ISSN 0206-5657. Вісник Львівського університету. Серія біологічна. 2024. Випуск 92. С. 67–89
Visnyk of the Lviv University. Series Biology. 2024. Issue 92. P. 67–89

ЕКОЛОГІЯ

УДК [582.795:581.524.2]:[574.1:502.211](4) HTTPS://DOI.ORG/10.30970/VLUBS.2024.92.06

REVIEW OF MODERN APPROACHES TO THE MANAGEMENT OF INVASIVE SPECIES OF THE GENUS *HERACLEUM* IN EUROPE

P. Nasadiuk, Z. Mamchur

Ivan Franko National University of Lviv
4, Hrushevskyi St., Lviv 79005, Ukraine
e-mail: zvenyslava.mamchur@lnu.edu.ua; *dzvinkamamchur@gmail.com*

The article discusses the relevance of the problem of invasive alien species (IAS) in Europe, highlights the bioecological characteristics of invasive species of the genus *Heracleum* (*H. mantegazzianum*, *H. persicum*, and *H. sosnowskyi*) and historical ways of introduction. Statistics on the spread of these species and their negative impact on biodiversity and ecosystem resilience are presented. The spread of invasive species of the genus *Heracleum* has far-reaching consequences, affecting ecosystem sustainability, the economy, and healthcare. It has been shown that the ecological consequences of the impact are manifested not only in the ability of these species to displace native flora and disrupt natural ecosystems, but also in various areas of economic activity. These plants' aggressive growth and allelopathic effects lead to significant economic costs associated with land management and agricultural productivity. The examples of different mechanisms of impact of invasive species of the genus *Heracleum* highlight their detrimental effects on ecosystems and human health. In particular, the phototoxic substances of *Heracleum* spp. pose severe risks to human health, causing skin inflammation and long-term photosensitivity. Various methods of controlling, eradicating and preventing the spread of *Heracleum* spp. species in Europe are discussed in detail, including mechanical, biological, and chemical methods and preventive strategies. Attention is also focused on post-eradication control methods, disposal of plant waste generated during eradication, and restoration of natural vegetation. The key steps of an integrated approach to effectively reduce the invasion of *Heracleum* spp. in new areas are analysed.

The urgent need for integrated management strategies to mitigate the impact of invasive *Heracleum* species and prevent further spread is shown. It is noted that IPM control is an important international issue that requires coordinated efforts at the EU and UN levels. The conclusion is drawn about an integrated management approach that combines physical, chemical and biological methods adapted to specific regional conditions and aligned with international biodiversity goals. The article also discusses the role of public awareness and education in preventing the spread of invasive species. Public involvement in early detection and rapid response initiatives is emphasised, which is crucial for the successful management of alien invasive plant species.

Keywords: Heracleum mantegazzianum, Heracleum persicum, *Heracleum sosnowskyi*, invasive alien species, control of *Heracleum* species, biodiversity

Invasive alien species (IAS) represent one of the five principal drivers of global biodiversity loss, along with land and water use change, direct exploitation of organisms, climate change and pollution [107]. The introduction of more than 37,000 alien species as a consequence of human activities has occurred across all regions and biomes of the Earth. Furthermore, the rate of new alien species being recorded is approximately 200 per year, representing an unprecedented change. A review of the scientific literature reveals that more than 3,500 of these species, including the invasive *Heracleum* species, have been classified as IAS due to their documented negative impacts. The proportion of alien species identified as invasive varies across taxonomic groups, with rates ranging from 6 % of all alien plants to 22 % of all alien invertebrates. Invasive alien species have been identified as the primary cause of 60 % of recorded global extinctions, with a further 16 % of documented extinctions of animals and plants attributed to this factor alone [107].

In 2019, global annual expenditure on biological invasions exceeded 423 billion US dollars. Most of these expenditures (92 %) were directed towards addressing the adverse effects of integrated pest management on the natural environment and quality of life. In comparison, only 8 % were allocated towards controlling and managing biological invasions [70]. The economic consequences are equally significant, with annual costs estimated at least €12 billion in Europe [107]. The acceleration of globalisation in trade and travel has facilitated the spread of invasive species, resulting in profound environmental and socio-economic impacts worldwide. The unprecedented spread of alien species, including invasive *Heracleum* spp., is a consequence of human activity. These species are now present in all regions and biomes of the world, with negative and, in some cases, irreversible impacts on nature, including the loss of unique biological communities.

The introduction of invasive alien species has the potential to impede the efficacy of conservation and restoration initiatives significantly. In addition to causing significant damage to the natural environment and the economy, many invasive alien species also contribute to the emergence and spread of infectious diseases, which threaten humans and wildlife. The rate of spread of invasive alien species has increased in recent years. Of the 1,872 species currently considered threatened in Europe, 354 are threatened by invasive alien species (IAS). Without efficacious control measures, the rate of invasion and the associated risks to our natural environment and human health will continue to increase [20].

The necessity for the control of invasive alien species (IAS) is acknowledged in the United Nations Convention on Biological Diversity. “It is imperative to prevent the spread, control or eradicate those alien species that threaten ecosystems or species” [86]. The Kunming-Montreal Global Biodiversity Framework (2022) sets out one of the global targets for reducing threats to biodiversity, as follows: “Eliminate, minimise, reduce and mitigate the impact of IAS on biodiversity and ecosystems by identifying pathways for the introduction of alien species, preventing the spread and establishment of IAS by at least 50 per cent by 2030” [46]. The European Green Deal 2050 asserts that ecosystems are indispensable for sustaining life, providing essential resources such as food, fresh water, clean air, and shelter. They play a role in mitigating the impact of natural disasters, pests, and diseases and regulating the climate. The document emphasises the importance of conserving and restoring ecosystems and biodiversity [13].

The EU Biodiversity Strategy 2030 underscores the necessity to address the issue of invasive alien species. One of the principal elements of the EU’s Nature Recovery Plan for the restoration of terrestrial and marine ecosystems represents a crucial aspect of the fight against invasive alien species. The implementation of the EU Invasive Alien Species Regulation and other pertinent legislation and international agreements has been intensified. The objective is to minimise and, where feasible, eradicate the introduction and proliferation of invasive alien species within the EU’s natural environment. The aim is to regulate the existing invasive alien species and reduce the number of Red List species threatened by them by 50 % [86].

Both *Heracleum mantegazzianum* and *Heracleum persicum* were initially introduced to Europe as ornamental garden plants, a pattern common to many invasive alien species. Europe is home to approximately 800 botanical gardens, which have played a key role in introducing and spreading non-native plant species over the past 500 years [31]. While these gardens have provided numerous economic and social benefits through agriculture, horticulture, and medicine, they have also unintentionally contributed to the escape and naturalization of various IAS into local ecosystems. Recognizing the significance of this issue, the Council of Europe developed the European Code of Conduct for Botanic Gardens in 2013 to address the risks posed by IAS [31]. This Code provides essential guidelines for botanic garden staff, emphasizing the need for awareness, prevention, and control measures to manage non-native species responsibly. The main components of the Code include conducting audits of plant collections, preventing the introduction of invasive species, ensuring compliance with national and international regulations, and sharing information with other institutions. Outreach and public education also form critical parts of the Code, as botanic gardens play a crucial role in raising awareness about invasive plants' ecological and economic dangers. By implementing these guidelines, botanic gardens can significantly reduce the spread of IAS and contribute to global biodiversity conservation efforts.

Materials and methods

A comprehensive review of the last scientific publications, other literature, and online sources from numerous European countries, including Belgium, Bulgaria, the Czech Republic, Denmark, Estonia, Finland, Ireland, Latvia, Lithuania, Luxembourg, Germany, Norway, Poland, Switzerland, Ukraine, and the United Kingdom, was conducted. The analysis encompassed various sources, including scientific articles, monographs, dissertations, recommendations from international organisations and government agencies, online resources, databases, etc.

Furthermore, the literature review assesses the legislative and regulatory measures adopted by the EU and the UN to manage and mitigate the impact of invasive species. This comprises an examination of the efficacy of existing control strategies and recommendations regarding optimal practices for managing invasive species of the genus *Heracleum*. The combination of policy analysis and scientific research offers valuable insight into the complex challenges posed by *Heracleum* species, emphasising the necessity for coordinated action to address these issues.

Ecobiotic prerequisites for the invasion of species of the genus *Heracleum*

The primary biological and ecological prerequisites that contribute to the invasiveness of species of the genus *Heracleum* are listed in Table 1 [23, 37, 55, 62, 77]. These characteristics render the *Heracleum* spp. particularly adept at spreading and establishing themselves in new areas thereby posing significant challenges to biodiversity conservation and ecosystem management.

Table 1

Biological and ecological prerequisites for the invasion of the species of the genus *Heracleum*

Environmental prerequisites	
Flexibility in terms of habitat	Thrive in disturbed habitats such as roadsides, riverbanks and abandoned fields. Withstand a wide range of soil types, moisture levels and light conditions
Climate adaptability	They are adapted to different climatic conditions from temperate to subarctic regions Effective disruption of the dormant period by low winter temperatures
Lack of natural predators	Often lack natural herbivores or pathogens in non-native ranges that could control their populations in their native habitat
Biological background	
Reproductive strategy	Early spring germination, preceding the emergence of the root system. High seed productivity, seed viability for several years, seeds are dispersed by wind, water, snow and human activity Opportunities for self-pollination for viable seeds
Growth and competitiveness	Rapid growth, ability to compete with native vegetation for light, nutrients and space, possible allelopathy, which inhibits the growth of surrounding plants

Ecological and biological mechanisms of the impact of invasion of species of the genus *Heracleum*. The introduction of invasive species of the genus *Heracleum* has been observed to exert a considerable influence on the ecological and biological characteristics of the ecosystems in which they become established [37, 38]. This impact is manifested in a number of ways, including changes to trophic levels, genetic diversity, habitats, modifications to nutrient regimes and disruption of succession patterns [41, 49].

