Adaptation strategies of *Heracleum sosnowskyi* in Ukrainian Polissia

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Article info
Received 08.01.2024
Received in revised form 10.02.2024
Accepted 28.02.2024


*Heracleum sosnowskyi* is an invasive transformer species dangerous for biodiversity and human health. The materials for this study were the standard geobotanical descriptions made on the territory of Ukrainian Polissia in the period from 2004 to 2022. The relevés were classified using the Braun-Blanquet methods and used for synrophytoindication evaluation of the environmental factors, rating ecofactors, estimated based on the ecological scales of the species that form a phytocoenosis. *Heracleum sosnowskyi* was observed to occur in plant communities belonging to 13 classes, 16 orders, 21 alliances, and 29 associations. According to the synrophytoindication, it most often grew in mesophytic, hemihygrocontrastrophic (moderately moistened habitats that are sporadically moistened), subacidophilic, semi-eneurophilic, acaronemophilic, nitrophilic, hemsieraphilic (moderately aerated habitats), submicrothermal (habitats that receives 20–30 kc/sm²), subbromophilic, hemooceanic, subcryophilic (habitats with the average temperature of the coldest month of the year is approximately –4), semi-illuminated, euemorobic (habitats that have been altered or created by humans and are under anthropogenic influence) habitats. The competitive advantages of Sosnowsky’s hogweed over the native species are the combination of the ability to change and K strategies, depending on the environmental conditions, with the production of a large number of seeds that are dispersed from a tall peduncle, maintaining a significant germination rate for several years, and allelopathy and efficient assimilation of nitrogen compounds, which helps it to increase the size of the shoot. Ruderal and natural grass ecosystems are the most vulnerable to the penetration of *H. sosnowskyi* in the early stages of autogenic succession (value of natural dynamic was 3.0–4.0 points). The highest projective cover and the density of its population were observed in the nitrified forest edges of associations Elytrigio repentis-Aegopodietum podagrariae var. *Heracleum sosnowskyi* (value of natural dynamic was 3.0–4.0 points). Forest ecosystems with multi-tiered vegetation (value of natural dynamic was above 9.5 points) and meadows with thorough sod (value of natural dynamic was above 4.8 points) were less vulnerable to invasions.

Introduction

In the pursuit of high, easy, but short-term benefits, people lay ticking bombs beneath their feet. This is related not only to formation of policy or construction of economic systems. Our relations with the environment have been illustrated by a great number of negative examples. Events that had occurred in the second half of the 20th century and in early 21st century are conspicuous examples of how people lack strategic foresight when they develop and realize their plans of using natural resources. Such shortsightedness has entailed numerous evident implications. One of them is ruination of the natural ecosystems and decrease in biodiversity (Harbar et al., 2021). People often live an illusion of their independence from the number and quality of natural ecosystems. However, despite all those technological achievements of the mankind, we still depend on them directly or indirectly. Therefore, by extensively exploiting agroecosystems, planted forests, and individual types of aquatic ecosystems, we forget about several important conditions for their sustainable existence, first of all, fullness of ecological niches of those ecosystems and their completeness, and secondly, influence of other natural environments on the ecosystems we exploit. For example, monoculture woodlands without saturated ecotones are more vulnerable to dangerous climatic and biotic factors; agroecosystems need microclimatic protection from neighboring woodlands, and aquatic ecosystems are dependent on an entire complex of natural ecosystems of their drainage basins. Preservation of biodiversity of exploited and natural ecosystems is a guarantee of sustainable development of mankind.

