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Populations of *Heracleum sosnowskyi* and *H. mantegazzianum* (Apiaceae) in Kyiv (Ukraine)

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Abstract

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In connection with the increasing negative impact of invasive alien species on biodiversity and the environment in general, their research, as well as throughout the world, is relevant. The distribution of the *Heracleum sosnowskyi* and *H. mantegazzianum* of the secondary range on the example of the Kyiv agglomeration is investigated in the work. In our study we aimed to evaluate the possibility of spontaneous spread of giant hogweeds in the secondary range, adaptation of the species to the new conditions of the environment that favor to control of these species' expansion and reduce the threat to the urban ecosystems and citizens' health. We hypothesise that in the secondary range *H. sosnowskyi* and *H. mantegazzianum* settle sites with relatively high temperature (Tr), lightening (Lc), and soil moisture conditions similar to that in their natural range. 17 populations and four localities (sites) of *H. sosnowskyi* and *H. mantegazzianum* were studied. They were found within forest, meadow, riverine and ruderal plant communities. It is indicated that the advent species fully adapted to the conditions of the environment. The difference by ecological indicators Lc2 and Tm1 is pointed out. According to the results of our research, for the area of Kyiv urban agglomeration the growth of *H. sosnowskyi* and *H. mantegazzianum* is indicated in the plants communities of six classes. They spread most in ruderal plant communities of the: Robinietea, Artemisietea, Epilobietea classes. The studied species belong to invasive plant species in Ukraine and are characterized by extremely high effect on the environment and high invasive potential.

Keywords

giant hogweeds, invasive alien species, Kyiv, populations

Introduction

During the recent decades in the world the negative effect of the alien plant species on the environment has increased due to the transformation of natural ecosystems by a man, particularly the regulation of reservoirs, large-scale deforestation, recreational load, artificial drainage and flooding of the territories, and, also, climate change (McNeely et al., 2001; Stukalyuk et al., 2019; Rai and Singh, 2020). This issue has been of great importance as the invasion of alien plant species causes irreparable damage to the existence of the aboriginal species and normal function of the ecosystems. The fight with the most dangerous alien plant species, according to the data of the Global Invasive Species Programme (GISP), costs mankind 1.4 trillion dollars annually. The modern world practice considers the problem of the biological invasions to be one of the greatest threats to the biotic diversity (Reaser et al., 2003; *Biological invasions: a growing threat to biodiversity, human health and food security,* 2012; *European Strategy on Invasive*

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Alien Species, 2015; *European Commission,* 2017). Over the past 20–30 years the rapid spread and active invasive potential of *Heracleum sosnowskyi* and *H. mantegazzianum* (Apiaceae) have been recorded all over the world (Lamdon et al., 2008; *Centre for Agriculture and Biosciences International* (CABI), 2019).

Now, the alien range of Sosnowski's hogweed (*Heracleum sosnowskyi)* recognized as invasive in a number of countries: the Baltic States (Balezentiene et al., 2013; Mezaka et al., 2016), Republic of Belarus (Laman et al., 2009), Ukraine (Vykhor and Prots, 2012), European part of Russia (Panasenko, 2017; Arepieva et al., 2021), sporadically occurring Poland (Klima and Synowiec, 2016), Hungary (Kabuce and Priede, 2010) and Denmark (Jahodová et al., 2007). In a number of countries Sosnowski's hogweed received the status of invasive and was not officially registered at the state level, particularly in Denmark, Serbia, Bulgaria (Vladimirov et al., 2019), Georgia, Armenia, Azerbaijan, Turkey, the Russian Federation (*Centre for Agriculture and Biosciences International* (CABI), 2019).

The Giant hogweed (*Heracleum mantegazzianum*) is recognized as invasive in a number of countries: the USA (Case and Beamon, 1992), Canada (Page et al., 2006), and European countries: Hungary (Csiszár et al., 2020); Slovakia (Fehér, 2000; Pauková et al., 2019); Germany (Rajmis et al., 2016); Czech Republic (Moravcová et al., 2018); Denmark (Andersen and Calov, 1996); Ireland (Caffrey, 1999) and other countries. In a number of countries hogweed received the status of invasive and was not officially registered at the state level, particularly in Australia, New Zealand, Turkey, Iran, Georgia, the Russian Federation, Ukraine, the Republic of Poland, Greece, Iceland, Latvia, Slovenia, Bosnia and Herzegovina (Maslo, 2010; *Centre for Agriculture…*, 2019).

In Central Europe, *Heracleum* species had been as decorative plants since 1890 (Mandenova, 1950). However, quite rapidly the two properties were manifested, that limiting their cultivation: frequent cases of dermatitis, and a fast spread by self-seeding and vegetatively beyond the measures of cultivation (Sazyperova, 1984; Burda, 2007).

Apart from being of great threat to the biodiversity, giant hogweeds are toxic for livestock and people health (Drever and Hunter, 1970a). The stems, leaves, and fruits of the giant hogweed contain noxious sap that raises the skin's sensitivity to the sunlight. Due to the presence of furocoumarins (psoralens) in the cell sap, touching these plants can cause skin irritation, severe dermatitis (phytophotodermatitis) and a second-degree burn. Effects may include welts, rashes, and blistering, followed by pigmented scarring that may persist for as long as six years. The giant hogweeds are also dangerous for children, especially if the juice penetrates into the eyes. In extremely rare instances, full skin thickness burns or epidermal necrosis occur (Patocka and Cupalova, 2017).

It is worth mentioning that being a part of the flora of Ukraine the alien species that got adapted to the changing conditions quite rapidly settle new localities, and sometimes intensively increase the number of the species that leads to the phytoinvasions (Burda et al., 2015). Those alien species include invasive species, in particular the ones being under the research *H. sosnowskyi* and *H. mantegazzianum* (Apiaceae).

Due to the absence of competitors and natural enemies, those giant hogweeds make up dense thickets of the populations Giant sizes, speed of biomass accumulation and a high degree of plasticity allow these plants be able to alter the structure of the population of the aboriginal species, particularly, in the meadow-forest and coastal-water communities, up to their total displacement, in a short period (Vykhor and Prots, 2012).

Actually, the spread of the giant hogweeds in Ukraine began from the Transcarpathian region to the Polissya region. Expansion of giant hogweeds in Ukraine took place at the end of 1976, when they began to occupy the disturbed forests and nodes, floodplains, ravines, beams, parks, gardens, roadsides (Protopopova et al., 2002). The peculiarities of giant hogweeds spread on the territory of Ukraine were enlightened in the publications, in particular on the territory of Polissya (Lukash and Zavyalova, 2003; Mykhalyuk et. al., 2017; Khomyak et al., 2019; Oitsius et al., 2020) and Transcarpaphiya (Protopopova et al., 2006; Simpson et al., 2011; Vykhor and Prost, 2012). It was pointed out that the harmful for the peoples health wild plants of the mentioned species from the genus of *Heracleum* (Burda, 2005) often come out the agricultural landscape of Ukraine. In particular, intensive spread of these two species along the springs and beams in Zhytomir (town Ovruch and village Ruzhyn), Vinnytsya (town Shargorod and village Teplyk) and Kyiv (village Velyka Snyatynka) regions was showed.

