaeagnus angustifolia, Robinia pseudoacacia*) and four of them are also considered to be transformers (*Acer negundo, Ailanthus altissima, Amorpha fruticosa, Elaeagnus angustifolia*). Five species are of North American origin (*Acer negundo, Amorpha fruticosa, Fraxinus pennsylvanica, Gleditsia triacanthos, Robinia pseudoacacia*), four species have their native ranges in Asia (*Ailanthus altissima, Morus alba, Prunus armeniaca*, *Ulmus pumila*), and one species has a Mediterranean origin (*Elaeagnus angustifolia*).

Here we provide data about the revealed species, their cultivation in the Ukrainian steppe region, and the localities in Mykhailivka department.

1. *Acer negundo* L. (Aceraceae). According to available data (see Protopopova, Shevera, 2014.), this species was initially cultivated in the Ukrainian steppe region in 1825–1830 in the Trykraty Park of Count Skarzhynskyi, now in Mykolayiv Region. Nowadays, it is widespread on and along the roadsides and in other ruderal areas; it also can be a component of the forest belt edges. In the area of our investigation, it was found occasionally on the slopes of ravines.
2. *Ailanthus altissima* (Mill.) Swingle (Simaroubaceaeh). In the Ukrainian steppe region, it was probably first planted in 1820 (Simferopol, Crimea), but its dynamic introduction process began in 1875–1883. Now, this species is used in forestry as a component of forest belts, but it also spread widely in rural areas.In the Mykhailivka department, we found one location of this species on the border of the reserve and Mykhailivka village (see Fig. 1).
3. *Amorpha fruticosa* L. (Fabaceae). The first reliable record of this species in the Ukrainian steppe was in the mid-19th century in the Trykraty Park (see above). Nowadays, this transformer species spreads dynamically, mainly along waterways, but also on roadsides and other disturbed habitats. In the territory of our investigations, only a few shrubs were found in a ravine thalweg and a small group near Mykhailivka village.
4. *Elaeagnus angustifolia* L. (Elaeagnaceae) was introduced in the steppe region in Ukraine-around 1830 as an ornamental plant in private gardens (Palimpsestov, 1855). Then the species was cultivated along railways and roads, and in plantations in the Black Sea region. Since that period, it spread widely (Protopopova et al., 2006). In the surveyed territory, it occurs as a subdominant species in artificial forest plantations, from where it spreads through the gorges at the limestone outlets, at the border of the thalwegs, and slopes of ravines (see Fig. 1).
5. *Fraxinus pennsylvanica* Marshall (Oleaceae) has beenknown in steppe forestry since 1783, as well it was used as an ornamental plant (Sokolov, 1960). We found one location in the Mykhailivka department on the northern border of the reserve on the edge of a *Gleditsia triacanthos* plantation.
6. *G. triacanthos* L. (Fabaceae) in the steppe zone was used for hedgerows as reclamative and ornamental trees since the beginning of the 19th century (Sokolov, 1958). This species is frequently used in forestry as the main component of forest belts in the steppe region. In the Mykhailivka department, this species is present as a dominant in *G.triacanthos–Cotinus coggygria* forest belts in the western part of the reserve and also in a monodominant plantation in the northern part (see Fig. 1).
7. *Morus alba* L. (Moraceae) is known as a cultivated plant in the steppe zone at least since the 7th century. In modern forestry, this speciesis commonly used as a component of the forest belts all over the steppe region. Within the territory of our investigation, *M. alba* was found occasionally in the forest belts.
8. *Prunus armeniaca L.* (*Armeniaca vulgaris* Lam.) (Rosaceae) has beenknown within the present-day territory of Ukraine since ancient times. The first archaeological findings are dated back to about 4 millennium BC (Yanushevich, 1976). In modern forestry, *Prunus armeniaca* is commonly used as a component of forest belts all over the region. In the