Negative anthropogenic impacts on biodiversity vary. On the one hand, the outcomes can be direct destruction or exclusion of species from ecosystems, and on the other hand, they could be a transformation of the living environment, altering the optimum environmental parameters for species that live in it. In this case, those are both abiotic and biotic factors. Therefore, the number of redundant ecosystem connections—even despite being high—can decline to such a critical level that the likelihood of existence of a certain species decreases. It is especially dangerous when biotic and abiotic changes occur at the same time. The reason of such changes is often the spread of invasive transformer species. Those species are more competitive than the indigenous species, not only because their generative potential, but also because of their vegetation rates. They alter the entire environment of the ecosystem, causing changes in the chemical composition of soil, light conditions, microclimate, species composition of the main groups of organisms, etc. (Harvey et al., 2020). For example, they affect birds (Gričůdžička & Riet, 2022) and other animals (Cereková, 2020). In other words, the content of ecotones noticeably reforms. Shifts of species’ ranges occur all the time. This has been always taking...
place naturally as a result of events occurring on the surface of our planet. It has to be noted that such actions have been often accompanied by massive extinction, one of the underlying conditions being loss of necessary eomes. Since we do not want to become another kind of fossilized remains, we must first of all support sustainability of ecosystems that surround us. At the same time, we spontaneously or intentionally shift a high number of species beyond their ranges. We cultivate some species, expecting a fast and easy profit. However, some species go out of our control, and begin to reproduce and spread on their own. In the case when they occupy a free ecological niche and do not transform the ecosystem dramatically, they only enrich the species and cenotic diversity. Despite the fact that many species have naturalized in this particular way, this occurs rarely, since ecological niches in natural ecosystems of most regions are full (Sax & Brown, 2002). Therefore, most species capable of active invasions are aggressive transformers (Oitsis et al., 2020). It is a global problem, and Polissia is one of specific regions under threat. After the last ice age, this region has been re-inhabited by the higher vascular plants. It is similar to the nemoral zone by the climatic conditions, and to the boreal zone by the edaphic conditions, which makes it a universal study ground for behavior of invasive species (Khomiak, 2018). On the other hand, despite being largely forested, there are areas with significantly disturbed vegetative cover, with not all the niches filled. This makes such territories extremely vulnerable to invasions (Khomiak et al., 2019).

Of the great number of invasive species, especially dangerous are those that – beside an indirect threat to sustainable development of the area – are also dangerous to the human health. Such a species as common ragweed (Ambrosia artemisiifolia L.) is able to cause acute respiratory allergy, and some Heracleum plants (first of all, Heracleum mantegazzianum Sondir & Leyrer and Heracleum sosnowskyi Manden) cause acute phyto dermatitis (Jermendy & Visolyi, 2022). Since those species are synanthropic and mostly occur in areas around people, they pose a double threat – to the environment and the human health. Despite the awareness of this problem among researchers way back since Carl Linnaeus in the 18th century, as well as public concerns over the recent decade, we have so far come nowhere near a solution (Egerton, 2007). The problem turned out to be not the scales of financial support of our searches for the solution, since attempts to handle invasive species failed in both poor small countries and the global leaders (Cuddington et al., 2022). The reason was most likely direct single-vector means rather that a systemic approach to the issue (Grzędzicka, 2021). Traditional methods, such as use of herbicides, as well as more elaborate methods, all fail (Hpoó et al., 2020).

Another reason of our failures in the combat against dangerous transformer species has been their fast spread. This complicates the process of monitoring and planning of adequate control means. Route-expedientional and stationary methods of studying populations of invasive species are good for identifying their places in the ecosystems, but do not satisfy the needs of continuous monitoring (Martin et al., 2020). Today, there are more and more suggestions of using a remote monitoring using hyper-spectral imaging in different seasons (Bzdęga et al., 2021). This method has its advantages as a monitoring system, but faces a whole number of obstacles (Turňáko et al., 2020). In numerous cases, invasive species provide an advantage to ecoregions that have small horizontal sections. Identification of such living environments at a sufficient level is not always possible (Harbar et al., 2023). This limits the possibility of using satellite images (Visočièiene et al., 2020).

One of the most problematic invasive species is H. sosnowskyi. On the one hand, it is a synanthropic invasive transformer species, and on the other hand, being able to spread around places of constant human presence, it poses a direct threat to the life and health of people (Jermendy & Visolyi, 2022). This situation is becoming even more complicated because of presence of a large amount of natural and human-created hybrids and complexity of their identification (Gubar & Koniaèin, 2021). The abilities of H. sosnowskyi to invade natural ecosystems and oppose attempts to destroy it are far more complex than just its individual resilience against changes in the environmental factors or a broad ecological range (Rysiàk et al., 2021). We are dealing with a complex set of adaptive mechanisms that come together in the form of a quite successful strategy of spreading across new areas, transforming them, and holding them. The problem of invasive species is not confined to one region of Europe. Their invasions

infect harm on the ecosystems and people all across the continents, while efforts of researchers and practitioners, and also the large costs countries and private funds have spent, have demonstrated no notable success so far (Shackleton et al., 2020). Our experience of studying the adaptive advantages of H. sosnowskyi can be used not only to combat it in Eurasia, but to combat other invasive species all around the world.