The urbanisation favours adventisation of vegetation and exerts a negative effect on Kyiv's biotypes. New locations of invasive species giant hogweeds were recorded within the Holociivskyi forest (Burda, 2007; Bagatska, 2008; Onyshchenko et al., 2016); in the suburbs of the village Khotiv (Kyiv-Svyatoshyn region) and in the local landscape Feofania (Gubar and Koniakin, 2020). A location of single individuals of *H. sosnowskyi* was recorded on the shoreline of the lake Syretske in Kyiv (T. Bahatska personal communication). In this work the comprehensive research of giant hogweeds species was carried out for the first time in Kyiv and its suburbs to find out the ways of the species active spread and their intrusion into various communities.

In our study we aimed to evaluate the possibility of spontaneous spread of giant hogweeds in the secondary range, adaptation of the species to the new conditions of the environment that favour to control of these species' expansion and reduce the threat to the urban ecosystems and citizens' health. We hypothesise that in the secondary range *H. sosnowskyi* and *H. mantegazzianum* settle sites with relatively high temperature, lightening, and soil moisture conditions similar to that in their natural range.

Study species

The genus *Heracleum* (Apiaceae) includes 60–148 species of perennial or biennial herbs, distributed in the temperate northern hemisphere and in high mountains as far south as Ethiopia (*Tropicos.org. Missouri Botanical Garden*, 2021). Centres of the highest species diversity are the Caucasus Mountains (26 species) and China (29 species), particularly

Hengduan Mountains (Mandenova, 1950; Fading and Watson, 2005). We presented a brief botanical description of two studied species of the genus *Heracleum* (*H. sosnowskyi, H. mantegazzianum*).

Sosnowski's hogweed (*H. sosnowskyi)* was described as a separate species by I. Mandenova in 1944 (Lapiņš et al., 2002; Oboļeviča, 2001). *H. sosnowskyi* is biennial or perennial plant of the Caucasus origin (Mandenova, 1950). Height is usually 1–3 meters. The stem is ridged and sparsely hairy with purple blotches. On the upper surface the leaves are hairless and below slightly hairy. The leaf margins have short rounded teeth. The flowers are white, sometimes pinkish. Outer petals radiate, 9–10 mm long. Slightly convex compound umbels, 30–50 cm across 30–75 rays with only short hairs. The fruits are egg shaped or oval; 8–10 mm (–15 mm) long, when they are unripe, they are densely hairy. Fruits have very conspicuous oil ducts that do not reach the fruit base (Nielsen et al., 2005).

Giant hogweed (*H. mantegazzianum)* is a perennial, monocarpic herb (Krinke et al., 2005). The native range of *H. mantegazzianum* is the western Caucasus region. Height is usually 3–4 meters and may exceed 5 meters (Page et al., 2006). Stems are rigid, stout, typically 5–10 cm in diameter and are often purple spotted or continuously purple. Leaves are alternate with lower leaves 1–3.0 meters long, compound, irregularly shaped in ternate or pinnate segments, deeply lobed, and irregularly toothed. White or rarely pinkish flowers are clustered in an umbrella-shaped head (umbel) that is up to 80 cm across with 30–150 rays (Neilson et al., 2005; *Global Invasive…,* 2021). *H. mantegazzianum* has a thick, yellow branching taproot 15 cm in diameter and up to 60 cm long (Page et al., 2006; *Global Invasive*…, 2021). Fruits are dry schizocarps consisting of two mericarp seeds 6–18 mm long, 4–10 mm wide and about 1 mm thick, which are joined until ripening. The endosperm is oily and mature fruits have a strong resinous smell (Tiley et al., 1996).

Materials and methods

The research was carried out at the territory of Kyiv agglomeration (the total area is 847 square km). Its green zone is approximately 49,133.52 hectares, or 58.80% from the entire city's territory. The biotic diversity of the city of Kyiv depends mostly on physical and geographical position, and geomorphological structure of the territory, which is a part of the two landscape zones: the zone of the mixed forests or Polissya and forest-steppe zone (Marynych et al., 2003). Kyiv's urban ecosystems comprise various biotopes, where fragments of deciduous forests, coniferous and mixed forests, meadows, hydrotopes, agricultural ecotopes, residential ecotopes, technogenic ecotopes and others prevail (Aloshkina, 2011). By population we mean a number of all the organisms of the same group or species who live in a particular geographical area and are capable of interbreeding. Locality (site) means individual individuals that grow at a distance from the main population and are only separate centers of its expansion.

In the majority of habitats, the isolation between of giant hogweeds populations is absent; consequently, they are inclined to interspecific hybridisation. That's why the morphometrical characteristics (the fruit shape) were used to identify these species. During growing seasons of 2019–2020, the field researches of giant hogweeds populations were carried out by the route method making full florist lists. The lists of plants communities with the participation of these two species were made considering taxonomic summaries (Mosyakin and Fedoronchuk, 1999; Tutin et al., 1964–1994).

The field researches foresaw the establishment of floristic compound of the communities comprised of giant hogweeds by the implementation of the geobotanical description using the methods (Westhoff and Maarel, 1978) considering population density of invasive species. A total of 34 phytosociological reveles, in accordance with the Braun-Blanquet method, were used to analysis the floristic composition and habitat conditions, in which two *Heracleum* species occurs in Kyiv agglomeration (Braun-Blanquet, 1964). The higher syntaxonomic units are given in accordance with the latest edition of «Vegetation of Europe…» (Mucina et al., 2016).

The size of the trial plot varied from 100 to 8,000 m^2 and depended on the number of individuals of the population and the homogeneity of the plant community. It was calculated the number of individuals of giant hogweeds in the pregenerative and generative stages. The computer technologies SAS Plane Portable 14 Final, Coral Draw 15 were used to draw up maps of populations areas and processing the results. Geographic coordinates of spatial location of each population were identified using GPS map 76CSx. On the basis of a detailed classification, three types of the studied populations were identified: invasive type – plants are found in the form of seedlings, juveniles and vegetates individuals and don't complete the full development cycle; normal type – plants are in optimal conditions and have a high percentage of generative individuals; regressive type – plants bloom, bear fruit and do not regenerate generatively (Rabotnov, 1946; Kravtsiv and Cherevko, 2007).

The assessment of Complex indicator values (CIV) for each population giant hogweeds populations was conducted by processing geobotanical description according to the ecological scales (Ellenberg, 1988; Tsiganov, 1983; Didukh, 2011). Median values of ten ecological scales were used: thermal climate (Tm), continental climate (Kn), humidity (Om), cryo-climate (Cr), as well as for soils – soil humidity (Hd), carbonate content in soil (Tr), nitrogen content (Nt), acidity (Rc), variability of damping (Fh) and light in community (Lc). The numerical of Complex indicator values (for example, lighting Lc1 and Lc2) meant ecological scales of lower and higher values for each species individually (Didukh, 2011).