Recent experiments in Slovakia (2024) have demonstrated the allelopathic influence of the invasive *Heracleum mantegazzianum* on native plant species. Research revealed that extracts from *H. mantegazzianum*—particularly those derived from leaves collected in April—significantly impacted barley (*Hordeum vulgare*) and summer wheat (*Triticum aestivum*) germination and growth. The study found variability in the extracts' effects depending on the plant material's collection period and the model plant species tested [25].

In addition to the ecological consequences, the introduction of invasive *Heracleum* species can have direct negative implications for human health and socio-economic activities. [16, 17, 50]. As an illustration, the sap of *Heracleum* spp. can induce dermatological irritation and allergic reactions, impacting recreational activities and agricultural practices. Furthermore, *H. persicum* has the potential to negatively impact fisheries and aquaculture, reduce tourist attractions, and contribute to negative impacts on local economies, thereby exacerbating the broader socio-economic impacts of invasive species. It is of the utmost importance to understand the mechanisms and effects to develop effective management strategies that will mitigate the detrimental impacts of invasive *Heracleum* spp. and protect local biodiversity and ecosystems [15, 22].

Table 2 outlines the various mechanisms through which invasive *Heracleum* species harm ecosystems and human health. Each impact mechanism is accompanied by specific examples that illustrate how these species disrupt natural habitats, displace native flora, and pose significant health risks [28, 55, 59, 61].

Table 2

Mechanisms of impact of *Heracleum* species invasion

The mechanism of influence	**Examples**
Allopathic	*H. mantegazzianum* produces allopathic chemicals that inhibit the growth of other plants
Poisoning and allergic reactions	The juice of *Heracleum* spp. can cause severe skin irritation, burns and photodermatitis
Competition - monopolisation of resources	*H. persicum* can form dense thickets, displacing native vegetation
Competition - shading	*H. mantegazzianum* shades out native species, reducing their access to sunlight
Hybridisation	*H. persicum* hybridises with native *Heracleum* species, potentially altering their genetics
Rapid growth	*H. mantegazzianum* grows rapidly, dominating the areas it enters

Distribution of invasive species of the genus *Heracleum* in Europe

For this study, three of the 20 representatives of the genus *Heracleum* present in Europe [55] were selected: *H. mantegazzianum*, *H. sosnowskyi* and *H. persicum*, commonly known as giant hogweed. They represent the most prominent examples of highly invasive and aggressive plants that have spread across Europe in recent decades. All three species (*H. sosnowskyi, H. persicum*, and *H. mantegazzianum*) are included in the European list of Invasive Alien Species of Union concern (Commission Implementing Regulation (EU) 2022/1203 of 12 July 2022 amending Implementing Regulation (EU) 2016/1141 to update the list of invasive alien species of Union concern), with *H. sosnowskyi* and *H. persicum* added in 2016 and *H. mantegazzianum* in 2017. Together, they represent 7.3 % of the invasive alien plant species on the list (i.e., 3 out of 41 invasive plant species listed as of today) [12]. These species are also listed as invasive alien species nationally in many EU countries.

***H. mantegazzianum* Sommier & Levier** – originally from the western part of the Greater Caucasus in southern Russia and Georgia [100, 105]. It was first introduced to the UK as an ornamental garden plant at Kew Botanic Gardens in 1817. By 1862, it was already recorded in Ireland, Denmark, the Netherlands, and Germany [34]. It is the most widespread invasive *Heracleum* species in the world, from the USA to New Zealand. It is registered in 33 European countries, including Austria, Belarus, Belgium, Bosnia and Herzegovina, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Hungary, Iceland, Ireland, Italy, Latvia, Liechtenstein, Lithuania, the Netherlands, Norway, Poland, Portugal, Russia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, and the United Kingdom (Fig. 1.) [9, 26, 39, 54, 60, 85, 100, 101]. Studies show that with global climate change [67], the range of *H. mantegazzianum* could expand by 20 % in Northern Europe. It is expected that most range changes predicted for 2100 may occur as early as 2041 [4].

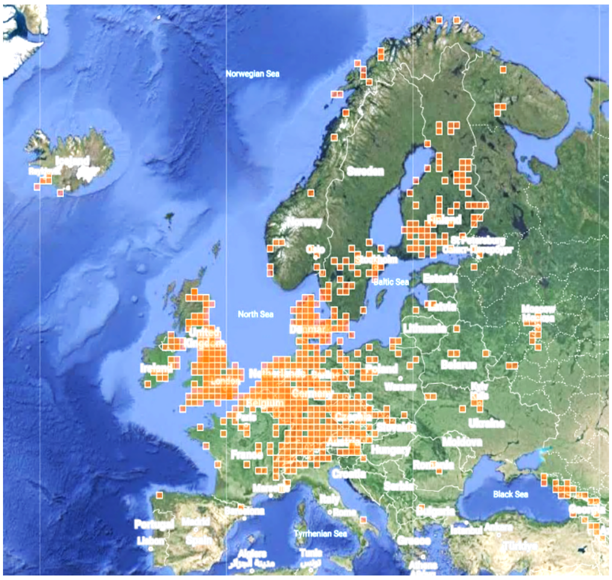

Fig. 1. Distribution of *Heracleum mantegazzianum* Sommier & Levier in Europe [101]

***H. sosnowskyi* Manden** is native to the eastern portion of the Main Caucasus Range and the southwestern and eastern Transcaucasian regions. The species was first described in 1944 by Mandenova from the Meskheti region of Georgia. The species was first introduced to Russia in 1947, where it was cultivated as a highly productive fodder crop for livestock. Subsequently, it was introduced to other countries: Belarus, Poland, Ukraine, the Baltic States and the eastern part of Germany [59, 99]. It is currently undergoing a period of rapid dissemination throughout Europe, with registration in 20 countries on the continent: Austria, Belarus, Bulgaria, Denmark, Estonia, Finland, France, Georgia, Germany, Hungary, Italy, Latvia, Lithuania, Poland, Romania, Russia, Serbia, Spain, Ukraine, and the United Kingdom (Fig. 2) [7, 9, 27, 39, 47, 82, 90, 99, 101, 102].

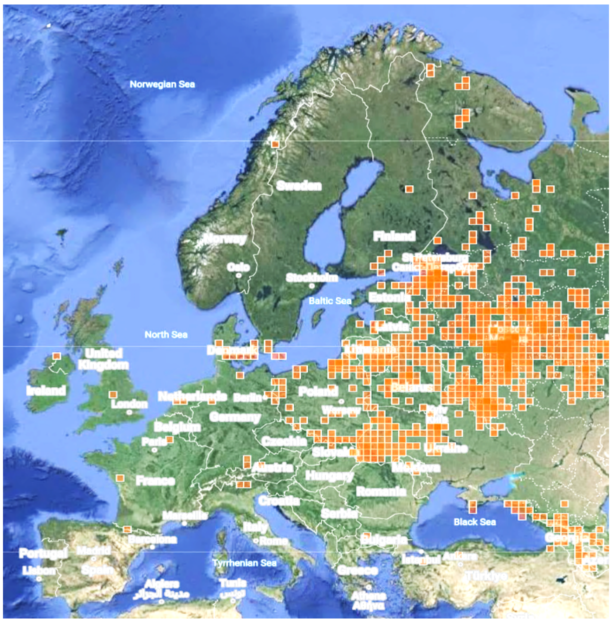

Fig. 2. Distribution of *Heracleum sosnowskyi* Manden in Europe [102]

H. persicum **Desf. ex Fisch** - originally from Iran, Iraq and Turkey [21]. It was first introduced to the UK as an ornamental garden plant in 1829 and then to northern Norway in 1836 [34]. Subsequently, the species expanded its range southwards across Northern Europe, and is currently registered in nine European countries. The species is present in the United Kingdom, Norway, Sweden, Denmark, Finland, Iceland, Estonia, the Czech Republic and Hungary. Some sources report isolated cases in Germany and France (Fig. 3) [9, 14, 39, 68, 69, 94].

Fig. 3. Distribution of *Heracleum persicum* Desf. ex Fisch in Europe [103]

Table 3 illustrates the principal impacts of the invasive species of the genus *Heracleum* in Europe.

Table 3

Environmental impacts of invasive *Heracleum* species

Consequences of exposure	**Examples**
Changed trophic level	Disruption of food chains caused by the dominance of *Heracleum* spp. in the ecosystem
Altered gene pool / selective loss of genotypes	Reduction of genetic diversity in plant populations due to hybridisation of *H. persicum*
Ecosystem change/habitat alteration	The loss or transformation of habitats changes local ecosystems
Modification of the nutritional regime	Changes in soil nutrient availability due to the growth of *H. mantegazzianum*
Modification of succession models	Disruption of natural succession due to *H. sosnowskyi* invasion
Formation of a monoculture	The dominance of *H. mantegazzianum*, which leads to the formation of a monoculture
Negative impact on human and animal health	Skin irritation and allergic reactions caused by the juice of *Heracleum* spp.
Negative impact on aquaculture/fisheries	Damage to fish populations and disruption of aquaculture due to *H. persicum*
Negative impact on tourism	Reduced tourist attraction and negative impact of *Heracleum* spp. on the local economy
Reducing the value of comfort	Reduction of aesthetic appeal of the territory due to *H. mantegazzianum* infestation
Decrease in local biodiversity	Extinction of native plant and animal species caused by *Heracleum* spp.
Negative impact on agriculture	Yield reduction and competition with *H. persicum*
Impacts on ecosystem connectivity	Disruption of natural processes, such as pollination and nutrient cycling, due to *Heracleum* spp.
Vulnerability to intrusion	Creates conditions favourable for the penetration of other invasive species

Control, eradication and prevention of *Heracleum* species in Europe

In Europe, the control and management of *Heracleum* species is based on a multi-faceted approach, encompassing prevention, eradication and post-eradication strategies. A variety of approaches are employed by different countries in their efforts to combat the invasive nature of these species, with numerous studies being conducted to this end.