The objective of the study was a systemic analysis of the adaptive strategies of H. sosnowskyi in the territory of Ukrainian Polissia, and to achieve it we set the following goals:

1) to analyze the ecological-senotic characteristics of H. sosnowskyi;
2) model the main adaptive mechanisms of H. sosnowskyi in various ecosystems;
3) develop algorithms to predict the spread of H. sosnowskyi in the ecosystems of Ukrainian Polissia.

Materials and methods

The materials for the study were standard geobotanical relevés, conducted in the Ukrainian Polissia in the period from 2004 to 2023. To develop the relevés, we used the route-expedientional field study methods for the entire period of the monitoring and stationary methods between 2007 and 2019. The relevés were written according to the rules of ecological-floristic approaches of the Swiss-French school of Braun-Blanquet (1964). The relevés were done in homogenous areas where the vegetative cover had formed with participation of H. sosnowskyi. We concluded on the homogeneity based on according to the visual similarity of the edaphic conditions, phytosociometrics of cenosis, micrørelief, and the dominant in visible strata. The sizes of areas correlated with the height of the dominants of the highest stratum. For meadow vegetation, the size was 2 x 2 m, for the shrubs and young forests it was 10 x 10 m, and for mature forests it was 25 x 25 m. If the vegetation was arranged in a band-like formation, the relevé was conducted following its natural boundaries, and in the lengths of 2 m (herbaceous vegetation), 5 m (shrub), and 10 m (forest), respective (Yakubenko et al., 2020). In addition, the relevés were expanded using the data from the maps of the area and soils, using a GPS navigator and a GPS Test mobile app (manufactured by Chartcross Limited, UK, 2015). The relevé of microrelief included the slope exposure, determined using the Cliniometer mobile app (manufactured by Plain Code Limited, UK, 2017). The projective cover of species was identified according to the classic seven-point scale of Braun-Blanquet. The relevé was added to the database using the Turboveg 2.0 software (Hennemann, 2009).

The stationary study was performed for 12 years in the territory divided into eight orographically and edaphically similar areas. It was on the left bank of the Kamianka River, south of Zhytomyr. At the beginning of the study in 2007, the territory was evenly covered with H. sosnowskyi in over 75.0%. Using special measures, all the territory was divided into three zones: meadow, shrub, and forest-shrub. In the meadow zone, we preliminary removed all phanerophytes, in the shrub zone we removed all trees, and the forest-shrub zone remained unaltered. The meadow and forest-shrub zones were divided into three plots where H. sosnowskyi plants were subjected to pressure of various degrees. On the first plot, three-time mowing of the herbaceous layer was performed with removal of the mown phytomass outside the plot. On the second plot, only individuals of H. sosnowskyi were removed. The removal was performed by cutting the plant with a spade shoved in the region where the root turns into the stem. The third plot was the control. Since the meadow-shrub zone included a large number of undergrowth of phanerophytes, and also representatives of the Rubus genus, mowing was the correct practice to employ. Therefore, this zone was divided only into two areas – the control and the one where only H. sosnowskyi was removed.

The parameters of environmental factors were determined using the phytosociological principals, ascribing points to ecofactors, estimated based on the ecological scales of the species that form a phytocoenosis. The values of factors were identified according to points of the unified scales of Didukh-Pliuta (Diduh, 2012). The estimates were carried out using the Simagril 1.12 software based on the Ecobase 5d data base (Khomiak et al., 2020). For this purpose, the classical scheme of Braun-Blanquet was transformed into five-point scale. Therefore, the projective cover above 75.0% (5 points by seven-point scale) was rated 5 points; 50.0% to 75.0%
Results

During the field studies and further analysis of the collected materials, we determined that the vegetation of the living environments with participation of *H. sosnowskyi* included 13 classes, 16 orders, 21 alliances, and 29 associations. Syntaxonomic scheme of the vegetation was as follows:


- *Phytocenotic diversity of classes of plant groups containing *H. sosnowskyi***