The difference between populations in CIV median was assessed using the Kruskal-Wallis test and follow-up Mann-Whitney U-test for pairwise comparisons. Both statistical tests were performed in R 4.05 (R Core Team, 2020). We employed the principal component analysis (PCA) to assess the structures of CIV based on data sets for both studied species. To develop the workflow of the analysis, we used the methodology described by Radoslaw Puchalka with co-authors (Puchalka et al., 2018).

Results

Within the biotopes of Kyiv agglomeration it was found out 17 populations and four localities of giant hogweeds which are the part of the forest, meadow, and riverine fragments (Fig. 1). The total area of populations covered 2,186 hectares.

The number of individuals of giant hogweeds was 4,495, their ontogenetic stage was mainly pregenerative – 3,552 individuals and generative 943. Table 1 shows ontogenetic and spatial characteristics of studied populations during 2019–2020. We found out that 11 populations are a part of normal type of dynamics (1–3; 6–13, 15–17), one belong to invasion type (14), and two are of regressive type (4–5). The largest number of species within communities with participation of giant hogweeds was presented in populations 10, 15, 1, 7, 9. The number of generative individuals was higher (populations 3, 4, 5) if soil-vegetation cover was altered or at a place of logging under forest canopy. Also, in Table 1, based on geobotanical descriptions according to Brown-Blanquet, the stratification of the population, the projective cover of the species, absolute density of giant hogweeds in 1 m^2 and their ontogenetic structure were determined.

Giant hogweeds are a part of various groups of biotopes. Aquatic biotopes are represented by floodplains of the Vita Creek and non-overgrown areas of ponds (C2.1 – population 1, 2; C3.65 – population 12). In herbaceous biotopes (E2.61 – population 13; E2.64 – population 8) the distribution of hogweed was revealed in artificially planted lawns, xeromesophytic and mesoxerophytic artificial grass stands. The largest populations noted in forest biotopes (G11 – population 10, G1.C – populations 3, 14; G1.C3 – population 5, G1.D – population 6) are riverside and gallery forests of *Alnus* Mill., *Populus* L., *Salix* L.; artificial forest plantations, *Robinia* L. plantings and orchards. In semi-natural biotopes (I2.1 – population 4, I1.2 – population 7, I1.53 – populations 12, 17), they were found in ecosystems of gardens and garden plots, large parks and fallow fields with groups of perennial weeds. Artificial biotopes (J1.3 – population 11, J4.1 – population 9; J6.1 – populations 15, 16) cover urban and suburban development, underutilized roads, railways and other hard surface areas, as well as areas with construction waste (*European Nature Information System,* EUNIS).

Population 1. *H. sosnowskyi* grows in the community of the class Phragmito-Magnocaricetea Klika in Klika et Novak 1941 (Mucina et al., 2016) on a thalweg of the beam, alongside which the stream Vita flows (the suburbs of Kyiv – the village of Khotiv), taking up the area of 1,645 m^2. The area is under seasonal flooding, represented by meadow-swamp soils with a high aquiferous horizon. A number of giant hogweeds in the population is 333 plant individuals. The total projective coverage is 70%. The basis of the vegetation is made up by: *H. sosnowskyi, Parthenocissus quinquefolia* (L.) Planch., *Carex acutiformis* Ehrh., *Phragmites australis*

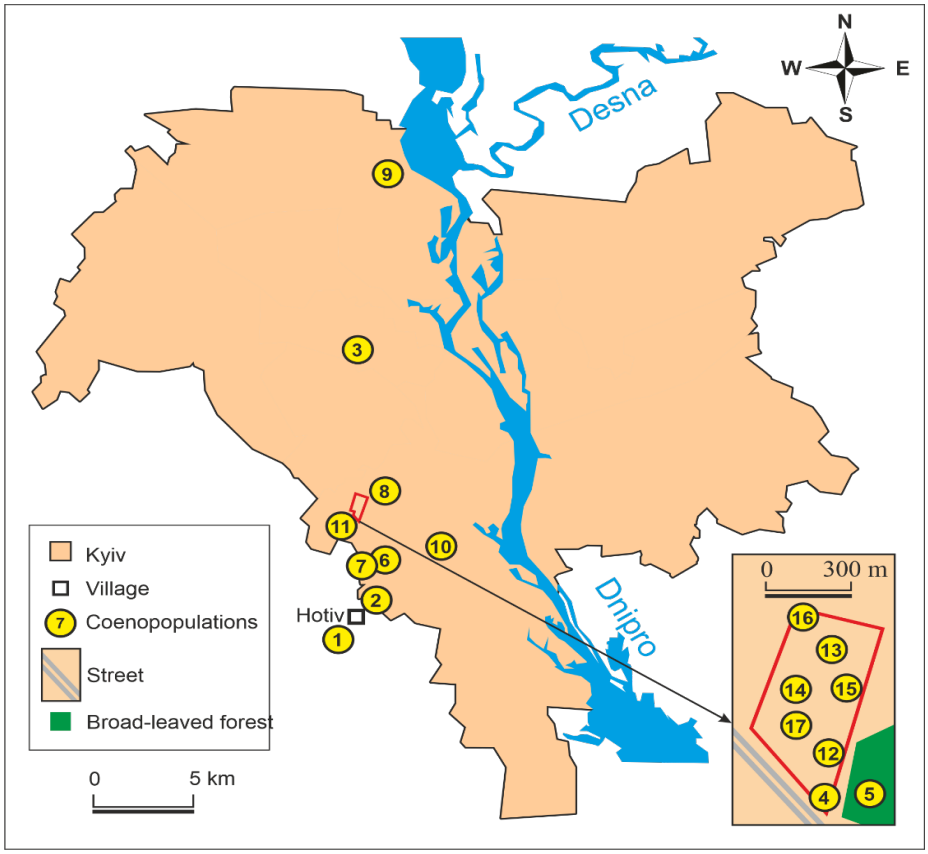

Fig. 1. A schematic map of the giant hogweeds populations areas in Kyiv (made in QGIS with Natural Earth).

Table 1. Ontogenetic and spatial characteristics of giant hogweeds populations

No		A	Pc (%)	Ic (%)	D per 1 m^2	Pg	G	Type of population	H, m	Geographic coordinates	
										Latitude	Longitude
1	*H. sosnowskyi*	2	20	62.3	3	130	203	N	130	50.324800	30.485717
2	*H. sosnowskyi*	2	11	70.3	1	8	15	N	120	50.327283	30.486267
3	*H. mantegazzianum*	3	22	73.2	9	168	113	N	154	50.458267	30.462550
4	*H. sosnowskyi*	2	45	66.0	2	186	23	R	192	50.363867	30.469400
5	*H. mantegazzianum*	3	5	57.8	1	65	12	R	199	50.363350	30.472717
6	*H. mantegazzianum*	2	25	60.7	1	53	29	N	187	50.350333	30.489550
7	*H. sosnowskyi*	2	30	64.3	4	281	47	N	186	50.351627	30.485962
8	*H. mantegazzianum*	1	50	72,9	6	268	7	N	167	50.377817	30.482283
9	*H. mantegazzianum*	2	45	58.7	1	49	17	N	178	50.532936	30.476306
10	*H. sosnowskyi*	2	20	66.6	2	96	10	N	120	50.366700	30.541000
11	*H. sosnowskyi*	2	25	88.8	5	484	14	N	182	50.361807	30.466392
12	*H. sosnowskyi*	1	20	82.2	5	1,090	25	N	169	50.365017	30.469817
13	*H. mantegazzianum*	2	23	60.8	3	91	26	N	184	50.368383	30.469317
14	*H. sosnowskyi*	2	18	58.8	1	13	–	FI	184	50.369283	30.468883
15	*H. sosnowskyi*	2	23	72.0	3	415	279	N	183	50.368033	30.468183
16	*H. sosnowskyi*	2	20	71.4	1	20	13	N	180	50.366850	30.467883
17	*H. sosnowskyi*	2	20	73.9	2	121	97	N	183	50.365883	30.468817

A , tiers number in a community; Pc, the projective cover of the species (%); Ic, a part of synantropic plant species within the cenos expressed in %; D, absolute density of giant hogweeds in 1 m^2; Pg, number of individuals pregenerative; G, number of individuals generative; the population types marked: N – normal, R – regressive, Fl – invasive, H, m – absolute relief indicators.