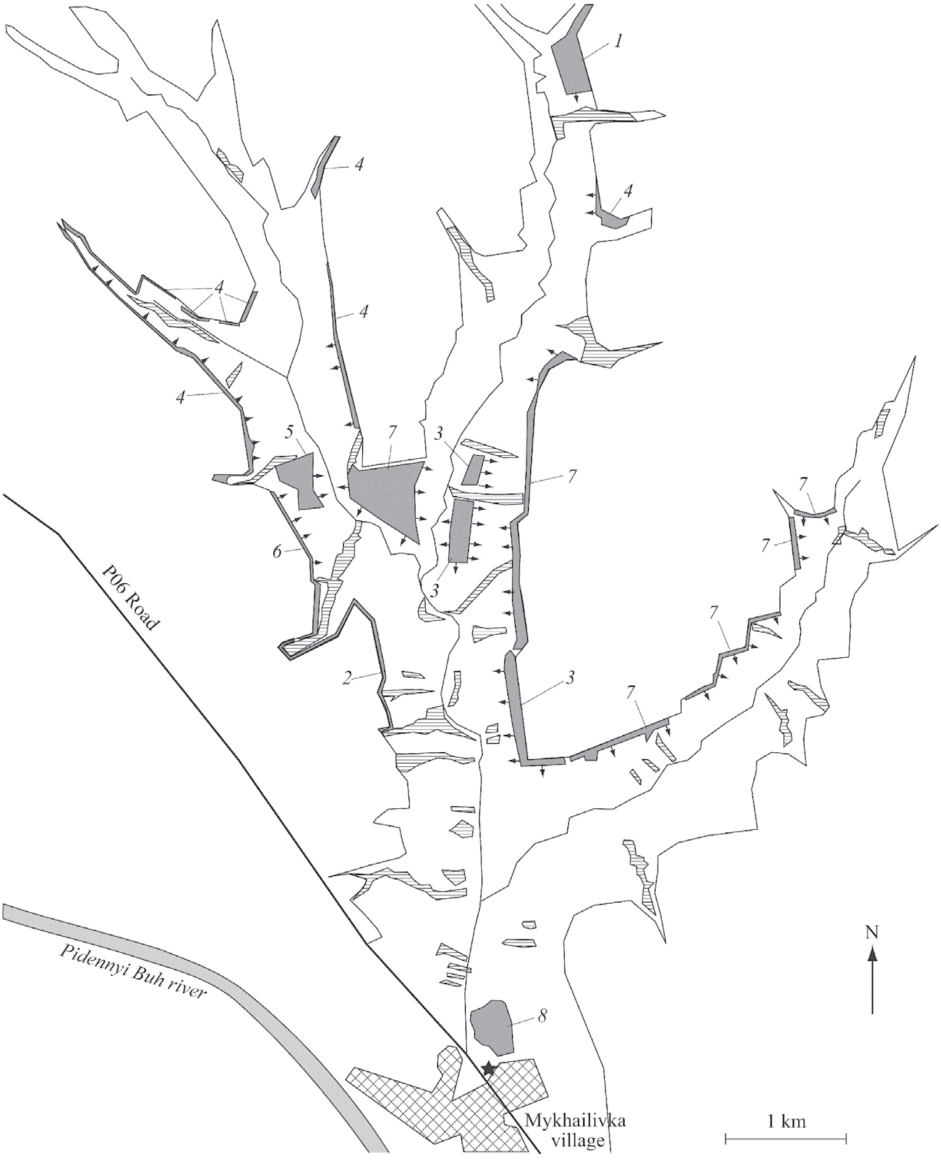

Fig. 1. Map of the locations of tree communities with invasive tree species and invasive species pathways of dispersal: ▩ — Forest plantation which includes invasive species; 1 – monodominant plantation of *Gleditsia triacanthos*; 2 – old-aged forest belt with *G.triacanthos* in the shelter and *Cotinuscoggygria* in the shrub layer; 3 – monodominant plantations of *Ulmus pumila* L.; 4 – plantations with participation of*U.pumila*; 5 – monodominant plantations of *Robinia pseudoacacia*; 6 – plantations with participation of*R.pseudoacacia*; 7 – plantations with participation of*U. pumila* and *R.pseudoacacia*; 8 – plantations with participation of*U.pumila* and *Amorpha fruticosa*; ▨ – ravine forest with *Elaeagnus angustifolia*; ★ – location of *Ailanthus altissima*; ◄— – pathways of invasive species dispersals.