<table>
<thead>
<tr>
<th>Class of plant groups</th>
<th>Number of associations</th>
<th>Percentage of the overall number of relevés</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Artemesietea vulgaris</em></td>
<td>5</td>
<td>35.6</td>
</tr>
<tr>
<td><em>Galio-Urticetea</em></td>
<td>3</td>
<td>23.3</td>
</tr>
<tr>
<td><em>Molinion-Arhenatheretum</em></td>
<td>3</td>
<td>10.9</td>
</tr>
<tr>
<td><em>Epilobietea angustifolii</em></td>
<td>2</td>
<td>6.9</td>
</tr>
<tr>
<td><em>Heracleum sosnowskyi</em></td>
<td>3</td>
<td>5.5</td>
</tr>
<tr>
<td><em>Alnetum</em></td>
<td>4</td>
<td>4.1</td>
</tr>
<tr>
<td><em>Salicetalia purpureae</em></td>
<td>3</td>
<td>4.1</td>
</tr>
<tr>
<td><em>Rubetea plicati</em></td>
<td>2</td>
<td>2.7</td>
</tr>
<tr>
<td><em>Lonicerio-Rubetea plicati</em></td>
<td>1</td>
<td>1.4</td>
</tr>
<tr>
<td><em>Trifolio-geranietea</em></td>
<td>1</td>
<td>1.4</td>
</tr>
<tr>
<td><em>Trifolio-geranietea</em></td>
<td>1</td>
<td>1.4</td>
</tr>
<tr>
<td><em>Polygono-Coronopion</em></td>
<td>1</td>
<td>1.4</td>
</tr>
<tr>
<td><em>Bidentietum tripartiite</em></td>
<td>1</td>
<td>1.4</td>
</tr>
</tbody>
</table>

During the stationary studies, we determined that decline in the number of individuals down to complete vanishing of *H. sosnowskyi* occurred on the meadow plot where separate individuals had been removed (after 3 years) and on the control forest-shrub plot, where the natural multistratum vegetation of association *Ribo* *s* *nigri-Alnetum* was formed (11 years later). On the meadow plot, where regular mowing was conducted during the study period, 2–3 individuals appeared each year (the projective cover near 10.0%), and remained unaltered on the control plot. At the same time, the latter underwent active succession processes, with formation of a nitrophilic group of association *Urtico-Aegopodietum podagraceae*. There, the projective cover of *H. sosnowskyi* increased from 75.0% to 90.0%. After the completion of the 12-year cycle of the studies, mowing of the meadow plots in the territory continued, but without removal of phytomass. As a result, available-to-plants nitrogen compounds started to accumulate in the soil. This was indicated by the synphytoindication data and increase in the areas of nitrophilic species (*Aegopodium podagraceae*), which represented 35.6% and 23.3% of all the relevés, respectively (Table 1).

According to the data obtained by the method of synphytoindication of *H. sosnowskyi*, occurred in mesophyte, hemihydrocontraphothophic (moderately moistened habitats that are sporadically moistened), subacrophilic, semiiptrophic, acarbonataphilic, nitrophilic, hemiaerophobic (moderately aerated habitats), submicrothermal (habitats that receives 20–
The average temperature of the coldest month of the year is approximately –8°C, semi-illuminated, euhemeric (habitats that have been altered or created by humans and are under anthropogenic influence) habitats (Table 3).

<table>
<thead>
<tr>
<th>Characteristics of relevés</th>
<th>Standard geobotanical relevés</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species</td>
<td>Number of relevés</td>
</tr>
<tr>
<td></td>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15</td>
</tr>
<tr>
<td></td>
<td>Projective coverage*</td>
</tr>
<tr>
<td></td>
<td>D.s. var. Elytrigio repens-Aegopodietum podagriae var. Henraucum sosnowskyi**</td>
</tr>
<tr>
<td></td>
<td>D.s. As. Elytrigio repens-Aegopodietum podagriae***</td>
</tr>
<tr>
<td></td>
<td>D.s. Ord. Aegopodietum podagriae****</td>
</tr>
<tr>
<td></td>
<td>D.s. C. Galio-Urticetec*****</td>
</tr>
<tr>
<td></td>
<td>D.s. C. Molino-Arhenatheretec******</td>
</tr>
<tr>
<td></td>
<td>Other species</td>
</tr>
</tbody>
</table>