(Cav.) Trin. ex Steud. (diagnostic species); *Urtica dioica* L., *Carex lasiocarpa* Ehrh., *Geranium palustre* L., *Equisetum arvense* L., *Rubus caesius* L., *Humulus lupulus* L., *Salix alba* L. (constant species) and 79 other plant species. The population includes of 94 plant species from 45 families.

Population 2. *H. sosnowskyi* in the class community Phragmito-Magnocaricetea (Mucina et al., 2016) alongside the levee near stream Vita together with meadow-swap biotypes (village of Khotiv) occupy the territory of 178 m^2. The location is under insignificant seasonal flooding, as the soils are meadow-swap. The number of *H. sosnowskyi* population is 23 individuals. The total projective coverage makes 60%. The basic of the plant coverage is made by: *Urtica dioica, Salix alba* (diagnosing species); *Parthenocissus quinquefolia, Solidago canadensis* L., *Elymus repens* (L.) Gould*, Carex acutiformis, Equisetum arvense, Eupatorium cannabium* L., *Stellaria nemorum* L. (constant species), and 40 other plant species. The population includes of 54 plant species from 27 families.

Population 3. *H. mantegazzianum* grows in the community of the class Robinietea Jurko ex Hadac et Sofron 1980 (Mucina et al., 2016) at the bottom of the beam «Shulyavska», that presents the channel of the already non-existent stream Pischanyi (territory of the Kyiv zoo). The studied population comprises 2,125 m^2. The territory is under a slight anthropogenic load: littered with solid household wastes and organic wastes. The soils are sod-podzolic. The number of *H. mantegazzianum* population is 281 individuals. The general projective coverage is 85%. The basis of the plant coverage is composed by: *Urtica dioica, H. mantegazzianum, Acer negundo* L., *Chelidonium majus* L., *Impatiens parviflora* DC (diagnosing species); *Parthenocissus quinquefolia*, *Robinia pseudoacacia* L., *Acer platanoides* L., *Ambrosia artemisiifolia* L. (constant species) and 36 other plant species. The population includes of 56 plant species from 30 families.

Locality 3 (1). *H. mantegazzianum* grows down along the beam from the main population 3 at the distance of 50 m. The area is 12 m^2, the number of the locality *H. mantegazzianum* is 6 plant individuals (3 ones are pregenerative, and the other 3 are generative individuals). In the undergrowth *Acer negundo, Ulmus laevis* Pall. are marked. In the grassy level *Urtica dioica, Galium aparine* L.*, Solidago canadensis* prevail; and *Dactylis glomerata* L., *Elymus repens, Scirpus sylvaticus* L. are growing at insignificant numbers.

Population 4. *H. sosnowskyi* grows in the community of the class *Robinietea* (Mucina et al., 2016) at the territory of the forest-park zone of the National complex «Expocentre of Ukraine», that adjoins the territory of the National park «Holosiivskyi». The studied population comprises 756 m^2. The area is under significant recreational load and littering of solid household wastes was found out. Besides, there is seasonal mowing of grassy vegetation. The soils are sod-moderate and-light-podzolic, sandy and loamy. The number of *H. sosnowskyi* in the population makes 209 individuals. The total projective coverage is 60%. The basis of the vegetation level is made by: *Acer negundo, Erigeron annuus* (L.) Pers*., H. sosnowskyi* (diagnosing species); *Urtica dioica, Artemisia vulgaris* L., *Chelidonium majus* (constant species) and 41 other plant species. The population includes of 56 plant species from 31 families.

Population 5. *H. sosnowskyi* grows in the community of the class *Robinietea* (Mucina et al., 2016) on the area of the forest- park zone of the National complex «Expocenter of Ukraine», that adjoins the territory of National Park «Holosiivskyi». The studied population occupies the area of 351 m^2. The locality is under insignificant recreational load, and, also, local weathering is pointed out. The soils are light grey and grey and were formed on the forest and boulder loams. The number of *H. sosnowskyi* in the population is 77 individuals. The total projective coverage is 55%. The basis of the vegetation is made by: *Impatiens parviflora, Sambucus nigra* L., *Urtica dioica, Chelidonium majus, Geranium robertianum* L. (diagnosing species); *H. sosnowskyi, Xanthoxalis stricta* (L.) Small, *Arrhenatherum elatius* (L.) P. Beauv. ex J. Presl & C. Presl., *Geum urbanum* L., *Quercus robur* L., *Robinia pseudoacacia* (constant species) and 25 other plant species. The population includes of 39 plant species from 26 families.

Population 6. *H. mantegazzianum* grows in the community of the class Robinietea (Mucina et al., 2016) on the abandoned plantations of nut breeding trees (academic Lebedev street), taking up the area of 200 m^2. The area is under significant anthropogenic load: littering by solid household wastes, weeding and destruction of the structure of soil-vegetation level in the process of carrying out construction. The soils are light grey on forest loams and sandy in places. The number in the population giant hogweeds is 82 plant individuals. The total projective coverage is 85%. The basis of the vegetation is made by: *Urtica dioica, Juglans regia* L.*, Acer negundo, Glechoma hederaceae* L., *Geum rivale* L., *Humulus lupulus* (diagnosing species); *Parthenocissus quinquefolia, H. mantegazzianum, Ballota nigra* L.*, Impatiens parviflora, Quercus rubra* L. (constant species) and 15 other plant species. The population includes of 29 plant species from 18 families.

Population 7. *H. sosnowskyi* grows in the community of the class Artemisietea vulgaris Lohm., Prague. Et al. ex Von Rochow 1951 (Mucina et al., 2016) on the territory of the abandoned fruit-berries plantations within scientific-experimental base of the Institute of Botany of the National Academy of Sciences of Ukraine (Metrologychna street 11-B). The studied population takes up the area of 405 m^2. The area is under significant anthropological load, particularly, littering by solid household wastes and weeding. The soils are sod and slightly podzolic. The number of giant hogweeds in the population is 328 plant individuals. The total projective coverage is 65%. The basis of the vegetation is made up by: *Ambrosia artemisiifolia, Erigeron annuus, Melilotus albus* Medik., *Acer platanoides* L.*, H. sosnowskyi* (diagnosing species); *Artemisia vulgaris, Polygonum aviculare* L., *Convolvulus arvensis* L., *Cirsium arvense* (L.) Scop. (constant species) and 73 other plant species. The population includes of 90 plant species from 29 families.