Mykhailivka department, it was found occasionally on steppe slopes and in forest belt.

9. *Robinia pseudoacacia* L. (Fabaceae) has beenwidely cultivated in the steppe region since the beginning of the 18th century as a reclamative and ornamental plant, as well as a dominant in the forest belts (Sokolov, 1958). Nowadays, it has widely spread in ruderal areas, but it is still commonly used as a component of forest belts. It is widespread in the territory of the Mykhailivka department, in particular, in the forest plantations as a dominant and a subdominant (see Fig. 1). These plantations are held by the Mykolaiv Forest Management State Company.
10. *Ulmus pumila* L. (Ulmaceae). It is frequently used in forestry in the steppe region and also as an ornamental. This species is also widespread in the Mykhailivkadepartment as a dominant and subdominant in forest plantations (see Fig. 1). These plantations are managed by the Mykolaiv Forest Management State Company.

Figure 1 shows the locations of tree communities with invasive tree species and directions of dispersal of these species. In the northern part of the reserve on the top of ravine, there is an old-aged monodominant plantation of *Gleditsia traicanthos* (see Fig. 1). Here, this species started spreading downward by massive root shoots.It happens most likely due to disturbance of phytocoenoses and the soil layer in general which is caused by agricultural activity in this zone, in particular, laying of the dirt road. The most common species planted in the territory are *Robinia pseudoacacia* and *Ulmus pumila* (see Figs 1, 3–8). Both species have high seed productivity and are relatively active in spreading in the parts of the ravine with soil disturbance or phytocoenosis degradation, in particular, erosion, soil alluviation from fields on the perimeter, and fire-damaged and overgrazed areas. *Elaeagnus angustifolia* is confined to ravine forests and is found on slopes throughout the reserve.

According to our preliminary investigation results, four most widespread species (*Ulmus pumila*, *Gleditsia triacanthos*, *Elaeagnus angustifolia*, *Robinia pseudoacacia*) were selected as the model taxa and were involved in the ecological analysis (see Fig. 2).

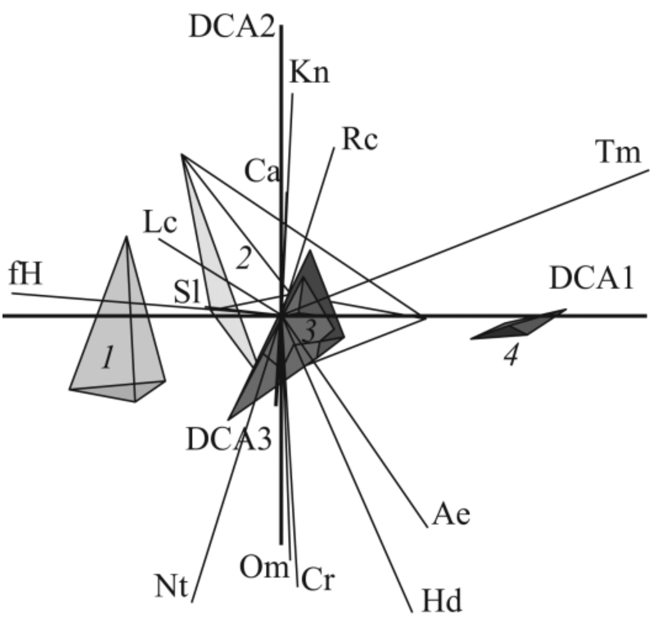

Fig. 2. Results of the DCA-ordinations of model species: 1 – *Gleditsia triacanthos* L.; 2 – *Ulmus pumila* L.; 3 – *Elaeagnus angustifolia* L.; 4 – *Robinia pseudoacacia* L.

The DCA-ordination analysis on biotopes formed by model species showed that ecological differentiation was mainly determined by the salinity and variability of damping for *Gleditsia triacanthos* L. and by the aeration for *Robinia pseudoacacia* L. Therefore, some limitation for their further spread does exist. There is no dependence observed for the distribution patterns of *Ulmus pumila* L. and *Elaeagnus angustifolia* L. The steppe communities' stable structure is the main factor that restricts the spread of alien species, including even some invasive ones.