The principal methods employed to control *Heracleum* species are mechanical and chemical [32]. The application of mechanical control methods, such as the cutting of roots, does not result in the immediate death of the plant. Rather, the plant dies only after repeated treatments over several seasons due to the depletion of its nutrient reserves. The use of ploughing as a control method on farmland has been demonstrated to be effective, with deep ploughing resulting in a significant reduction in infestations. This is due to the destruction of seed germination in the topsoil, where most seeds are concentrated. The most productive results are achieved when invasive vegetation is controlled mechanically or chemically before ploughing.

The successful eradication of invasive species often necessitates the implementation of comprehensive and persistent measures over a period of seven to ten years. Nevertheless, managing populations on steep slopes and in inaccessible areas continues to present a significant challenge for manual treatments. Preventive strategies are oriented towards maintaining dense vegetation cover, to prevent gaps and increase the diversity of endangered plant communities [48].

While **mowing** is an effective method for large-scale vegetation management, it necessitates two to three repeated applications during the active growth season to prevent regrowth [88].

This is true regardless of whether the mowing is done manually or with mechanical cutting tools. Some guides suggest that mowing should be performed as frequently as every two weeks. To prevent the dissemination of seeds, mowing should be conducted prior to the maturation of the plant. It is not advised to cut plants exceeding a height of 1.5 metres, due to the elevated difficulty and risk of contact with the sap. Adhering to the prescribed safety protocols and utilising the appropriate personal protective equipment is of the utmost importance. It is recommended that hand mowing with tools such as scythes or trimmers be employed for small areas or in situations where mechanical mowing is not available [4, 43, 45, 53, 55, 62].

The aforementioned mowing methods can potentially expose workers to health risks due to direct contact with the plant. Consequently, as a more secure alternative, agricultural machinery manufacturers provide **remote-controlled mowers** that permit operation at distances of up to 300 metres and facilitate the management of challenging terrain, in addition to mulching plants. Equipment manufacturers assert that mulching represents the most productive methodology for large populations, necessitating the initial trimming of juvenile plants and subsequent mowing at ten-day intervals to forestall the regrowth of shoots. This process should be repeated for a period of ten years, with regular monitoring to ensure the complete destruction of all plants and the absence of viable seeds [98].

Root cutting represents an efficacious mechanical control method, particularly when initiated at an early stage. For plants up to five years old, aAn effective cutting depth of 15 cm has been observed, while for younger plants, a depth of 10 cm has been found to be sufficient. The results of field research conducted in Poland indicate that cutting roots in late April proved more effective than cutting them in mid-June. The most productive strategy for biennial plants was the repeated cutting of roots three times during the growing season (April, June and August) over a five-year period, which destroyed 97.2 % of the initial number of plants.

It was determined that cutting the roots of three-year-old *H. sosnowskyi* plants at a depth of 10 and 15 cm resulted in their complete destruction. The complete eradication of five-year-old plants necessitated a deeper cut, whereas seven-year-old plants were not entirely eliminated, indicating that a deeper cut was more effective. It is noteworthy that the seven-year-old plants exhibited considerably higher root biomass and longer crown roots than the three-year-old plants, which may have contributed to their enhanced resilience.

This method is most effective for young plants growing in moist soil. For larger plants, using loppers to cut off the upper parts is recommended, as this provides better access to the stem and taproot. To prevent regrowth effectively, the roots should be cut to a depth of 20 cm. Furthermore, a shovel angled at 45 degrees can sever the taproot at a depth of approximately 15 centimetres below the soil surface. In areas susceptible to erosion or with pronounced topography, excising the taproots to a depth of 25 cm may be advisable. It is recommended that the cuttings be removed or allowed to dry off-site [6, 29, 55, 63, 89].

The practice of **ploughing** is an effective method for cultivating agricultural land. However, deep ploughing has been observed to have a detrimental impact on seed germination in the topsoil. In areas with no sensitive species, deep ploughing, reaching depths of up to 24 cm, can be an effective control measure for *Heracleum* species. This method simultaneously excises the taproot and interreds the majority of the seeds to a depth that precludes germination. The optimal results for *H. mategazzianum* are achieved when existing vegetation is first controlled by mechanical or chemical means before ploughing. The optimal time for this procedure is during the autumn months, as subsequent frosts and low temperatures facilitate the degradation of shoots. Removing large roots from the ploughing area is crucial to prevent their regrowth [6, 29, 35, 54, 55, 62, 63]. Conversely, research conducted in Latvia suggests that ploughing or disc harrowing has a comparatively limited impact on *H. sosnowskyi* and may even have a detrimental effect on the growth of the local flora, reducing diversity and number of plants [36].

The **removal of inflorescences** is an essential procedure in the control of plant populations. One of the most common methods employed is the removal of flower heads, which should be carried out before the formation of seeds in order to prevent further spread. Experimental evidence from the Czech Republic indicates that the removal of all flower heads of *Heracleum* species during peak flowering results in a significant reduction in seed production. Pruning the plants during the middle of the flowering period prevents the formation of new seeds. However, if this is done too early, it can stimulate the formation of secondary stems that may also flower. Removing flowering heads in early or late summer represents a short-term, interim method of preventing further seed spread, particularly when other methods have been exhausted. It is important to note that this method does not result in the death of the plant [29, 55, 62].

Using **chemical control methods** is regarded as an efficacious and cost-effective approach for managing species belonging to the genus *Heracleum*.

The efficacy of glyphosate and triclopyr against *H. mantegazzianum* has been demonstrated, indicating potential vulnerability to other species of *Heracleum*. Nevertheless, the proliferation of *H. persicum* through vegetative growth can diminish the efficacy of glyphosate, as it solely targets the aboveground portion of the plant [5].

Studies conducted in Lithuania, Latvia, and Finland have evaluated the efficacy of herbicide mixtures comprising tribenuron-methyl and methylsulfuron-methyl in controlling *H. sosnowskyi*, showing positive results [92]. Glyphosate applied alone did not give the expected results, but the combination with triasulfuron was effective [36]. However, the use of these herbicides is restricted in certain areas, such as near water bodies and forest edges, to ensure environmental safety.

Polish researchers have found that triclopyr mixtures provide 90–95 % control of *H. sosnowskyi*, including triclopyr + fluroxypyr + clopyralid, as well as mixtures of propoxycarbazone sodium + iodosulfuron methyl sodium + amidosulfuron [36]. Latvian researchers recommend applying glyphosate, triclopyr and imazapyr in March-May to control *H. sosnowskyi*. The application of glyphosate after spring germination in combination with deep ploughing has been demonstrated to be an effective method in Latvia [36].

A five-year study conducted in Poland substantiated the efficacy of herbicide treatments in controlling the growth of *H. sosnowskyi*. A single application of glyphosate was observed to be less effective than a mixture of glyphosate and flazasulfuron, with the latter exhibiting superior control with an increased frequency of treatments. The most effective approach was a three-time application of a mixture of glyphosate and flazasulfuron, which resulted in 91 % control in the second year and 100 % control in the fifth year. Furthermore, it was observed that plants treated on three occasions during each growing season did not produce any generative shoots, indicating the importance of sequential and repeated treatments for the successful eradication of *H. sosnowskyi*. From a chemical perspective, the most effective approach is a three-time application of a herbicide mixture containing glyphosate and flazasulfuron over a five-year period, which provides complete control of *H. sosnowskyi* [43].

An integrated approach incorporating chemical, mechanical, and biological methods is the most effective for controlling *H. sosnowskyi*. The mixtures tribenuron-methyl + methyl sulfuron-methyl and fluroxypyr + methyl sulfuron-methyl demonstrated rapid efficacy, with only a few plants remaining in the plots following application. The selection of an appropriate herbicide combination, with due consideration of environmental factors, is of paramount importance for the effective management of invasive species.

By UK guidelines, the optimal time for herbicide application is when the plant has reached a height of approximately 50 cm with fully developed leaves, typically in mid to late April (or March if the spring is early). It is recommended that the site be monitored in May and early June to identify any new plants or those that were missed during the initial treatment. If re-treatment is required, this should be conducted using a spot or continuous spraying method. It is important to note that the combination of aminopyralid and triclopyr is permitted for use only once per year. It is therefore recommended that glyphosate should be used should further spot treatments be required [29].

A five-year field experiment (2018-2022) was conducted to assess the effectiveness of **pyrolysis liquid mulch (PLM)**, biodegradable mulches, and glyphosate in controlling Heracleum mantegazzianum, an invasive plant species spreading across Europe. The study found that PLM had limited success in reducing mature H. mantegazzianum populations, while traditional plastic and biodegradable mulches, as well as glyphosate, were more effective. These results highlight the need for improved biobased weed control methods in managing the spread of this species [33].