Locality 7 (1). *H. mantegazzianum* grows down alongside the beam Feofaniya (the sixth forest block of the park Feofaniya) at the distance of 2 meters from the paved road. The area is 2 m^2. The number of the locality *H. mantegazzianum* is 6 pregenerative plant individuals. The

wooden tier is made up by *Quercus robur*, *Carpinus betulus* L. The closeness of the trees crowns reaches 0.4–0.5. In the vegetation *Chelidonium majus, Conium maculatum* L., *Dactylis glomerata, Lysimachia nummularia* L., *Urtica dioica* and others prevails.

Locality 7 (2). *H. sosnowskyi* grows on the flowerbed alongside the building (Academic Zabolotnyi street, 148) at the distance of 580 meters from population 7. The area is 20 m^2. The number of the locality *H. sosnowskyi* makes up 8 pregenerative and 7 generative plant individuals. Single individuals of self-seeding *Robinia pseudoacacia, Ulmus glabra* Huds. were found out. The wooden tier is made up by *Quercus robur, Carpinus betulus.* In the grassy tier *Solidago canadensis, Conyza canadensis* (L.) Cronq., *Chenopodium album* L., *Portulaca oleracea* L., *Setaria viridis* (L.) P. Beauv., *Bidens frondosa* L. and others were noted.

Population 8. *H. mantegazzianum* grows in the community of the class Epilobietea angustifolii Tx. et Preising ex von Rochow 1951 (Mucina et al., 2016) on the territory of National complex «Expocenter of Ukraine» under garden-park plantation (Academic Hlushko Avenue, 1). The studied population occupies the area of 96 m^2. The territory is under the significant recreational load: weeding, trampling of the grass cover, periodical mowing. The soils are urbansoils. The *H. mantegazzianum* in the population reaches 275 plant individuals. The total projective coverage is 45%. The basis of vegetation is made up by: *Elymus repens, Carex praecox* Schreb., *Trifolium medium* L., *Urtica dioica* (diagnosing species); *Polygonum aviculare, Taraxacum officinale* Wigg (constant species) and 29 other plant species. The population includes of 37 plant species from 23 families.

Population 9. *H. mantegazzianum* grows in the community of the class Epilobietea angustifolii Tx. et Preising ex von Rochow 1951 (Mucina et al., 2016) near lake Redkyne (Obolon district in Kyiv), taking up area of 128 m^2. The area is under significant recreational load: weeding, trampling of the grass cover. The soils are sod-sandy and podzolic. The number of *H. mantegazzianum* in the population makes up 66 plant individuals. The total projective coverage is 80%. The basis of the vegetation is made up by: *Calamagrostis canescens* (Weber) Roth, *Asclepias syriaca* L., *Artemisia vulgaris, Rubus caesius*, *Dactylis glomerata, H. mantegazzianum, Bromus inermis* Leyss., *Erigeron annuus* (diagnosing species); *Aristolochia clematitis* L., *Salix caprea* L., *Solidago canadensis* (constant species) and 48 other plant species. The population includes of 63 plant species from 26 families.

Locality 9 (1). *H. mantegazzianum* grows behind the railways from the main population 9 at the distance of 45 m. The area is 4.0 m^2. The number of the locality *H. mantegazzianum* is 13 plant individuals (10 are pregenerative, 3 are generative ones). In the grassy tier *Calamagrostis canescens, Artemisia vulgaris, Erigeron annuus* and others.

Population 10. *H. sosnowskyi* grows in the community of the class Salicetea purpureae Moor 1958 (Mucina et al., 2016) on the territory of the National natural park «Holosiivskyi» (Kyiv ponds). The studied population approximately covers 1,340 m^2. The locality is situated under insignificant recreational load: weeding, trampling of the grass cover. The soils are light-grey, meadow-swamp. The number of giant hogweeds in the population is 106 plant individuals. The total projective coverage is 60%. The basis of the vegetation is made by: *Elymus repens, Urtica dioica, Iva xanthiifolia* Nutt. (diagnosing species); *Parthenocissus quinquefolia, Solidago canadensis, Conyza canadensis*, *Lactuca serriola* L., *Ambrosia artemisiifolia, Polygonum aviculare* (constant species) and 93 other plant species. The population includes of 105 plant species from 45 families.

Population 11. *H. sosnowskyi* grows in the community of the class Robinietea (Mucina et al., 2016) in the Academic Zabolotnyi, 64 street (the outskirts of Feofaniya market), covering the area of 243 m^2. The area is under anthropogenic load: weeding, trampling, and mowing. The soils are urbansoil. The number of giant hogweeds in the population is 498 plant individuals. The total projective coverage is 75%. The basis of the vegetation is made by: *Glechoma chederaceae, Ballota nigra*, *Urtica dioica, Elymus repens, Conyza canadensis* (diagnosing species); *Reynoutria × bohemica* Chrtek & Chrtkova, *Dactylis glomerata, Linaria vulgaris* Mill., *Sonchums oleraceus* L., *Erigeron annuus, Xanthoxalis stricta* (constant species) and 37 other plant species. The population includes of 54 plant species from 24 families.

Population 12. *H. sosnowskyi* grows in the community *Artemisia vulgaris* (Mucina et al., 2016) on the territory of forest-steppe zone of National complex «Expocenter of Ukraine», Academic Hlushkov Avenue, 1. The studied population covers 1,345 m^2. The territory is under significant anthropogenic load: weeding, trampling of the grass cover, mowing. The soils are grey forest, urbansoils. The number of giant hogweeds in the population counts 1,115 plant individuals. The total projective coverage is 60%. The basis of the vegetation is made by: *Solidago canadensis, Elymus repens, Achillea millefolium* L., *Ballota nigra* (diagnosing species); *Artemisia vulgaris, Lysimachia nummularia*, *Plantago major* L., *Potentilla argentea* L., *Trifolium repens* L., (constant species) and 24 other plant species. The population includes of 39 plant species from 20 families.

Population 13. *H. mantegazzianum* grows in the community of the class Molinio-Arrhenatheretea R. Tx. 1937 (Mucina et al., 2016) near the (National complex «Expocenter of Ukraine», Academic Hlushkov Avenue, 1), covering the area of 96 m^2. The locality is situated under the anthropogenic load. The number of *H. mantegazzianum* in the population is 117 plant individuals. The total projective coverage is 60%. The basis of the vegetation is made up by: *Arrhenatherum elatius, Solidago canadensis, Vicia cracca* L., *Dactylis glomerata* (diagnosing species); *Ballota nigra, Urtica dioica* (constant species) and 18 other plant species. The population includes of 24 plant species from 15 families.