For each species, the values of ecological parameters were calculated using the synphytoindication method. Also, we calculated the values for natural plant communities for this area, which are represented by communities of alliances *Festucion valesiacae* Klika 1931, *Stipion lessingianae* Soo 1947, *Potentillo arenarie–Linion czerniaevii* Krasova et Smetana 1999, from the class *Festuco-Brometea* (see Table 1). Detailed characteristics of syntaxa are given in our earlier publication (Konaikova, 2019).

It is established that the actual ecological amplitudes of alien species for some factors are wider than the theoretically estimated amplitudes for these species and factors (Didukh, 2011). Ecological amplitudes of steppe communities and alien species overlap for the fol-

T a b l e 1. Ecological characteristics of the analyzed species.

Characteristic	Ecological factors value											
	Hd	fH	Rc	Sl	Ca	Nt	Ae	Tm	Om	Kn	Cr	Lc
Gleditsia triacanthos												
Min.	9.6	5.5	8.5	7.3	7.6	5.3	5.95	9.6	10.7	8	8.38	6.3
Max.	10.72	6.7	8.85	8.35	8.1	5.72	6.8	10.5	11.5	9.75	10.13	7.25
Mid.	10.3	6	8.68	7.7	7.82	5.53	6.3	10.09	11.01	9.17	9	6.66
Theor. ampl.	8–15	5–9	5–11	7–12	9–12	3–7	4–8	10–12	6–12	6–13	9–11	7–9
Eleagnus angustifolia												
Min.	8.97	6.17	8.38	8.13	6.88	4.6	5.87	8.86	10.72	8.95	8.31	6.25
Max.	10.75	6.75	9.07	8.95	9.47	6.25	7	9.86	11.88	10.28	9.5	7.69
Mid.	9.57	6.39	8.74	8.53	8.23	5.42	6.2	9.43	11.23	9.4	8.87	7.22
Theor. ampl.	2–17	2–11	7–12	8–14	5–11	3–7	3–11	7–13	7–14	5–17	6–12	6–9
Robinia pseudoacacia												
Min.	8.54	5.7	7.38	7.13	6.13	5.42	5.58	8.38	10.15	7.5	8.2	6.88
Max.	11.25	6.93	9.04	8.9	9.15	7.5	6.71	9.62	13.25	9.89	9.63	7.85
Mid.	10.03	6.43	8.22	8.25	7.65	6.33	6.2	9.17	11.58	8.78	9	7.37
Theor. ampl.	5–16	4–10	5–12	5–10	5–9	5–10	3–8	8–14	11–15	5–10	9–12	5–9
Ulmus pumila												
Min.	7.79	6	7.5	7.17	6	4.77	5.44	9	9.86	8.63	.8	6.25
Max.	11.88	7.38	9.29	9.21	9.14	6.63	7.63	9.75	12.25	11.29	9.25	7.5
Mid.	10.03	6.45	8.7	8.39	7.9	5.46	6.42	9.27	11.2	9.68	8.44	7.09
Theor. ampl.	9–16	3–9	6–12	5–10	6–10	4–9	3–7	7–11	10–15	5–17	3–12	7–9
Steppe communities												
Amplitude	7–9	5–7	8–9	8–9	8–10	4–5	5–6	9–10	9–11	9–11	8–10	7–9

lowing ecological parameters: for edaphic factors –variability of damping (Fh), soil acidity (Rc), salt regime (Sl); and for climate factors –thermoregime (Tm), continentality (Kn), and cryoregime (Cr) (see Fig. 3).