The study on the use of **gibberellic acid (GA_3)** on flowering *H. sosnowskyi* was conducted in Lithuania between 2020 and 2022. The findings demonstrated that a double treatment with GA_3 during the flowering phase of the invasive plant *H. sosnowskyi* exhibited a consistent dose-response relationship, effectively reducing seed germination. Furthermore, two factors contributing to the reduction in the viability of mericarps resulting from the application of GA_3 on flowers were identified. (1) an increase in the proportion of seedless mericarps and (2) a decrease in the germination capacity of well-formed mericarps in the field. The study spanned a period of two years, during which time different dominant mechanisms were identified each year. It is anticipated that the reduction in seed viability resulting from applying GA_3 will impede the annual replenishment of the soil seed bank, thereby limiting the potential for further plant spread [92].

This approach may also prove effective for controlling other closely related invasive species, such as the monocarpic *H. mantegazzianum*. Nevertheless, further research is required to fully elucidate the mechanisms underlying the effects of exogenous GA_3 on the germination of well-formed mericarps under different climatic conditions. This research should encompass both the expansion of application methods and the investigation of underlying mechanisms. Before implementing this approach for commercial plant control, it is essential to gain a comprehensive understanding of the factors influencing its efficacy [92].

Microwaves, a form of electromagnetic radiation, could serve as an environmentally friendly method for controlling this species. A field experiment utilising microwaves was conducted in Poland in 2022. A 15-minute microwave exposure resulted in 100 % mortality of the plants, which was confirmed 7 and 75 days after the treatment. This indicates that longer microwave irradiation periods may be more efficacious in ensuring the complete eradication of *Heracleum* spp. during the flowering phase [78]. The study continued in 2024 and proved that microwaves do not affect soil ecotoxicity, as proved by the three biotests, which is a vital environmental benefit of this method [79]. The study found that microwaves effectively prevented hogweed regrowth for up to 14 days, with higher treatment times (up to 15 min) reducing root biomass by 55–67 %. The method also altered the biochemical composition of the plant, increasing sugar and saturated fatty acid levels, while having no adverse effects on soil ecotoxicity. Essential oils extracted from the roots showed increased diversity, with no highly photosensitizing compounds detected. These findings highlight MWT as a promising, sustainable approach for managing invasive species [79]. If proven to safely impact human health and surrounding ecosystems, this method could represent a promising new approach

The use of **sheep grazing** has been demonstrated to be an effective control method, particularly when employed for a minimum of ten years in areas with a high degree of infestation where machinery cannot be used [3]. This method has been employed in Denmark, the United Kingdom, Ireland, and Germany [3, 8]. An extensive experimental study on the efficacy of sheep grazing as a biological control method was conducted by the Scottish Invasive Species Initiative (SISI). The organisation posits that sheep are immune to the toxic sap of *Heracleum* spp. SISI is currently undertaking a practical experiment to identify the most effective strategies for land managers to utilise sheep in the control of the spread of *Heracleum* species [104]. This approach shows promise and warrants further investigation.

In addition to **grazing**, no evidence currently suggests that any other **biological control method** is effective. The surveys were conducted in the Caucasus, the native range of *Heracleum mantegazzianum*, to identify potential biological control agents. Numerous fungal species were discovered associated with the plant, many of which were newly recorded on this host. However, none of the surveyed pests, including insect species and fungal pathogens, demonstrated the necessary host specificity to be deemed safe for introduction into Europe as biological control agents [19]. At present, the impact of natural enemies on *H. mantegazzianum* is minimal, with the localised damage caused by certain fungal pathogens serving as an illustrative example. While different insects and fungal pathogens attack different parts of the plant, none of the natural enemies has demonstrated sufficient efficacy to be considered a viable biological control method in Europe. In the Caucasus mountains, where *Heracleum* species are found, the associated insects were either polyphagous or oligophagous, feeding on multiple *Heracleum* spp. and potentially other plants in the Apiaceae family. Laboratory studies demonstrated that certain oligophagous insects exhibited a broader dietary range encompassing a variety of Apiaceae plants. However, none of the insect species studied exhibited monophagous behaviour, feeding exclusively on *H. mantegazzianum*. A number of natural insect enemies were identified, including the weevil (*Nastus fausti* Reitter), the ceramide beetle (*Phytoecia boeberi* Ganglbauer), the small butterfly (*Agonopterix caucasiella* Karsholt) and the agromyza fly (*Melanagromyza heracleana* Zlobin). However, none of these were considered suitable for biological control due to their lack of significant impact on the plant. Similarly, studies of pathogens associated with *Heracleum mantegazzianum* have demonstrated that all known *Heracleum* species share a common mycobiota [11].

The biological control of invasive *Heracleum* species, in particular *H. sosnowskyi*, has been the subject of extensive research in Poland. Despite considerable efforts, no effective agent with a narrow enough spectrum of action to be considered safe has been identified for any invasive *Heracleum* species. Intensive research has explored the potential of natural enemies such as insects and pathogens. However, difficulties remain in identifying agents that do not damage other plants of the Apiaceae family, such as parsnips (*Pastinaca sativa*) [53].

Hybridisation poses additional challenges for the control and management of *Heracleum* species hybrids are frequently unidentified and may display an enhanced capacity for invasive growth. Hybridization within the genus *Heracleum* is documented [76]. Hybrids between *H. mantegazzianum* and the native *H. sphondylium* have been reported in Great Britain and Germany [56], occurring in areas where both species co-occur, though they remain relatively rare [24, 81]. Additionally, hybridization between *H. mantegazzianum* and *H. sosnowskyi* with the native *H. sibiricum* is anticipated in Lithuania. While hybridization between *H. sphondylium* and

H. mantegazzianum is considered possible [57], it occurs infrequently. Hybridization between *H. mantegazzianum* and *H. sosnowskyi* is also feasible [76]. *H. persicum* commonly hybridises with *H. sphondylium*, potentially complicating control efforts due to the increased invasiveness that hybrids can exhibit as a result of interspecific hybridisation. Such hybrids can have an impact on local biodiversity. Therefore, the identification and control of hybrids using developed markers is crucial for the conservation of local plant diversity [18, 74]. It is important to note that *H. persicum* and *H. mantegazzianum* are not sympatric in their natural ranges, and their distribution areas in Europe rarely overlap. This raises questions about the occurrence of hybridisation between these two species [21].

However, management of species of the genus *Heracleum* is complicated by a number of factors, including their morphological similarity, the uncertainty surrounding their taxonomic classification, and the possibility of hybridization. In such cases, a comprehensive understanding of the population genetics of *Heracleum* species may prove beneficial.

The utilisation of **unmanned aerial vehicles (UAVs)** and remotely operated machinery for implementing mechanical, chemical and other control measures represents a promising avenue for the management of *Heracleum* species. However, further investigation and testing are necessary to ascertain the efficacy and feasibility of these approaches. Thus far, unmanned aerial vehicles (UAVs) have been employed primarily for the detection and monitoring of invasive species [80]. However, with the advancement of the industry, they are poised to become a valuable tool in combating local and global *Heracleum* species invasions.

These findings thus emphasise the importance of implementing prompt and consistent control measures, as well as considering the age of the plant, its root development and the specific infestation sites when devising eradication strategies [58].

Control methods after eradication of invasive species of the genus *Heracleum*

Following the eradication of the species, it is of the utmost importance to implement programmes designed to facilitate the regeneration of dense vegetation cover, thereby preventing the re-infestation of the area by *Heracleum* species. For instance, the utilisation of grass mixtures and reforestation techniques may prove beneficial. It is also crucial to raise public awareness and encourage their involvement.

It is of the utmost importance to exercise caution when handling the **disposal of plant waste** from eradicating invasive species of the genus *Heracleum*. This is to prevent environmental contamination and the further dispersal of seeds. Waste material comprising inflorescences or seeds should be meticulously stacked, taking care to prevent contact with water and soil [51]. The aforementioned piles should subsequently be collected in bags and disposed of in accordance with the recommendations set forth below. It is not advised to leave plants with herbicide residues in the environment or to compost any *Heracleum* plant material containing seeds. In the event that the removal of waste in its current state is necessary, it can be done so in large bags. It may be feasible to utilise controlled burning as a method to prevent the dispersion of seeds by the application of heat. **Heat treatment of seeds** from invasive Heracleum can be crucial in slowing their spread and is particularly relevant for professionals such as road maintenance workers and farmers. Laboratory experiments in 2024 showed that Heracleum seeds are highly resilient to dry heat even with temperatures of 90–100 °C for several hours but more effectively destroyed by hot water or steam. Implementing efficient seed control measures could significantly reduce the dispersal of IAS and prevent costly management efforts [30]. Incineration is also a potential option, although it may prove costly. An alternative disposal method is the transportation of the waste to an authorised landfill site in closed containers, which will prevent seed dispersal. Upon arrival, the containers should be covered immediately. It is of the utmost importance to conduct a thorough assessment of the safety of the proposed waste disposal methods in order to minimise any potential environmental impacts [29, 59].

The **pyrolysis** of Heracleum biomass was studied in Poland for the first time in 2024 at temperatures ranging from 200 to 600 °C. Biochar produced at 200–300 °C showed strong hydrophobic properties and high heating values, making it suitable for solid fuel. When pyrolysis temperatures exceeded 400 °C, the biochar›s fertilizing properties improved due to increased nutrient content, particularly potassium. The study demonstrated that pyrolysis can efficiently convert Heracleum biomass into biochar without external energy input under specific conditions. These findings suggest the potential for sustainable utilization of Heracleum biomass as a valuable feedstock [83, 84].