Note: * – parameters of the projective cover according to the seven-point Braun-Blanquet scale (5 points – projective cover over 75.0%, 4 points – 50.0–75.0%, 3 points – 25.0–50.0%, 2 points 5.0–25.0%, 1 point – many individuals with the projective cover below 5.0% or one individual with over 50.0%, + – number of individuals with the projective cover below 5.0%, + + – single individual with projective cover of less than 5.0%); ** – block of diagnostic species of variant of association Elytrigio repens-Aegopodietum podagriae; *** – block of diagnostic species of association Elytrigio repens-Aegopodietum podagriae; **** – block of diagnostic species of variant of alliance Aegopodietum podagriae; ***** – block of diagnostic species of variant of class Galio-Urticetec; ****** – block of diagnostic species of class Molino-Arhenatheretec; – – species is absent in the relevé.

Table 2: Phytocenotic table of variant of associations of Elytrigio repens-Aegopodietum var. Henraucum sosnowskyi (class Galio-Urticetum)
The share of overlapping of the synphytoindicatory scale indicates a broad tolerance amplitude of the species according to the variety of moistening (34.9%) and acidity of soil (32.7%). At the same time, according to the ombroregime parameters (8.0%) and the general saline regime (9.7%), its amplitude was the lowest. According to the parameter of anthropogenic transformation, H. sosnowskyi can be classified to the intermediate position between mesopherneroch and ehuhermoro, gravitating towards the latter. According to the parameter of dynamics, its position corresponded to the transition from the stage of grassland to shrub-grass stage of autogenic succession.

Discussion

Successful invasion of the natural and synantropized ecosystems by H. sosnowskyi, its resilience against human activity, and expansion of the area it occupies cannot be explained by some of its characteristic alone. The plant achieves success by a complex of adaptations and a complex mechanism of management and control of their interaction. Furthermore, the activities of H. sosnowskyi are promoted by some kinds of human activities and specifics of some types of growing environments (Grzędzicka, 2022).

As we see from the results of the studies, there were types of plant groups that often included this species, those where it was rare, and those where it was absent. We did not consider wetlands, where moisture parameters are beyond the ecological range of this species. We only considered dryland ecosystems. Heracleum sosnowskyi did not occur in mature complete forest with thorough tree coverage. Also, it did not occur in mesophyte and mesohydrophyte meadows with dense sod and multi-stratum herbaceous vegetation. Therefore, for an initial invasion, it required eco-

Table 3

Statistical parameters of the environmental factors, identified using the synphytoindicative methods

<table>
<thead>
<tr>
<th>Parameter</th>
<th>HD</th>
<th>FH</th>
<th>RC</th>
<th>SL</th>
<th>CA</th>
<th>NT</th>
<th>AE</th>
<th>TM</th>
<th>OM</th>
<th>KN</th>
<th>CR</th>
<th>LC</th>
<th>HE</th>
<th>ST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>12.3</td>
<td>6.4</td>
<td>7.9</td>
<td>7.7</td>
<td>6.8</td>
<td>7.3</td>
<td>7.3</td>
<td>8.4</td>
<td>12.4</td>
<td>8.7</td>
<td>7.6</td>
<td>6.9</td>
<td>9.3</td>
<td>5.7</td>
</tr>
<tr>
<td>Maximum</td>
<td>14.6</td>
<td>9.1</td>
<td>8.5</td>
<td>9.3</td>
<td>8.4</td>
<td>8.5</td>
<td>9.2</td>
<td>9.2</td>
<td>13.7</td>
<td>9.6</td>
<td>8.4</td>
<td>7.8</td>
<td>10.8</td>
<td>9.5</td>
</tr>
<tr>
<td>Minimum</td>
<td>10.8</td>
<td>4.8</td>
<td>6.6</td>
<td>6.6</td>
<td>5.3</td>
<td>6.3</td>
<td>5.9</td>
<td>7.4</td>
<td>10.4</td>
<td>7.7</td>
<td>6.5</td>
<td>5.3</td>
<td>7.4</td>
<td>3.3</td>
</tr>
<tr>
<td>Amplitude</td>
<td>3.8</td>
<td>4.7</td>
<td>1.8</td>
<td>2.7</td>
<td>3.1</td>
<td>2.2</td>
<td>3.3</td>
<td>1.9</td>
<td>3.3</td>
<td>1.9</td>
<td>2.4</td>
<td>3.4</td>
<td>6.2</td>
<td></td>
</tr>
<tr>
<td>Share of the scale overlap (%)</td>
<td>16.7</td>
<td>34.9</td>
<td>32.7</td>
<td>9.7</td>
<td>20.9</td>
<td>27.9</td>
<td>14.7</td>
<td>19.2</td>
<td>8.0</td>
<td>19.4</td>
<td>12.4</td>
<td>21.0</td>
<td>13.4</td>
<td>16.3</td>
</tr>
</tbody>
</table>