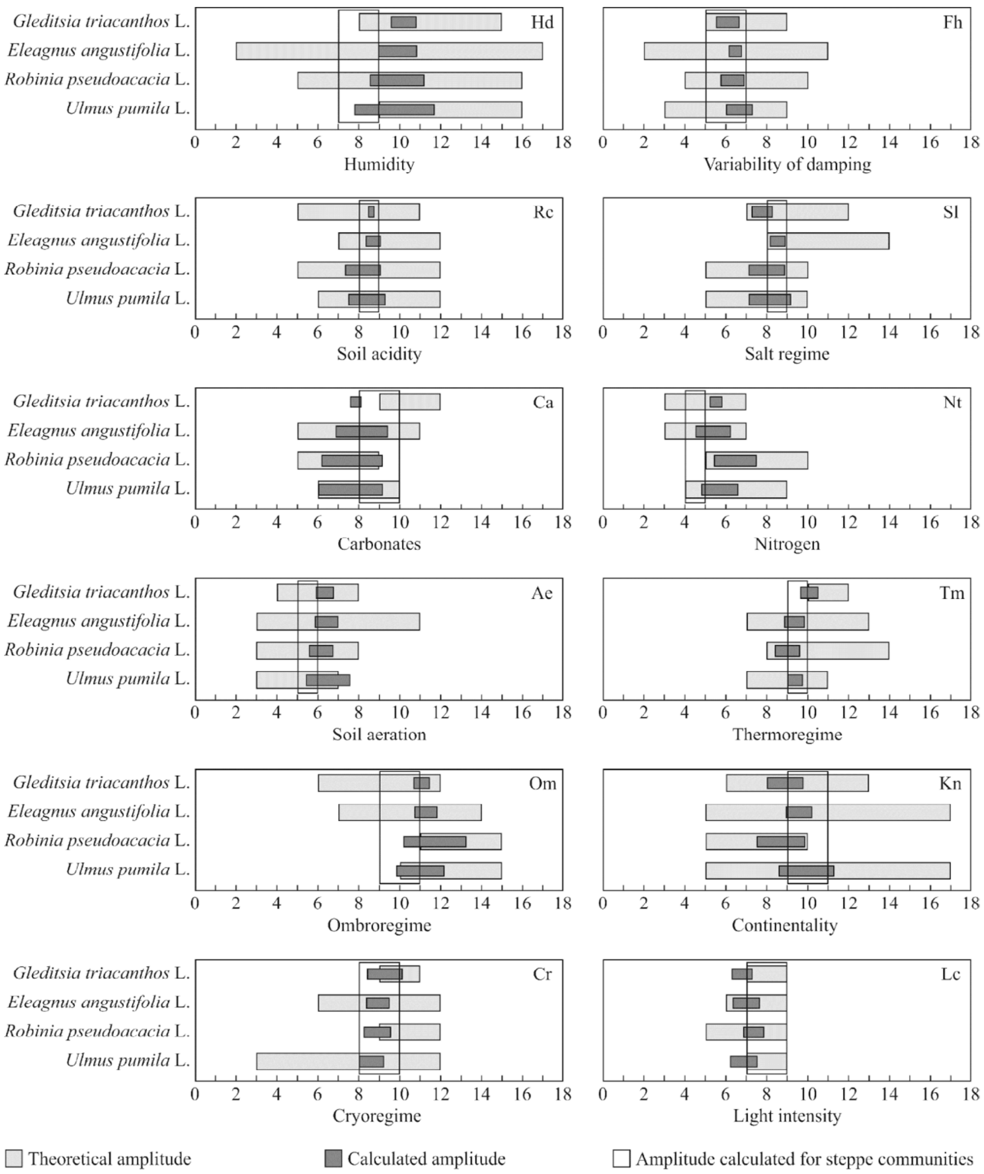

Fig. 3. Ecological factors amplitudes.

Phytoindication analysis by soil moisture gradient (Hd) showed that the studied species exist under unfavorable conditions because they belong to submesophytes – plants of dry forest–meadow ecotopes with moderate wetting of the root layer of soil and with annual precipitation and melted waters about 90 mm. However, the soil's natural conditions are subxerophytic and are represented by dry soils of meadow–steppe ecotops, with small rain and melted water moistening of the soil layer. The ecological requirements of *Ulmus pumila* most closely correspond to the humidity conditions of the steppe communities.