The restoration of vegetation is a crucial subsequent phase following the successful eradication of invasive *Heracleum* species. Once the invasive species has been removed, the land is susceptible to soil erosion and the potential for re-spread. The optimal solution is the regular utilisation of the land, such as the cultivation of crops or the grazing of livestock [52]. The resulting vegetative cover will serve to protect the land from erosion and prevent the reintroduction of invasive *Heracleum* species.

Sowing grass. The restoration of natural grass cover is of paramount importance for the effective management of land previously occupied by invasive *Heracleum* species. It is recommended that grass mixtures with higher seeding rates and species resistant to frequent mowing be sown. The optimal approach is to seed grass species that are indigenous to the region, demonstrate tolerance to flooding, possess well-developed adaptations, and exhibit competitive superiority over *Heracleum* spp. Mixtures that have been demonstrated to be effective include *Dactylis glomerata, Festuca rubra* (50:50) and *F. arundinacea, F. rubra* (35:65). It is advised that the seedlings be mown frequently when they reach a height of 20–30 cm [29, 55, 70].

One approach that has been investigated in Poland involves the utilisation of competitor plants, in particular certain grass species that are capable of producing 4000 seedlings per square metre, with the objective of eradicating *Heracleum* spp. Grasses such as *Dactylis glomerata*, a hybrid of *Festuolium, Lolium perenne*, *L. multiflorum, Polypogon viridis, Arundinum arundinum, Festuca rubra, F. arundinacea*, and *F. pratensis* have been demonstrated to be effective in the removal of *Heracleum* spp. from infested cereal pastures. Furthermore, native plants such as *Petasites albus* and *Petasites hybridus* have demonstrated the capacity to compete with invasive *Heracleum* species [53].

It is imperative to refrain from sowing grass mixtures on sandy floodplain soils and along riverbanks, as these areas are susceptible to the deposition of invasive *Heracleum* spp. seeds during floods. It is recommended that root cutting and pruning be undertaken prior to flowering as a more effective control method in these areas. The practice of mowing, particularly of native grass species such as *Elymus repens* and *Poa pratensis*, has been observed to facilitate the growth of a competitive grass cover, which in turn serves to reduce the density of invasive plants.

These integrated management practices are of great importance to the restoration of former agricultural land, employing mechanical, chemical and biological methods to effectively control and prevent the re-spread of invasive species. The diversity of grasses will increase as native broadleaf species repopulate the grassland. Following the revegetation process, the areas in question can then be utilised for agricultural or recreational purposes.

Afforestation represents a distinct approach within the field of cover crop strategies, specifically designed to control the proliferation of tall invasive *Heracleum* species. In instances where openings are created in a beech forest as a result of windfall or tree felling, these openings can be colonised by invasive *Heracleum* species. The implementation of further reforestation initiatives results in a gradual shading effect, which ultimately inhibits the growth of invasive *Heracleum* species. The efficacy of shading is contingent upon the species of trees involved. Beech forests (*Fagus sylvatica*) have been demonstrated to be highly effective at shading the plant, while firs (*Abies* species) and willows (*Salix* species) have been found to be less effective in this regard. Furthermore, different invasive species of *Heracleum* spp. demonstrate varying degrees of shade tolerance. For instance, *H. mantegazzianum* exhibits a lower tolerance than *H. sosnowskyi* [55, 59].

Minimising intrusion into new territories

Methods of prevention:

To effectively reduce the invasion of tall invasive species of the genus *Heracleum* into new areas, a comprehensive approach focusing on prevention, early detection and rapid response is needed. Here are the key steps to consider:

- Mapping existing populations, especially in regions adjacent to infested areas, is crucial. Due to their size, stands of *Heracleum* species are visible for most of the year and can be easily detected during flowering in early summer, making it relatively easy to track their spread.
- Recent field studies and experiments have demonstrated that Sentinel satellite time series and UAV data enable the characterization of vegetation classes at unprecedented spatiotemporal scales. The integration of data from multiple sensors, such as optical and synthetic-aperture radar (SAR) [64, 75], has significantly improved classification accuracy. Multispectral sensors on UAVs have proven effective in mapping invasive species and can serve as a valuable alternative to traditional field data for fitting and validating OCCs (one-class classifiers) based on satellite imagery [24]. However, the limited area coverage of UAVs, typically a few hectares, restricts their utility for extensive monitoring. Hyperspectral imaging offers greater precision by refining spectral distinctions between invasive species and their surrounding vegetation. Additionally, real-time kinematic (RTK) positioning of global navigation satellite systems (GNSS) [42, 71, 97] has been widely adopted to achieve precise relative positioning, further enhancing the accuracy of remote sensing applications [2, 40].
- Involvement of the public and volunteers can be a powerful tool in identifying *Heracleum* species. Informing the public about the problems caused by invasive species and enlisting their help in identifying populations can be achieved through social media, local media and targeted information campaigns. This method is well established in the UK [93].
- Citizen Science (CS) plays a significant role in shaping societal values towards biodiversity by facilitating valuable data collection. Public participation in recording invasive alien species (IAS) through innovative smartphone applications is already complementing official surveillance systems across EU Member States. However, the accuracy of data generated by these initiatives may limit their use for early warning, management, and control of IAS. In response, the Joint Research Centre (JRC) developed the "Invasive Alien Species in Europe" app, enabling users to report IAS of Union concern under EU Regulation 1143/2014. Additionally, the European Alien Species Information Network (EASIN) provides a centralized repository of IAS data, supporting EU Member States in implementing IAS-related policies and management strategies [1].
- Artificial intelligence (AI) is increasingly integrated into citizen science (CS) applications, particularly for taxonomic identification, where deep learning models are used to automatically identify species from uploaded images [10, 91]. These models not only identify the

species but also determine the confidence level of the identification [73]. Although conversational AI tools, like chatbots, are gaining traction for user interaction, simpler CS applications with structured databases and clear protocols do not necessarily require such complex systems. Instead, a straightforward system that provides real-time identification guidelines after a species name is entered can effectively assist observers. AI can also be employed to automate feedback once an expert validates a report. As an example of AI for species recognition tool is worth to mention Seek application based and integrated to iNaturalist platform. iNaturalist includes an automated species identification tool, and users further assist each other in identifying organisms from photographs. As of 9 July 2024, iNaturalist users had contributed approximately 197,660,888 observations of plants, animals, fungi, and other organisms worldwide [95].

- Use the online reporting platforms for mapping of invasive species, like the following list available in Europe which include both AI and expert recognition tools: UK- iRecord (https://www.brc.ac.uk/irecord/resources-verify); Germany – Naturgucker (naturgucker.de); Netherlands – Netwerk Ecologische monitoring invasieve vaatplanten (www.floron.nl/meedoen/exoten-melden); Switzerland – InvasivApp (https://www.infoflora.ch/invasiv-app); Norway – Artsdatabanken (https://www.artsobservasjon er.no/Home/About); Alpine space region – ALPTREES (https://www.alpinespace.eu/projects/alptrees/en /home) [1].
- It is necessary to develop targeted information programmes aimed at groups engaged in outdoor activities, such as fishing, agriculture, hunting and tourism [4].
- Reporting mechanisms should be clear and accessible so that the public knows where to report sightings of invasive *Heracleum* species.
- Outreach campaigns, outdoor and internet advertisement, video production are powerful tools for raising awareness and public engagement in monitoring, controlling and eradicating *Heracleum spp.*
- Rapid response by local authorities. Upon receiving reports of new infestations, the relevant authorities should have the resources to quickly confirm the identification, assess the situation and determine the appropriateness of control methods.

Conclusions

The current range of control methods is diverse, encompassing chemical, biological, and mechanical approaches. Despite the spread of the three invasive *Heracleum* species across different regions of the European continent, the control methods employed in various countries are largely similar. In recent years, novel control and management methods, such as the use of microwaves and pyrolysis, have also been studied. In this context, the involvement of EU projects, non-governmental organizations (NGOs), and volunteers in the identification, monitoring, and direct control of harmful species is of significant importance.

Outreach and public engagement play a critical role, supported by the production of various types of information resources, including short social media videos, posts, long educational videos for schools and broader audiences, and information banners, particularly in areas of high invasion. Additionally, tailored mobile apps that allow easy detection and reporting of invasions are worth mentioning. Ideally, the collected datasets would be integrated or made accessible to local authorities responsible for controlling and eradicating invasive species.

The selection of an appropriate control method is also contingent upon a number of factors, including the size of the plant population, its density and the accessibility of the area in question. The most prominent tools in this regard would be the use of AI and deep learning, particularly for detecting, mapping, and reporting *Heracleum* invasions, both by individuals and through UAVs.

Regardless of the method employed, the importance of repeated and correct application cannot be overstated, as this is crucial to obtaining satisfactory results. Therefore, treatments should be initiated at the earliest opportunity in the growing season and continued for several years until the soil seed stock and root system are depleted. The financial implications of controlling tall invasive *Heracleum* species are highly variable, contingent upon the availability of equipment and the cost of labour. It is evident that an efficacious strategy for the control of invasive *Heracleum* species necessitates a multi-year approach, encompassing both immediate eradication and long-term prevention of the spread.

The development of new guidelines based on modern technology and scientific research is a priority for enhancing the efficiency of eradicating, controlling, and managing invasive *Heracleum* species. An integrated strategy for controlling *Heracleum* species should aim to optimize efficiency, ecology, and economic management. This requires implementing flexible methods tailored to the specific needs of the area in question.