Population 14. *H. sosnowskyi* grows in the community of the class Robinietea (Mucina et al., 2016) on the territory of culture phytocenosis of the forest-park part of the National complex «Expocenter of Ukraine» (Academic Hlushkov Avenue, 1). The studied population covers 500 m^2. The territory is under significant anthropogenic load: weeding,

trampling of the grass cover. The soils are grey forest. The number of giant hogweeds in the population is 13 plant individuals. The total projective coverage is 45%. The basis of the vegetation is made up by: *Acer negundo, Euonymus europaeus* L., *Chelidonium majus, Humulus lupulus, Urtica dioica* (diagnosing species); *Carpinus betulus, Populus alba* L., *Rubus caesius, Sambucus nigra* (constant species) and 24 other plant species. The population includes of 35 plant species from 23 families.

Population 15. *H. sosnowskyi* grows in the community of the class *Molinio-Arrhenatheretea* (Mucina et al., 2016) on the territory of the lost landscape and architectural expositions (National complex «Expocenter of Ukraine», Academic Hlushkov Avenue, 1). The studied population covers the area of 8,245 m^2. The locality is situated under the significant anthropogenic load: weeding, trampling, littering by solid household wastes, organic wastes. The soils are grey forest, urbansoils. The number of giant hogweeds in the population makes up 694 plant individuals. The total projective coverage is 65%. The basis of the vegetation is made up by: *Arrhenatherum elatius, Calamagrostis canescens, Dactylis glomerata, Solidago canadensis, Taraxacum officinale* (diagnosing species); *Carex hirta* L., *Chenopodium album* L., *Elymus repens, Polygonum aviculare, Urtica dioica* (constant species) and 80 other plant species. The population includes of 94 plant species from 39 families.

Population 16. *H. sosnowskyi* grows in the community of the class Molinio-Arrhenatheretea (Mucina et al., 2016) on the territory of National complex «Expocenter of Ukraine» (Academic Hlushkov Avenue, 1), covering the area of 772 m^2. The territory is situated under the significant anthropogenic load: weeding, trampling, littering by solid household wastes, organic wastes. The soils are urbansoils. The number of giant hogweeds in the population is 33 plant individuals. The total projective coverage is 60%. The basis of the vegetation is made up by: *Dactylis glomerata, Elymus repens, Solidago canadensis* (diagnosing species); *Erigeron canadensis, Ballota nigra, Heracleum sosnowskyi* (constant species) and 20 other plant species. The population includes of 28 plant species from 16 families.

Population 17. *H. sosnowskyi* grows in the community of the class Artemisietea vulgaris (Mucina et al., 2016) near agrophytocenosis of the National complex «Expocenter of Ukraine», Academic Hlushkov Avenue, 1. The studied population covers the area of 1,723 m^2. The locality is situated under the significant anthropogenic load: weeding, trampling. The soils are medium-humus. The number of giant hogweeds in the population is 218 plant individuals. The total projective coverage is 60%. The basis of the vegetation is made up by: *Solidago canadensis, Tragopogon dubius* Scop., *Calamagrostis canescens* (diagnosing species); *Ballota nigra* (constant species) and 17 other plant species. The population includes of 23 plant species from 9 families.

The indicators of moisture supply of the soils (Hd) in the majority of the populations ranged from 6.7 to 16.9 corresponding to the dry forest-meadow type (Fig. 2). The soil's moisture (Fh) indicator ranged between 4.5 and 9.1 corresponding the relatively stable moisture from weak to moderate levels (Fig. 2).

The indicator values of general salt regime of the communities varied between 3.2 and 10.0 and corresponded to poor and salt-enriched soils contained HOC_3. The value of nitrogen content indicator ranged between 4.5 and 10.0 pointing to both poor and reach in nitrogen soils. The Rc-factor values of 2.1–11.0 indicated acidic and slightly acidic soils. The light (Lc), a limiting ecological factor of spreading of the studied species (Didukh et. al., 2000; Khomyak et al., 2019), varied between 1.0–5.7 and corresponded to sciophytic conditions of light and shadow forests (Fig. 2). The analysis of the vegetation communities by climatic factors indicated that the studied plants communities formed in the conditions from the sub-oceanic to subcontinental (Kn = 3.2–14.0) climate. The study area referred from nemoral and boreal forest to sub-mediterranean thermal zone (Tm = 5.0–13.0) within the range of frost resistance (Cr = 4.3–12.3), which is typical for the regions with severe and warm winters. The studied plants' communities formed in the conditions from sub-arid to sub-humid climate (Om = 3.9–11.0) (Fig.2).

According to the test Kruskal-Wallis with adjustment to connection (Table 2), statically significant difference in median values CIV for the population studied by indicators Lc2 (17 = 27.166, p = 0.03967) and Tm1 (17 = 31.964, p = 0.01011) was established. The variation Lc2 is connected to the populations 4–5 and 14, which are characterised by much lower medial values.

For Tm1 the indicators are connected to the populations 3 and 14. According to the results of the floristic analysis by species composition no significant difference between the populations was detected to confirm their belonging to one of the vegetation class – Robinietea.

Table 2. The Kruskal-Wallis tests for medians of CIV for vegetation plots between 17 study populations. The statistically significant p-values are marked in bold

CIV	Chi-squared	df	p-value
Tm1	31.964	16	**0.01011**
Tm2	19.14	16	0.2615
Kn1	17.763	16	0.338
Kn2	12.546	16	0.7056
Om1	19.962	16	0.2219
Om2	13.977	16	0.6004
Cr1	24.629	16	0.07663
Cr2	18.999	16	0.2687
Hd1	25.045	16	0.06904
Hd2	25.613	16	0.05973
Tr1	15.629	16	0.4792
Tr2	20.213	16	0.2108
Nt1	11.443	16	0.7813
Nt2	8.1834	16	0.9432
Rc1	15.781	16	0.4683
Rc2	10.348	16	0.8482
Lc1	8.9266	16	0.9164
Lc2	27.166	16	**0.03967**
Fh1	12.94	16	0.6771
Fh2	12.441	16	0.7131