According to the variability of damping (fH), the species *Elaeagnus angustifolia* and *Ulmus pumila* are in the hemihydrocontrastophilic conditions, as well as some steppe communities, and exist in ecotopes with irregular wetting of the soil layer where plant roots penetrate, badly humidified by precipitations and melted waters. *Gleditsia triacanthos* and *Robinia pseudoacacia* exist here under hemihydrocontrastophobic conditions and require precipitation and meltwaters enough for full soil wetting.

In relation to the acidic soil regime (Rc), our analysis evidenced that the species *Gleditsia triacanthos*, *Elaeagnus angustifolia*, and *Ulmus pumila* are similar to the species of steppe communities of neutrophilic soil conditions with a pH value of 6.5–7.1. Only *Robinia pseudoacacia* occurs here under slightly acidic conditions (pH values 5.5, 5).

The values of the total soil salt regime (Sl) indicate that *Elaeagnus angustifolia*, as well as steppe ecosystems, exists under eutrophic conditions. The rest of the studied species grow in semi-eutrophic conditions with a lower content of salts in the soil.

Analysis of the soil carbonate content demonstrates that all alien species, especially *Gleditsia triacanthos*, tend to be under carbonatophilic conditions, with small amounts of carbonate content in the soil (CaO, MgO = 0.5–1.5%). On the other hand, for the steppe communities, hemicarbonatophilic conditions on carbonate-enriched soils (CaO, MgO = 1.5–5%) are natural.

In relation to nitrogen content, alien species require nitrophilic conditions with 0.3–0.4% nitrogen content in the soil. Steppe conditions are heminitrophilic, poorer in mineral nitrogen (0.2–0.3%). The species most sensitive to nitrogen deficiency is *Robinia pseudoacacia*.

Values of thermo- and cryo-regime parameters demonstrate that alien species, as well as steppe communities, are in the same sub-mesothermal and hemicryophytic conditions.

As for the climate continentality, alien species, as well as the steppe communities, are in hemicontinental conditions.

In relation to climate humidity, the species under study are subaridophytes, and thus, they require higher climate humidity against the mesoaridophytic regime of the territory.

The data from the light intensity are not indicative because the species in the forest plantings grow with well-shaded species in the herb layer. Instead, in the steppe communities, all species in the relevés receive approximately the same amount of light.

In summary, invasions of alien species into natural communities are successful if the natural communities are in a stress zone and their coenotic structure is disturbed (Budzhak et al., 2019). Based on the obtained data, it can be assumed that *Ulmus pumila* and *Elaeagnus angustifolia* have the greatest ability, among the studied species under local conditions, to penetrate and change the steppe vegetation, since their dispersal is not restricted by the ecological factors, but is hampered only by the integrity of the structure of the steppe communities.

Conclusion

The value of the Ukrainian steppe region for biodiversity conservation is extremely high. Followingagriculturalactivities, afforestation, overgrazing, recreational activities, industry, fires, and climate changes have the greatest impact on steppe ecosystems loss. The artificial afforestation objects (such as plantations, forest belts, etc.) can act as sources of and migration pathways for alien species. Non-native species, such as *Ulmus pumila*, *Gleditsia triacanthos*, *Elaeagnus angustifolia*, *Robinia pseudoacacia*, are commonly used in forestry in the Ukrainian steppe region.

The following categories dominate in our list of alien woody plants: by the time of introduction (immigration) –kenophytes, by the mode of introduction –ergasiophytes, by the degree of naturalization –agrio-epoecophytes, by relation to moisture –xero-mesophytes, by the origin –North American.

According to the preliminary investigation data, the four most widespread woody species were chosen as the model ones and were involved in a more thorough ecological analysis. The model species are relatively active in spreading in the parts of the ravine system with soil disturbance or phytocoenosis degradation, in particular, erosion, soil alluviation from fields on the perimeter, fire-damaged areas, and overgrazed areas.

Taking into account the results of our ecological analysis, the alien species can be successful in their invasion into natural steppe communities if these natural communities are in a stress zone and their coenotic structure is disturbed. Additionally, dispersal of the species is not restricted by ecological conditions in the studied reserve, but by the integrity of the structure of the steppe communities. Meanwhile, *Ulmus pumila* and *Elaeagnus angustifolia* have the highest ability for spreading within the studied area and adjacent regions.

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