REFERENCES

1. *Adriaens T., Tricarico E., Reyserhove L.* et al. Data-validation solutions for citizen science data on invasive alien species // EUR 30857 EN, Publications Office of the European Union. Luxembourg, 2021. 31 p. doi:10.2760/694386
2. *Alexandridis T. K., Tamouridou A. A., Pantazi X. E.* et al. Novelty Detection Classifiers in Weed Mapping: Silybum marianum Detection on UAV Multispectral Images // Sensors. 2017. P. 1–12.
3. *Andersen U. V., Calov B.* Long-term effects of sheep grazing on giant hogweed (*Heracleum mantegazzianum*) // Hydrobiologia. 1996. P. 277–284.
4. *Anibaba A., Dyderski M. K., Jagodziński A. M.* Predicted range shifts of invasive giant hogweed (*Heracleum mantegazzianum*) in Europe // Sci. Total Environ. 2022. P. 154053. https://doi.org/10.1016/j.scitotenv.2022.154053
5. *Auškalnienė O., Kadžienė G., Ivashchenko O.* et al. Chemical control of Sosnowsky's hogweed (*Heracleum sosnowskyi* Manden.) in Ukraine // Zemdirbyste-Agriculture. 2022. P. 329–334. https://doi.org/10.13080/z-a.2022.109.042
6. Best Practice Management Guide for Invasive Alien Species // RAPID. 2018. 31 p. Downloaded from: https://invasives.ie/app/uploads/2021/09/RAPID_Good_Pratice_Management_Giant_hog weed_EN.pdf
7. *Burda R. I., Protopopova V. V., Shevera M. V., Kucher O. O.* Allien species of the flora of Ukraine: years and authors. Bibliographic index. Issue 7 // Kholodny Institute of Botany of the National Academy of Sciences of Ukraine, State Institution Institute of Evolutionary Ecology of the National Academy of Sciences of Ukraine. 2020. 159 p. (In Ukrainian).
8. *Buttenschøn R. M., Nielsen C.* Control of *Heracleum mantegazzianum* by grazing // Ecology and management of giant hogweed (*Heracleum mantegazzianum*). 2007. P. 240–254. https://doi.org/10.1079/9781845932060.0240
9. *Cardoso A. C., Tsiamis K., Deriu I.* et al. EU Regulation 1143/2014: assessment of invasive alien species of Union concern distribution // Publications Office of the European Union, Luxembourg, 2021. 178 p. doi:10.2760/11150, JRC123170
10. *Christin S., Hervet É., Lecomte N.* Applications for deep learning in ecology // Methods Ecol. Evol. 2019. Vol. 10. P. 1632–1644.
11. *Cock M. J. W., Seier M. K.* The scope for biological control of giant hogweed, *Heracleum mantegazzianum* // Ecology and Management of Giant Hogweed (*Heracleum mantegazzianum*). 2007. P. 255–271. doi.org/10.1079/9781845932060.0255

12. Commission Implementing Regulation (EU) 2016/1141 of 13 July 2016 adopting a list of invasive alien species of Union concern pursuant to Regulation (EU) No 1143/2014 of the European Parliament and of the Council. 2016. 5 p. Downloaded from: http://data.europa.eu/eli/reg_impl/2016/1141/oj
13. Communication From The Commission To The European Parliament, The European Council, The Council, The European Economic And Social Committee And The Committee Of The Regions The European Green Deal // COM/2019/640 final. 2019. 24 p. Downloaded from: https://eur-lex.europa.eu/resource.html?uri=cellar:71767319-9f0a-11ec-83e1-01aa75ed71a1.0001.02/DOC_ 1&format=PDF
14. *Cuddington K., Sobek-Swant S., Drake J.* et al. Risks of giant hogweed (*Heracleum mantegazzianum*) range increase in North America // Biol. Invasions. 2022. P. 299–314. https://doi.org/10.1007/s10530-021-02645-x
15. *Denisow B., Wrzesień M., Mamchur Z., Chuba M.* Invasive flora within urban railway areas: a case study from Lublin (Poland) and Lviv (Ukraine) // Acta Agrobot. 2017. P. 1–17. https://doi.org/10.5586/aa.1727
16. *Dubyna D., Iemelianova S., Dziuba T.* et al. Alien plant invasion in the ruderal vegetation of Ukraine // Environ. Socio-Econom. Stud. 2021. P. 57–70. https://doi.org/10.2478/environ-2021-0025
17. *Dubyna D. V., Dziuba T. P., Iemelianova S. M.* et al. Alien Species in the Pioneer and Ruderal Vegetation of Ukraine // Diversity. 2022. 14, 1085. 31 p. https://doi.org/10.3390/d14121085
18. *Ellstrand N. C., Schierenbeck K. A.* Hybridisation as a stimulus for the evolution of invasiveness in plants? // Proc. Natl. Acad. Sci. 2000. P. 7043–7050. https://doi.org/10.1073/pnas.97.13.7043
19. EPPO. *Heracleum mantegazzianum, Heracleum sosnowskyi* and *Heracleum persicum* // EPPO Bulletin. 2009. P. 489–499.
20. EU Biodiversity Strategy for 2030. European Commission. Brussels. 2020. 23 p. Downloaded from: https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en
21. *Fröberg L. Heracleum L.* // Flora Nordica (Thymelaeaceae to Apiaceae). Stockholm, Sweden: The Swedish Museum of Natural History. 2010. P. 224–234.
22. *Gazoulis I., Antonopoulos N., Kanatas P.* et al. Invasive Alien Plant Species—Raising Awareness of a Threat to Biodiversity and Ecological Connectivity (EC) in the Adriatic-Ionian Region // Diversity. 2022. P. 1–27. https://doi.org/10.3390/d14050387
23. *Goncharenko I., Koniakin S., Leshcheniuk O.* Giant hogweeds (*Heracleum mantegazzianum* and *H. sosnowskyi*) in Ukraine: distribution, ecological and coenotical features // Folia Oecologica. 2024. Vol. 51 (1). P. 93–107. Downloaded from: https://sciendo.com/article/10.2478/foecol-2024-0010
24. *Grace J., Nelson M.* Insects and their pollen loads at a hybrid Heracleum site // New Phytologist. 1981. Vol. 87. P. 413–423.
25. *Gruľová D., Baranová B., Eliašová A.* et al. Does the invasive *Heracleum mantegazzianum* influence other species by allelopathy? // Plants. 2024. P. 1–17. https://doi.org/10.3390/plants13101333
26. *Grzędzicka E.* Assessment of habitat selection by invasive plants and conditions with the best performance of invasiveness traits // Diversity. 2023. P. 1–18. https://doi.org/10.3390/d15030333
27. *Grzędzicka E.* Invasion of the giant hogweed and the Sosnowsky's hogweed as a multidisciplinary problem with unknown future: A review // Earth. 2022. P. 287–312. https://doi.org/10.3390/earth3010018

28. *Grzędzicka E., Hanzelka J., Reif J.* The impact of invasive Caucasian hogweeds on birds depends on areas of invaded and uninvaded habitats at various scales in Central European uplands // Ecol. Indic. 2022. Vol. 141. P. 1–17. https://doi.org/10.1016/j.ecolind.2022.109082
29. Guidance Note Management of Giant Hogweed // PCA UK. 2023. 16 p. Downloaded from: https://www.property-care.org/write/MediaUploads/Technical%20Documents/Management of Giant Hogweed-Nov2023 -TechnicalDoc.pdf
30. *Hall R. M., Urban B., Durec N.* et al. Heat treatment of seeds to control invasive common ragweed (*Ambrosia artemisiifolia*), narrow-leaved ragwort (*Senecio inaequidens*) and giant hogweed (*Heracleum mantegazzianum*) // Plants. 2024. P. 1–17. https://doi.org/10.3390/plants13030341
31. *Heywood V. H., Sharrock S.* European Code of Conduct for Botanic Gardens on Invasive Alien Species // Council of Europe, Strasbourg, Botanic Gardens Conservation International, Richmond. 2013. 64 p.
32. *Hoppe I., Haase M., Ritter S.* et al. Riesen-Bärenklau (*Heracleum mantegazzianum*), in: EN-VISAGE – Erfassung und Management invasiver Neophyten auf landwirtschaftlichen Nutzflächen zur Sicherung der landwirtschaftlichen Produktionsbedingungen // Berichte aus dem Julius Kühn-Institut. 2022. P. 19–40. https://doi.org/10.5073/20220427-100618
33. *Hyvönen T. T., Hagner M. M., Hurme T. K.* et al. Control of Heracleum mantegazzianum with pyrolysis liquid products // Weed Research. 2023. P. 311–316. https://doi.org/10.1111/wre.12593
34. *Jahodová Š., Trybush S., Pyšek P.* et al. Invasive species of Heracleum in Europe: an insight into genetic relationships and invasion history // Diversity and Distributions. 2007. P. 99–114. Downloaded from: http://www.blackwell-synergy.com/servlet/useragent?func=-showIssues &code=ddi
35. *Jauni M., Huusela E., Urho L., Hyvönen T.* Prioritizing management of invasive alien species of EU concern: A northern perspective // Diversity. 2023. P. 1–11. https://doi.org/10.3390/d15050585
36. *Jodaugienė D., Marcinkevičienė A., Sinkevičienė A., Stulginskis A.* Control of *Heracleum sosnowskyi* in Lithuania. Bekampfung von Heracleum sosnowskyi at Litauen // 28. Deutsche Arbeitsbesprechung über Fragen der Unkrautbiologie und -bekämpfung, 27.02. – 01.03.2018 in Braunschweig. 2018. P. 276–281. DOI: 10.5073/jka.2018.458.039
37. *Kabay Z., Mamchur Z.* Invasive plant species in the valley of the river Strwiaz (Rudkivska OTG Lviv region) // Scientific principles of biodiversity conservation. Proceedings of Vth (XVIth) International Scientific Conference of Young Scientists (Lviv, 18 October 2023). 2023. P. 70–72. (In Ukrainian).
38. *Kalarus K.* The influence of invasive alien plants on umbrella butterflies of the genus Phengaris and diversity of Heteroptera true bugs // Environmental Protection and Natural Resources. 2023. P. 26–36. https://doi.org/10.2478/oszn-2023-0003
39. *Kalusová V., Čeplová N., Danihelka J.* et al. Alien plants of Europe: an overview of national and regional inventories // Preslia. 2024. Vol. 96. P. 149–182. https://doi.org/10.23855/preslia.2024.149
40. *Kattenborn T., Lopatin J., Förster M.* et al. UAV data as an alternative to field sampling to map woody invasive species based on combined Sentinel-1 and Sentinel-2 data // Remote Sens. Environ. 2019. Vol. 227. P. 61–73.
41. *Khomiak I. V., Onyshchuk I. P., Vakerych M. M., Hasynec Y. S.* Adaptation strategies of *Heracleum sosnowskyi* in Ukrainian Polissia // Biosyst. Divers. 2024. P. 99–106. doi: 10.15421/012409