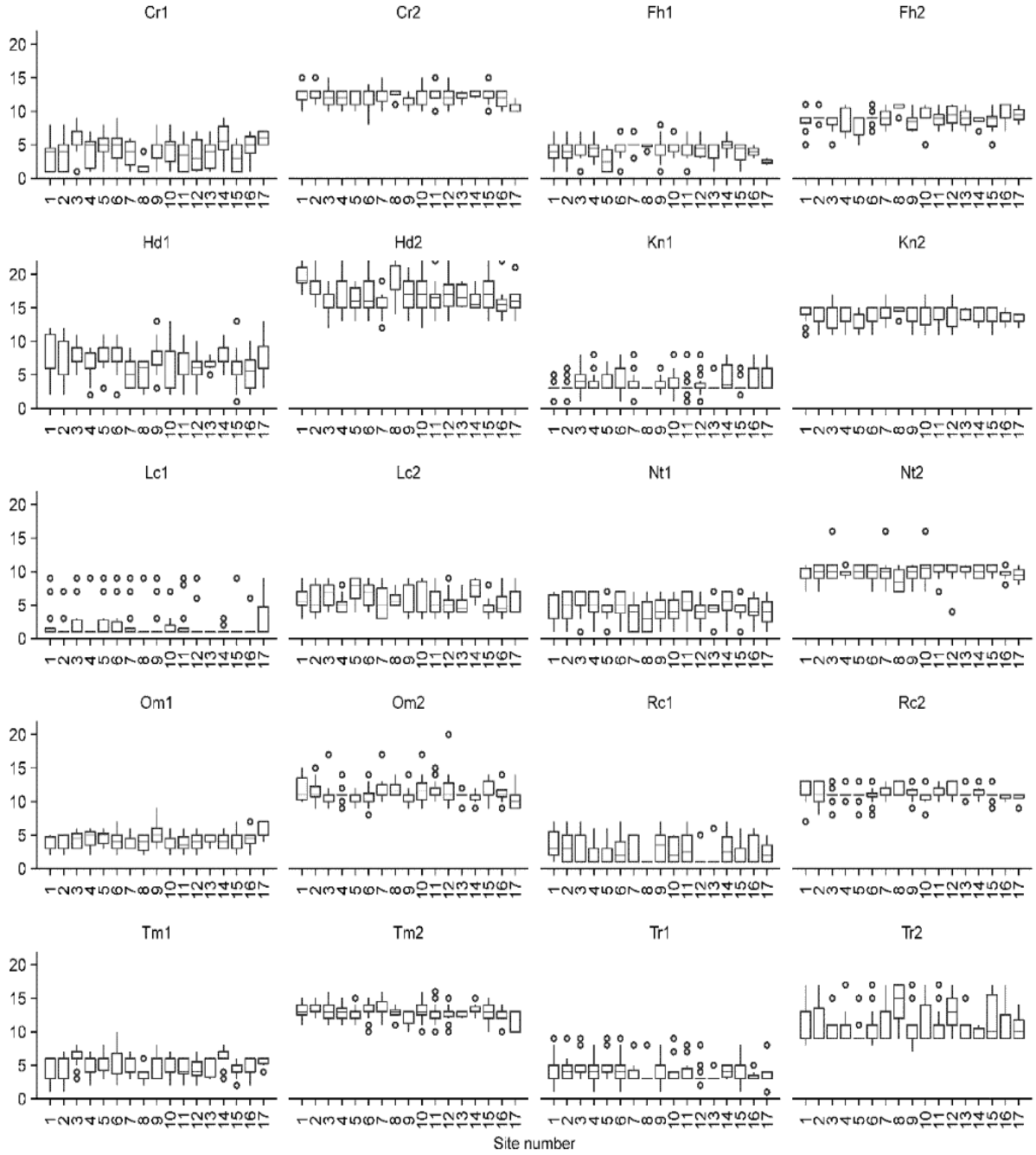

Fig. 2. Analysis of CIV for study populations: the lower and upper hinges indicate the 25th and 75th percentiles, the horizontal lines denote the median values, the whiskers extend from the hinges to the largest and smallest values within the 1.5 inter-quartile range, and the points indicate outliers. CIV codes: Tm – climate thermal mode, Kn – continental, Om – arid/humid, Cr – cryophytes, Hd – mesophytes, Tr – eutrophes, Nt – nitrophiles, Rc – acidophilic, Lc – helioscyophytes, Fh – contrastophobes.

Figure 3 presents the results of principal component analysis (PCA) that performed using the CIV data set for Tm1 and Lc2. The first two principal components were required to extract 67.1 the total inertia for *H. sosnowskyi* and 81.1 *H. mantegazzianum*. The first principal component PC1 explained ca. 53.4% and 61.3% of the total Tm1 and Lc2 variance and the second component PC2 explained ca. 13.7% and 19.8% of the total inertia in species *H. sosnowskyi* and *H. mantegazzianum* respectively. The PC1-2 at factor maps clearly split CIV up into two groups, i.e with higher Lc2 and lower Tm1 along negative PC1 and with lower Lc2 and higher Tm1 along positive PC1. The populations of both species tend to set the sites with higher Lc2 and lower Tm1, i.e. clear open-space and less hot territories (Figure 3: A, C) (Khomyak et al., 2019; Lepeshkina, 2019).

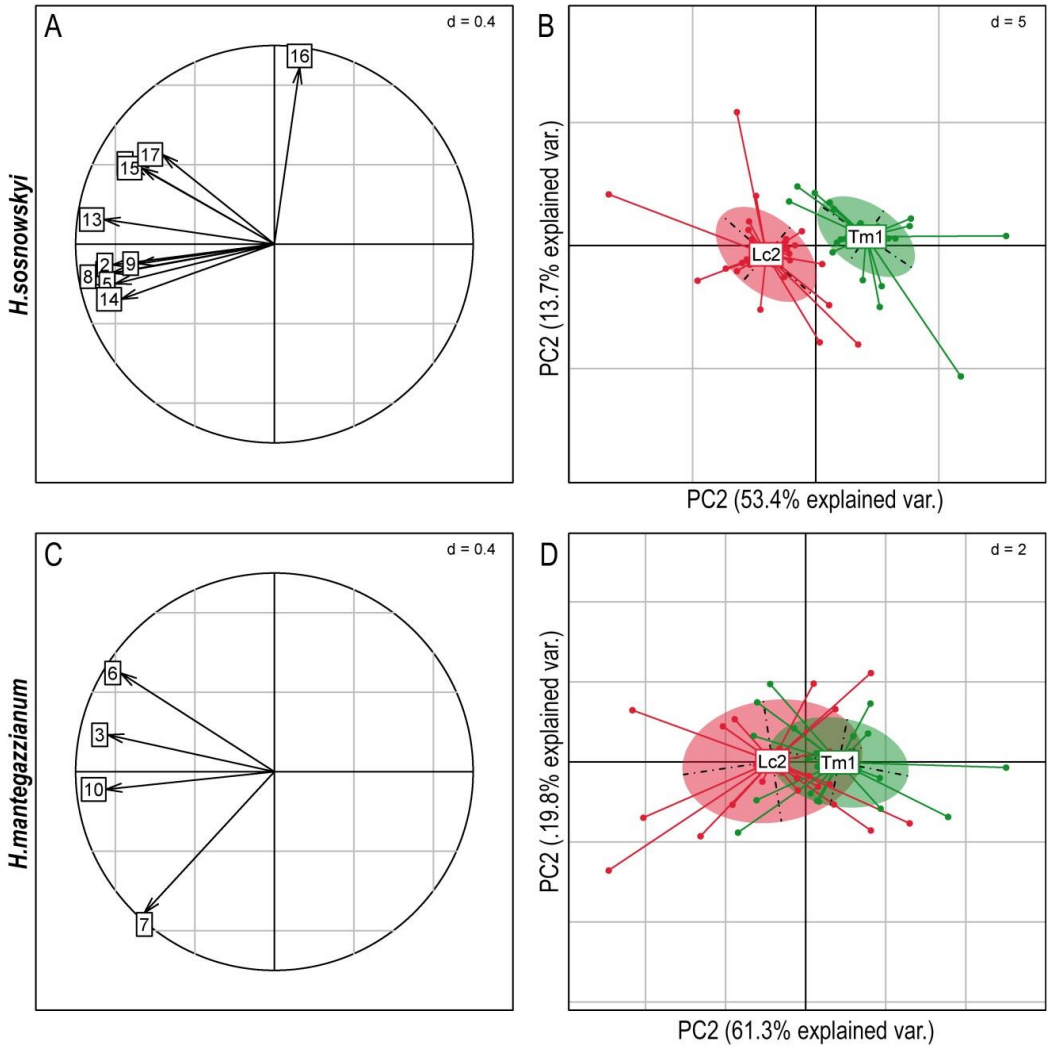

Fig. 3. The results of PCA analysis applied separately to two *Heracleum* species: correlation matrix, i.e. scores, for the populations (A, C) and factor maps, i.e. scores, for Tm1 and Lc2 values (B, D).