The share of overlapping of the synphytoindicatory scale indicates a broad tolerance amplitude of the species according to the variety of moistening (34.9%) and acidity of soil (32.7%). At the same time, according to the ombroregime parameters (8.0%) and the general saline regime (9.7%), its amplitude was the lowest. According to the parameter of anthropogenic transformation, H. sosnowskyi can be classified to the intermediate position between meso-hermoroehy and euhermoroehy, gravitating towards the latter. According to the parameter of dynamics, its position corresponded to the transition from the stage of grassland to shrub-grass stage of autogenic succession.

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As we see from the results of the studies, there were types of plant groups that often included this species, those where it was rare, and those where it was absent. We did not consider wetlands, where moisture parameters are beyond the ecological range of this species. We only considered dryland ecosystems. Heracleum sosnowskyi did not occur in mature complete forest with thorough tree coverage. Also, it did not occur in mesophyte and mesohydrophyte meadows with dense sod and multi-stratum herbaceous vegetation. Therefore, for an initial invasion, it required eco-

I. crashes involving the spread of hogweed makes it a potential weed (Malakul et al., 2015).

Invasion by H. sosnowskyi and development of its cenopopulation can be blocked by one of the two mechanisms – shading from 2.5–3.0 m tall multi-stratum vegetation or formation of a thorough sod with multi-tiered herbaceous vegetation on open grounds. While tree species are able to form forestlands without grass cover on their own, one layer we created was enough to block the invasion. After the experiment, on the stationary study plot, fruit trees were planted, including Morus nigra L. Under this tree, the herbaceous cover had notably thinned out (up to 10.0%), exposing the soil. However, there were no individuals of H. sosnowskyi under M. nigra. At the same time, some single individuals emerged around the perimeter of action of its influence zone, phytorange. This is because in such ecotone areas, shading is not thick enough to inhibit the plant, but it does not promote the formation of thorough herbaceous cover of the meadow vegetation, and therefore thorough sod. On the other hand, such ecotones are invaded by species from neighboring ecosystems, which enrich their phytodiversity, but some ecocenes nonetheless remain vacant and the vegetative coverage interrupted. The ecotone character of spread of H. sosnowskyi was pointed out by other researchers (Baležentiene et al., 2021).

A similar effect could be caused by human activity. Such ecotones are formed between completely human-altered technotopes and cultivated or spontaneous tree stands (Gubur & Koniaik, 2021), for example, on roadsides, along the windbreaks or rivers. The same situation was also well described in the territory of Latvia (Baležentiene, 2013). Furthermore, on early stages of vegetation recovery on fallows, there developed ecosystems with vegetation that was not thorough enough and had many vacat ecocenes (Khrionia, 2018). This category contained a large number of ecosystems with autotrophic block appearing as the class of groups of Artemisietea vulgaris. The definite leader there was the Elymus plants of association Agropyretum repens, which are often the first stage of recovery of disturbed vegetation. The same process can occur during formation of incomplete meadow censuses of the order Galletietea veri (class Molinio-Arrhenatheretea). According to our data, the most vulnerable there were the associations Carici praecoci-Alopecuretum pratensis and Achillea submiefolium-Dactyletum glomeratae. Theoretically, other associations of this order were targets for invasion by H. sosnowskyi, but its active development was suppressed by lower moisture and richness of soil, necessary for its fast and powerful growth. Mesophyte meadows of the order Arvenhathetalia elatiori were observed to be invaded by H. sosnowskyi through local disturbances of sod around their perimeter, where the vegetation had been inhibited by partial shade dropped from phanerophytes (Otsiub et al., 2020).