42. *Kim E., Kim S.-K.* Global navigation satellite system real-time kinematic positioning framework for precise operation of a swarm of moving vehicles // Sensors. 2022. P. 1–21. https://doi.org/10.3390/s22207939
43. *Klima K., Synowiec A.* Field emergence and the long-term effectiveness of control of *Heracleum sosnowskyi* plants of different ages in southern Poland // Weed Research. 2016. 9 p. DOI: 10.1111/wre.12214
44. *Koco Š., Dubravská A., Vilček J., Gruľová D.* Geospatial approaches to monitoring the spread of invasive species of Solidago spp. // Remote Sens. 2021. P. 1–19. https://doi.org/10.3390/rs13234787
45. *Krippel Y., Richarz F.* Verbreitung und Management von *Heracleum mantegazzianum* Somm. et Lev. (Apiaceae, Spermatophyta) in der Obersauerregion in Luxemburg // Bulletin de la Société des naturalistes luxembourgeois. 2013. P. 3–13.
46. Kunming-Montreal Global Biodiversity Framework // CBD/COP/DEC/15/4. 2022. 15 p. Downloaded from: https://https/www.cbd.int/doc/c/e6d3/cd1d/daf663719a03902a9b116c34/cop-15-l-25-en.pdf
47. *Letz D. Heracleum sosnowskyi* in the mountainous part of the Banská Štiavnica Mountains // SITA. 2024. P. 55–56.29.
48. *Makukh Y., Ivaniuk I., Remeniuk S.* et al. Control of *Heracleum sosnowskyi* plant numbers in agricultural and forestry phytocenoses of Ukraine // Scientific Horizons. 2021. P. 45–56.
49. *Mamchur Z., Chuba M.* The ecological features of synanthropic flora in the central dense housing area of Lviv // Studia Biologica. 2016. P. 143–154. (In Ukrainian).
50. *Mamchur Z., Chuba M., Drach Y.* The ecological features of plants on railway tracks in Lviv City // Studia Biologica. 2017. P. 135–146. (In Ukrainian).
51. *Matarrese E., Renna M.* Prospects of Hogweed (*Heracleum sphondylium* L.) as a New Horticultural Crop for Food and Non-Food Uses: A Review // Horticulturae. 2023. P. 1–19. https://doi.org/10.3390/horticulturae9020246
52. *Mežaka A., Zvaigzne A., Tripane E. Heracleum sosnowskyi* Manden. Monitoring in protected areas—A case study in Rezekne municipality, Latvia // Acta Biol. Univ. Daugavp. 2016. Vol. 16 (2). P. 181–189.
53. *Motyka B., Motyka Z.* Alien invasive hogweeds control. 2016. 11 p. DOI: 10.13140/RG.2.2.33828.07041
54. *Müllerová J. Heracleum mantegazzianum* (giant hogweed). 2024. Subject to the CABI Digital Library Terms & Conditions, available at https://cabidigitallibrary.org/terms-and-conditions. Downloaded from https://cabidigitallibrary.org by 92.253.236.159, on 07/18/24.
55. *Nielsen C., Ravn H.P., Nentwig W., Wade M.* (eds.). The Giant Hogweed Best Practice Manual. Guidelines for the management and control of an invasive weed in Europe // Forest & Landscape Denmark, Hoersholm. 2005. 44 p.
56. *Ochsmann J. Heracleum mantegazzianum* Sommier & Levier (Apiaceae) in Germany. Studies on biology, distribution, morphology, and taxonomy // Feddes Repertorium. 1996. Vol. 107 (7–8). P. 557–595.
57. *Perrier C.* Une belle Caucasienne aux ambitions damsire's: la Berce du Caucase (*Heracleum mantegazzianum* Sommier et Levier, Apiaceae) // Bulletin de la Société Botanique du Dauphiné. 2001. P. 11–14. http://www.tela-botanica.org/papyrus.php?menu=215
58. PM 10/25 (1), PM 10/26 (1) Phytosanitary treatments Traitements phytosanitaires // Bulletin OEPP/EPPO Bulletin. 2018. P. 533–535
59. PM 9/9 (2) *Heracleum mantegazzianum, H. sosnowskyi* and *H. persicum* // Bulletin OEPP/EPPO Bulletin. 2020. Vol. 50 (3). P. 515–524. https://doi.org/10.1111/epp.12687

60. *Protopopova V., Shevera M. Heracleum mantegazzianum* Sommier et Levier in Ukraine. The ecology and management of the Giant Alien *Heracleum mantegazzianum* // Final Inter. Workshop of the «Giant Alien» Project: programme and proceedings (21–23 Feb. 2005, Giessen). 2005. P. 26.
61. *Prots B.* Invasion success of alien plant species in the Carpathian region of Ukraine // Scientific Herald of Chernivtsi University. Biological systems. 2013. P. 116–121.
62. *Pyšek P., Cock M. J. W., Nentwig W., Ravn H.* Ecology and management of giant hogweed: (*Heracleum mantegazzianum*). 2007. 326 p.
63. *Rajmis S., Thiele J., Marggraf R.* A cost-benefit analysis of controlling giant hogweed (*Heracleum mantegazzianum*) in Germany using a choice experiment approach // NeoBiota, 2016. Vol. 31. P. 19–41. DOI: 10.3897/neobiota.31.8103
64. *Rapinel S., Hubert-Moy L.* One-Class Classification of Natural Vegetation Using Remote Sensing: A Review // Remote Sens. 2021. Vol. 13, Article 1892.
65. Regulation (EU) No 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species. 2014. 21 p. Downloaded from: http://data.europa.eu/eli/reg/2014/1143/oj
66. *Renčo M., Jurová J., Gömöryová E., Čerevková A.* Long-Term Giant Hogweed Invasion Contributes to the Structural Changes of Soil Nematofauna // Plants (Basel). 2021. 18 p. DOI: 10.3390/plants10102103
67. *Resiga O. E.* The effects of future climate change on physiological traits and competitive abilities of invasive riparian plants *Impatiens glandulifera* and *Heracleum mantegazzianum* // Durham theses, Durham University. 2022. 96 p. Available at: http://etheses.dur.ac.uk/14644/
68. *Rijal D., Alm T., Lennart N., Alsos I.* Giant invasive *Heracleum persicum*: Friend or foe of plant diversity? // Ecol. Evol. 2017. P. 1–15. DOI: 10.1002/ece3.3055
69. *Rijal D. P.* Invasive Heracleum in northern Europe: Introduction history and impact on native plant diversity. 2016. 44 p.
70. *Roy H. E., Pauchard A., Stoett P.* et al. Summary for Policymakers of the Thematic Assessment Report on Invasive Alien Species and their Control of the Intergovernmental Science // Policy Platform on Biodiversity and Ecosystem Services. IPBES secretariat, Bonn, Germany. 2023. 56 p. https://doi.org/10.5281/zenodo.7430692
71. *Sabat-Tomala A., Raczko E., Zagajewski B.* Comparison of Support Vector Machine and Random Forest Algorithms for Invasive and Expansive Species Classification using Airborne Hyperspectral Data // Remote Sens. 2020. P. 1–21. https://doi.org/10.3390/rs12030516
72. *Savinkova V., Mamchur Z.* Plant invasions in the Dniester Canyon National Natural Park // Materials of the All-Ukrainian Scientific Conference "The State and Biodiversity of the Ecosystems of the Shatsky National Natural Park and Other Nature Conservation Areas", dedicated to the memory of Professor, Doctor of Biological Sciences Kostya Adrianovich Tatarynov (September 9–12, 2021, Lviv). Lviv: SPOLOM, 2021. P. 102–103. (In Ukrainian).
73. *Schermer M., Hogeweg L.* Supporting citizen scientists with automatic species identification using deep learning image recognition models // Biodiversity Information Science and Standards. 2018. Vol. 2. e25268. https://doi.org/10.3897/biss.2.25268
74. *Schierenbeck K., Ellstrand N.* Hybridisation and the evolution of invasiveness in plants and other organisms // Biological Invasions. 2009. Vol.11. P. 1093–1105.
75. *Schulte to Bühne, H., Pettorelli N.* Better Together: Integrating and Fusing Multispectral and Radar Satellite Imagery to Inform Biodiversity Monitoring, Ecological Research and Conservation Science // Methods Ecol. Evol. 2018. Vol. 9. P. 849–865.