Discussion

The systematic analysis of the plant species of the populations' giant hogweeds showed that most plants belonged to: Asteraceae (38), Poaceae (31), Rosaceae (16), Lamiaceae (11) plant families. The participation of other families is significantly reduced. According to the ecology and cenotic confinement in the structure of the community with participation of giant hogweeds the synanthropic species (40.7%), forest species (24.0%), meadow species (22.9%) prevail. The part of synanthropic species in populations varies from 57.8 to 88.8% (Table 1). The basis of populations is made up by synanthropic plants which belong to forest and meadow biotopes with domination of rhizomatous perennial herbs. In some populations the activity of alien invasive species is observed: *Solidago canadensis* (present in 16 populations), *Erigeron annuus* (15), *Acer negundo, Ballota nigra* (13), *Parthenocissus quinquefolia* (12), *Conyza canadensis* (11), *Impatiens parviflora* (9), *Robinia pseudoacacia, Ambrosia artemisiifolia* (8). The percentage of native plant species in average makes 38.1%.

The studied species in the primary area grow in the middle and upper belts of the mountainous forests, on the meadows and forest-meadows of the beech and fir-beech woods and in the beech crooked forests. The species are also met at the alpine meadows of the subalpine belt and at the river banks at the foothill forest-steppe zone of the Northern Caucasus (Mandenova, 1950; Pysek, 1991; Luneva, 2014).

In the secondary area the plants prefer anthropogenically altered plants communities with well-lit areas with fertile soils. However, they also may conquer less fertile soils (Jahodova et al., 2007). The studied species are widely spread at wastelands and roadsides, woodlands and on the borders of forests and fields, on ravines and beams, springs and rivers valleys. A number of European researchers provide examples of different plants communities where the studied species penetrate (Sobisz, 2007; Abramova et al., 2017; Khomyak et al., 2019; Arepieva et al., 2021).

Mainly these are the classes of ruderal communities – Artemisietea, Epilobietea (Sobisz, 2007; Abramova et al., 2017; Khomyak et al., 2019; Arepieva et al., 2021),

Bidentetea Tx. et al. ex von Rochow 1951 (Didukh et al., 2016), forest communities – Salicetea purpurea and Querco-Fagetea (Khomyak et al., 2019; Didukh et al., 2016) and meadowland community – Molinio-Arrhenatheretea (Khomyak et al., 2019; Didukh et al., 2016) vegetation. According to the results of our research, for the area of Kyiv urban agglomeration the growth of *H. sosnovskyi* and *H. mantegazzianum* is indicated in the plants communities of six classes. The majority of the populations is located in the classes of ruderal plant communities Robinietea (populations 3–6, 11, 14), Artemisietea (populations 7, 12, 17) and Epilobietea (populations 8–9). The classes Molinio-Arrhenatheretea, Phragmi-Magnocaricetea and Salicetea purpureae are represented only in 5 populations. In our opinion, this is due to the anthropogenic transformation of the study area, where the presence of such plants communities is limited.

According to the ecological specification, which was identified by the ecological scales (Ellenberg, 1974, 1988; Tsiganov, 1983; Didukh, 2011), it should be mentioned that the studied species prefer lit and warm growth conditions (Fig. 2, Table 2). These are the ruderal communities with the participation of *Robinia pseudoacacia* which form the sparse thickets that are more favorable conditions for the studied species. These conditions are explained by higher temperatures of urban environment (Klausnitzer, 1987). The other essential differences according to the ecological indicators were not indicated. According to the results of the research *H. sosnowskyi* and *H. mantegazzianum* grow in these conditions and are ecologically adapted species.

The results indicate broader ecological plasticity of *H. mantegazzianum* in relation to the ecological values Lc2 and Tm1. *H. sosnowskyi* is less plastic in terms of Lc2 and Tm1. Thus, this analysis indicates a higher ecological potential of *H. mantegazzianum* than *H. sosnowskyi*. But these insignificant differences will not negatively affect the condition, generative recovery and distribution of giant hogweeds in the study and adjacent territories.

Recommendations for the control and elimination of the localities of giant hogweeds

On the territory of the Kyiv urban agglomeration the populations of giant hogweeds occupy about 2.2 hectares. Caution should be taken when handling these weeds. Removing it manually becomes very difficult because of the danger caused by its sap. In order to avoid the spread of populations with their participation, methods of population control have been proposed and adapted according to international standards (Nielsen et al., 2005):

- For populations with the number of individuals from 1 to 50: pulling out by hand, cutting out roots, removing umbrellas, mowing (any habitat); chemical processing (agricultural land, pastures).
- For populations with the number of individuals from 50 to 1,000: mowing, intensive grazing (any habitat); chemical processing, soil plowing (agricultural land, pastures). All recommended methods should be carried out several times, taking into account the growing season – during germination and before fruiting.

The role of the main components (Tm1 and Lc2) in the general variability of ecological conditions for the populations of giant hogweed in kyiv indicates the active distribution of species in open-space territories. Therefore, to prevent further infestation, the clogging of such areas should be monitored. It is also necessary to maintain natural communities of open-space territories, preventing the expansion of ruderal plant communities.

Conclusion

According to the results of our research, for the area of Kyiv urban agglomeration the growth of giant hogweeds is indicated in the plants communities of six classes. From our point of view, giant hogweeds in the populations of Kyiv agglomeration are able to lessen the areas of numerous populations of native species, especially in meadow and forest communities, and rapidly accumulate biomass. According to the results of CIV, a difference was established in the ecological indicators Lc2 and Tm1 for the studied populations. Analysis of PCA diffraction relative to Lc2 and Tm1 shows a broad ecological plasticity of *H. mantegazzianum* and a narrower one for *H. sosnowskyi.* This indicates that these adventive species fully adapted to the new environment in secondary range. *H. sosnowskyi* and *H. mantegazzianum* behave as aggressive species which are able to invade into new ruderal communities: Robinietea, Artemisietea, Epilobietea. It was found out that increase in numbers of the seedlings, juveniles and immature individuals were observed on the regularly mowed areas. The data about invasion of the giant hogweeds can be used to monitoring the invasive species in Kyiv biotopes, especially in populations 4–5, 8, 12–17 which belong to the recreational area of the Natural Reserve near Expocenter of Ukraine. The studied species belong to invasive plant species in Ukraine and are characterized by extremely high effect on the environment and high invasive potential. They are rather difficult to control and effective measures are quite expensive.

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