At the same time, not only are there ecosystems which are vulnerable to the spread of hogweed, but, likewise, this plant is able to directly transform its environment locally in the direction it would benefit from. In places where it had existed for many years and had been a dominating species, within its phytorange, there developed a variant of association Agropyretum repens var. Heracleum sosnowskyi. This variant represented 16.4% of the relevés with participation of H. sosnowskyi. This occurs due to the ability of the plant to grow at fast rates and cast shade from its leaves on less tall plants. Therefore, it promotes the formation of favorable conditions for new generation of its seeds to germinate. Since the projective cover of this species in a local phytocenosis can be

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considered a feature of its vitality, according to it one can identify its competitiveness and effect on the content of ecotones in the ecosystem (Diduš, 2012). Our analysis of the correlation between species of plants in groups with participation of *H. sosnowskyi* and its projective cover revealed that the plant demonstrated the best vitality parameters when its phytocenosis contained 4–5 species (Fig. 1). They remained relatively high until the number of species exceeded 7–8. Correlation between the mean values of the projective cover of *H. sosnowskyi* and the number of species of plants in the groups with its participation was observed for the approximation significance equating 0.2 and correlation parameter accounting for 0.4.

Decline in the number of species in Sosnovskyi’s hogweed’s phytocenoses is promoted not only by shade it drops on the herbaceous vegetation, but also by allelopathy (Burlėgaitė et al., 2012). This was observed in our experiment, conducted in order to identify effect of the extract from *H. sosnowskyi* on germinating qualities of the seeds of cucumbers, and also studies by other researchers (Moshkivska, 2015). Most often, the coenoses with *H. sosnowskyi* contained *Elytrigia repens* (L.) Nevski (43.9%), *Urtica dioica* L. (38.6%), *Artemisia vulgaris* L. (29.8%), *Aegopodium podagraria* L. (28.1%), *Taraxacum officinale* Webb. ex Wigg. (26.3), and *Arctium lappa* L. (21.1%).

*Hercules sosnowskyi* attains its competitive advantages through active growth and achieving large sizes in short time period because of more effective reaction to available nitrogen (nitrates and ammonium salt) in the soil. The distinction between nitrophile plants and other plants does not always lie in an expanded tolerance range that shifts towards higher levels of nitrogen compounds to avoid both deficiency and toxicity. They are usually more effective in using those compounds. In the laboratory experiments, most species positively reacted to increase in nitrates, similar to such observed in some ecotopes. However, in the natural environment, this efficiency gives them the competitive advantage from an increase in the radius of 5–6 m. Some part of the seeds can migrate large distances, carried by strong winds, which is especially noticeable during winter blizzards. However, most of the seeds were observed to remain around the mother plant, where its influence had prepared the soil and thinned the vegetative cover out for the seeds to germinate (Nathan & Safriel, 2020).

In favorable conditions, *H. sosnowskyi* switches to *r* strategy. According to the data of Litija Baležentienė, one plant is able to produce 15,444–16,164 thou seeds (Baleheniū, 2013). Their energy of germination equaled 78.0% and could maintain at this level for a long time (Moshkivska, 2015). Because of its tall peduncle (up to 3–5 m), the seeds spread in the radius of 5–6 m. Some part of the seeds can migrate large distances, carried by strong winds, which is especially noticeable during winter blizzards. However, most of the seeds were observed to remain around the mother plant, where its influence had prepared the soil and thinned the vegetative cover out for the seeds to germinate (Nathan & Safriel, 2020).

The results of the stationary studies revealed a relationship between the dynamics of ecosystems and their vulnerability to invasions. Ecosystems can have autotrophic blocks that belong to one syntaxon, but differ by parameters of natural dynamics, which reflect their position in successional series. That means they could have a developed block of diagnostic species and content of ecotones, but not enough individuals to fill this niche. In addition, there can be a dynamic ecosystem, when at certain stages of succession, there are species present from groups located nearby in the successive order. For example, in meadows, there were spotted pioneering ruderal species at early stages and planthropages at late stages (Khomik et al., 2019).