76. *Seier M. K., Wittenberg R., Ellison C. A.* et al. Surveys for natural enemies of giant hogweed (*Heracleum mantegazzianum*) in the Caucasus region and assessment for their classical biological control potential in Europe // Proceedings XI International Symposium on Biological Control of Weeds, Canberra, Australia. 2003. P. 149–154.
77. *Shevera M. V.* Tendency to the expansion of adventive plants on the railways in Transcarpathia // Ukrainian Botanical Journal. 1996. P. 136–138.
78. *Słowiński K., Grygierzec B., Synowiec A.* et al. Preliminary study of control and biochemical characteristics of giant hogweed (*Heracleum sosnowskyi* Manden.) treated with microwaves // Agronomy. 2022. Vol. 12 (6). 20 p. 1335. https://doi.org/ 10.3390/agronomy12061335
79. *Słowiński K., Grygierzec B., Baran A.* et al. Biochemistry of microwave controlled *Heracleum sosnowskyi* (Manden.) roots with an ecotoxicological aspect // Scientific Reports. 2024. Vol. 14 (1). P. 1–17. https://doi.org/10.1038/s41598-024-65164-4
80. *Solomiichuk M.* Systematic approach in the struggle against *Heracleum sosnowskyi* with GPS mapping usage // Quarantine and Plant Protection. 2024. P. 29–35. https://doi.org/10.36495/2312-0614.2024.2.29-35 (In Ukrainian).
81. *Stewart F., Grace J.* An experimental study of hybridization between *Heracleum mantegazzianum* Somm. & Levier and *H. sphondylium* (Umbelliferae) // Watsonia. 1984. Vol. 15. P. 73–83.
82. *Stojanović V., Stojanović S., Kovačević J.* et al. *Heracleum sosnowskyi* Manden. (Apiaceae) – A new invasive species in the flora of Serbia // Glasnik Šumarskog fakulteta [Bulletin of the Faculty of Forestry, University of Belgrade]. 2017. Vol. 116. P. 215–220. https://doi.org/10.2298/GSF1716215S
83. *Sužiedelytė Visockienė J., Tumelienė E., Maliene V.* Identification of *Heracleum sosnowskyi*-invaded land using earth remote sensing data // Sustainability. 2020. Vol. 12 (3). P. 2–13. https://doi.org/10.3390/su12030759
84. *Świechowski K., Rosik J., Bednik M.* et al. Heracleum sosnowskyi pyrolysis – Energy and environmental aspects of biochar utilization // Bioresour. Technol. 2024. Vol. 408. P. 1–10. https://doi.org/10.1016/j.biortech.2024.131169. (https://www.sciencedirect.com/science/article/pii/S0960852424008733)
85. *Tokaryuk A. I., Chorney I. I., Iakushenko D. M.* The alien flora of the National Nature Park «Vyzhnytskyi» // Biological systems. 2024. Vol. 16. Is. 1. P. 127–138. https://doi.org/10.31861/biosystems2024.01.126 (in Ukrainian).
86. UN Convention on Biological Diversity: text and annexes // Secretariat of the Convention on Biological Diversity. 2011. 36 p. Downloaded from: https://www.cbd.int/doc/legal/cbd-en.pdf
87. *Vanaga I., Gurkina J., Treikale O.* et al. Influence of *Heracleum sosnowskyi* control measures on weed diversity in agricultural fields in Latvia // Agron. Res. 2006. Vol. 4 (Special issue). P. 433–436.
88. *Vladimirov V., Assyov B., Petrova A.* First record of an invasive alien plant species of EU concern in Bulgaria: *Heracleum sosnowskyi* Manden. (Apiaceae) // Acta Zool. Bulg. 2017. Vol. 9. P. 47–51.
89. *Vykhor B., Prots B.* Control of the population of the Sosnowsky's hogweed (*Heracleum sosnowskyi* Manden.) // Youth and Progress in Biology: Proc. XI Int. Conf. (20–23 April, 2015, Lviv). 2015. P. 213–215. (In Ukrainian).
90. *Vykhor B., Prots B.* Sosnowsky's hogweed (*Heracleum sosnowskyi* Manden.) in the Transcarpathia: ecology, distribution and the impact on environment // Studia Biologica. 2012. Vol. 6. N 3. P. 185–196. (In Ukrainian).

91. *Wäldchen J., Mäder P.* Machine learning for image-based species identification // Methods Ecol. Evol. 2018. Vol. 9. P. 2216–2225.
92. *Žalnierius T., Šveikauskas V., Aphalo P. J.* et al. Gibberellic Acid (GA3) Applied to Flowering *Heracleum sosnowskyi* Decreases Seed Viability Even If Seed Development Is Not Inhibited // Plants. 2022. Vol. 11 (13). 314. 11 p. https://doi.org/10.3390/plants11030314
93. https://canalrivertrust.org.uk/things-to-do/canal-and-river-wildlife/canal-and-river-invasive-species-eradication-project-2021-2025
94. https://doi.org/10.1079/cabicompendium.120209
95. https://inaturalist.org/pages/about
96. https://gd.eppo.int/taxon/HERSO/distribution
97. https://gpsgeometer.com/en/blog/what-is-gnss-rtk-and-how-does-it-work
98. https://www.as-motor.uk/expert-tips/combating-giant-hogweed-with-as-motors-remote-controlled-ride-on-mower-as-940-sherpa-4wd-rc
99. https://www.cabidigitallibrary.org/doi/10.1079/cabicompendium.108958
100. https://www.cabidigitallibrary.org/doi/10.1079/cabicompendium.26911
101. https://www.inaturalist.org/taxa/130228-Heracleum-mantegazzianum
102. https://www.inaturalist.org/taxa/499936-Heracleum-sosnowskyi
103. https://www.inaturalist.org/taxa/516305-Heracleum-persicum
104. https://www.invasivespecies.scot/giant-hogweed-and-sheep-trial
105. https://www.nobanis.org/species-info/?taxaId=752
106. https://www.nonnativespecies.org/local-action-groups-lags/rapid-life-project
107. https://www.unep.org/resources/report/invasive-alien-species-report

Стаття надійшла до редакції 22.07.24

доопрацьована 18.09.24

прийнята до друку 20.09.24

ОГЛЯД СУЧАСНИХ ПІДХОДІВ ДО УПРАВЛІННЯ ІНВАЗІЙНИМИ ВИДАМИ РОДУ *HERACLEUM* У ЄВРОПІ

П. Насадюк, З. Мамчур

Львівський національний університет імені Івана Франка
вул. Грушевського, 4, Львів 79005, Україна
e-mail: zvenyslava.mamchur@lnu.edu.ua; dzvinkamamchur@gmail.com

У статті розглянуто актуальність проблеми інвазивних чужорідних видів (ІЧВ) у Європі, висвітлено біоекологічні характеристики інвазивних видів роду *Heracleum* (*H. mantegazzianum*, *H. persicum*, та *H. sosnowskyi*) та історичні шляхи інтродукції. Наведено статистику поширення цих видів та їхній негативний вплив на біорізноманіття і стійкість екосистем.

Поширення інвазивних видів роду *Heracleum* має далекосяжні наслідки, впливаючи не лише на стійкість екосистем, а й на економіку та охорону здоров'я. Показано, що екологічні наслідки впливу виявляються у здатності цих видів не лише витісняти місцеву флору та порушувати природні екосистеми, а й впливати на різні сфери господарської діяльності. Агресивний характер росту й алелопатичні ефекти цих рослин призводять до значних економічних витрат, пов'язаних з управлінням земельними ресурсами та продуктивністю сільського господарства. Наведені приклади різних механізмів впливу інвазивних видів роду *Heracleum* підкреслюють їхній згубний вплив на екосистеми та здоров'я людини. Зокрема, фототоксичні речовини *Heracleum* spp. створюють серйозні ризики для здоров'я людей, зумовлюючи запалення шкіри та довготривалу фоточутливість. Детально розглянуто різні методи контролю, викорінення та профілактику поширення видів *Heracleum* spp. у Європі, а саме механічні, біологічні й хімічні методи, а також профілактичні стратегії. Акцентується також увага на методах контролю після викорінення, утилізації рослинних відходів, що утворюються під час ліквідації, відновлення природної рослинності. Проаналізовано ключові кроки комплексного підходу для ефективного зменшення вторгнення *Heracleum* spp. на нові території.

Показано гостру потребу в комплексних стратегіях управління для пом'якшення впливу інвазивних видів роду *Heracleum* і запобігання подальшому поширенню. Зазначається, що контроль ІЧВ є важливою міжнародною проблемою, яка потребує скоординованих зусиль на рівні ЄС та ООН. Зроблено висновок про інтегрований підхід до управління, який поєднує фізичні, хімічні та біологічні методи, пристосовані до конкретних регіональних умов і узгоджені з міжнародними цілями щодо біорізноманіття. Обговорено роль громадської обізнаності й освіти в запобіганні поширенню інвазивних видів. Підкреслено важливість залучення громадськості до ініціатив із раннього виявлення та швидкого реагування, які мають вирішальне значення для успішного управління чужорідними інвазивними видами рослин.

Ключові слова: Heracleum mantegazzianum, Heracleum persicum, Heracleum sosnowskyi, інвазивні чужорідні види, контроль видів роду *Heracleum,* біорізноманіття