Ecosystems, where *H. sosnowskyi* lives, play different roles in its spread. There are ecosystems that are the most vulnerable to its initial invasion. They are easily infiltrated by the seeds of this species, which have a high chance to germinate there. However, it is not just any eco-

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**Fig. 1.** Correlation between the number of species in relevé (abscissa) and the mean value of the *H. sosnowskyi* projective cover (ordinate), approximated with the linear trend line

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Correlation between the number of species in relevé (abscissa) and the mean value of the *H. sosnowskyi* projective cover (ordinate), approximated with the linear trend line.
tern that the plant invades which allows it to thrive with a powerful and numerous population. Sosnowsky’s hogweed benefits from the second type of ecosystem, where it lives in the optimum ecological conditions. The third type of ecosystem is those that it can infiltrate sporadically and where it has poor chances of high percentage of germinated seeds and developed mature plants, and therefore little prospects of developing a powerful cenopopulation (Khomiak et al., 2019). Ecosystems in the early grassland stages of autogenic succession were found to be the most vulnerable to invasions. According to the scale of natural dynamics, this corresponded to the level of 3.0–4.0 points. According to the data of the phytocenosis library of the Laboratory of the Theory of Ecosystems of the Ivan Franko Zhytomyr State University, this category included 50.0% of the relevés of the associations Poa annuae-Coronopodetum squamati (class Polygono arenustri-Poëtea annuai), 49.9% of Agropyropetum repensis, 33.3% of Echino-Verbascetum, and 23.3% of Arctio-Artemisietum vulgaris (class Artemisietea vulgaris), 25.0% of Trifólio-Festucetum rubrae, and 14.3% of Deschampsietum caespitosae and Poëtum pratensis (class Molinio-Arrhenatheretea). Presence of such groups and their sustainable existence in settlements and the zone of spread of hogweed seeds pose a potential threat to its spread. Exceptions can include ecosystems that have other factors that limit its spread. Therefore, for an ecosystem with the association Poo annuae-Coronopodetum squamati – this would be excessive trampling, for Echino-Verbascetum – low moisture (10.3 points on average), and for all groups of class Bidentetaria triparti, which have natural-dynamics parameters within 2.4–6.3 points, those factors would be too high moisture parameters (on average 15.0 points according to the unified Diduch-Pluta scale). Thus, hogweed infiltrates such areas sporadically and has little opportunity to transform those ecosystems in the way it needs to spread further.

According to the projecting cover and number of individuals, the species reaches the maximum in ecosystems with the dynamics parameter equaling 4.0–7.0 points. The most promising for its local flourish was ob- wind that receives 20–30 kcs/m2, subombrophytic, hemioceanic, subcryophytic (habitats with the average temperature of the coldest month of the year –8), semi-illuminated, euhemerobic (habitats that have been altered or created by humans and are under anthropogenic influence) habitats. The competitive advantage of H. sosnowskyi over the native species comprised the following characteristics: ability to switch from r to K strategy, depending on the environmental conditions; producing a large number of seeds, spread from a tall peduncle, which maintained a high germination rate for several years; and allelopathy and efficient absorption of nitrogen compounds, which fostered the sizes of the shoot. Ruderal and natural environments of grasslands at early stages of autogenic succession (3.0–4.0 points of natural dynamics) were the most vulnerable to invasion by H. sosnowskyi. The highest projecting cover and density of its po- population was observed on the nitrified forest edges of the variant of asso- ciation Elytrigio repens-Aegopodietum podagrariae var. Heracleum sosnowskyi (the parameter of natural dynamics of 4.0–7.0 points). Forest ecosystems with multi-stratum vegetation (the parameter of dynamics above 9.5 points) and meadows with thorough sod (parameter of dyna- mics above 4.8 points) were less vulnerable to invasion. At the same time, disturbance of the completeness of the tree stand or integrity of sod created additional opportunities for its infiltration of this territory. Having invaded the natural or ruderal ecosystems, H. sosnowskyi most often transformed their autotrophic blocks into a variant of association Agropyropetum repensis var. Heracleum sosnowskyi of class Artemisietea vulgaris, which are a more favorable phytocenosis for its intensive reproduction and spread.

The authors declared no conflicting interests.

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