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European and Mediterranean Plant Protection Organization
Organisation Européenne et Méditerranéenne pour la Protection des Plantes PM 9/9 (2)

National regulatory control system

PM 9/9 (2) *Heracleum mantegazzianum, H. sosnowskyi* and *H. persicum*

Specific scope

This Standard describes the control procedures aiming to monitor, contain and eradicate *Heracleum mantegazzianum, H. sosnowskyi* and *H. persicum*. In the text, where possible, the three species are referred to as *Heracleum* spp. in order to reduce repetitions.

Specific approval and amendment

First approved in 2009-09. Revision approved in 2020-09.

1. Introduction

In most of the EPPO region *Heracleum mantegazzianum* Sommier & Levier, *H. sosnowskyi* Mandenova and *H. persicum* Fischer (Apiaceae) are considered invasive in managed and unmanaged ecosystems. They are a threat to biodiversity and can increase riverbank erosion, decrease recreational resources, cause economic loss and pose a human health risk as they cause skin blistering (phototoxic dermatitis) on contact (Nielsen *et al*., 2005; Pyšek *et al*., 2007a).

H. mantegazzianum and *H. sosnowskyi* are herbaceous, usually monocarpic (flowering only once in a lifetime), seed-propagated herbs living usually between 3 and 6 years. *H. persicum* is a herbaceous, polycarpic (it blooms several times during its life), perennial seed-propagated herb. For *H. mantegazzianum* seed viability in soil decreases quickly, but few seeds may remain viable after more than 7 years (Moravcová *et al*., 2007; Moravcová *et al*., 2018). The seed bank longevity of *H. sosnowskyi* is thought to be shorter, with a low percentage viable after 3 years (Moravcová *et al*., 2007). There is no information on seed bank longevity for *H. persicum*.

The three species look alike, which can make it difficult to distinguish between them; however, they do differ in size. In addition, there are a number of closely related *Heracleum* species and hybrids (e.g. *H. lehmannianum* and *H. pubescens*) that may be non-native in parts of the EPPO region, which can further complicate identification.

H. sosnowskyi and *H. persicum* are included in the EPPO A2 List. *H. mantegazzianum* is included in the EPPO List of Invasive Alien Plants. All three species are Invasive Alien Species of Union concern (EU) (European Union, 2017).

The following section details specific aspects on the biology, taxonomy and distribution of each species. All three species can grow in similar conditions and have high fecundity and regeneration potential. This section is not meant to be exhaustive but to introduce the species. Details on the biology, distribution and economic importance of *H. mantegazzianum*, *H. sosnowskyi* and *H. persicum* can be found in EPPO (2009) and EPPO (2020).

Heracleum mantegazzianum

H. mantegazzianum is native to the Western Greater Caucasus (Russia, Georgia) (EPPO, 2020). It was first introduced into the United Kingdom as a garden ornamental plant around 1817 and is now recorded in at least 19 European countries. It is also naturalized in Canada and the United States.

The species usually flowers in its third to fourth year post germination, although flowering may occur during the second year. The flowering stem of *H. mantegazzianum* is usually 2–3 m tall, although it can reach up to 5 m. The stem can be 10 cm in diameter at the base. It is ridged, with purple blotches, and covered with pustulate bristles. Leaves are alternate, 1–2.5 m, or even up to 3 m, long, ternately or pinnately lobed and coarsely toothed; upper leaves are progressively smaller, with the upper leaf surface glabrous and the underside pubescent, as is the petiole. The size and aspect of first leaves produced in spring may strongly

vary depending on plant age (Fig. 1). The main inflorescence (first-order) is a terminal compound umbel of 50–60 (80) cm in diameter with (40) 50–120 (170) unequal hairy rays, each 10–40 cm long. There are also up to eight satellite umbels which usually overtop the main one.

Fig. 1 Spring emergence of *H. mantegazzianum* plants of different ages, including minute seedlings and 1- and 2-year-old plants. (EPPO Global Database: Image courtesy: E. Branquart).

Heracleum sosnowskyi

H. sosnowskyi is native to the Eastern and Central Caucasus, Eastern and Southern Western Transcaucasia, and Northeast Anatolia (Turkey) (EPPO, 2020). It was first introduced to Russia in 1947 as a highly productive fodder crop for livestock. Later it was introduced to other countries such as Belarus, Poland, Ukraine, the Baltic countries and the eastern part of Germany. The cultivation of the species was abandoned due to the change in agriculture practice, the plants affecting the flavour of meat and milk from animals which grazed on the species, in addition to health risks to humans and livestock (Kabuce & Priede, 2010).

The species flowers between the second and fourth years post germination. *H. sosnowskyi* is usually between 1 and 3 m tall. The stem is ridged with a sparsely hairy stem and blotches of purple colour. The flowers are white, sometimes pinkish. Outer petals radiate, 9–10 mm long. The species has slightly convex compound umbels, 30–50 cm across, and 30–75 rays with only short hairs.

Heracleum persicum

H. persicum is native to Turkey, Iran and Iraq (EPPO, 2020). Its alien distribution is restricted to northern countries of the EPPO region (e.g. Denmark, Finland, Norway, Sweden). It was the first *Heracleum* species detailed in this Standard to be described, as early as 1777, and it is likely that some subsequent identifications as *H. persicum* were probably mistaken for other large *Heracleum* spp.

H. persicum is the smallest of the invasive hogweeds and individual plants can grow up to 1.5–2.5 m in height. The species flowers in its second to fourth year post germination. The stem is purple and 1.5−4 cm thick at the base. Leaves are more divided than for *H. mantegazzianum*. They may be up to 2 m in length and deeply incised with very sharp points, with two to three pairs of lateral leaf segments and less deeply serrated. Umbels are nearly convex, 30–50 cm wide, and the rays are straight or bent inwards, 8–22 cm.

The main pathway of introduction for all three species was plants for planting for use as ornamentals (especially for *H. mantegazzianum*) or as fodder crops or honey plants (especially for *H. sosnowskyi* in Russia and in the Baltic countries) (Laiviņš & Gavrilova, 2003). Seeds may also be introduced involuntarily, as contaminants of soil and growing media, from used machinery, vehicles, plants for planting or footwear.

Once introduced, *Heracleum* spp. reproduce very efficiently from seed, which are spread by wind (e.g. 4 m), water (up to several kilometres) and human activities (Laiviņš & Gavrilova, 2003). Seeds can float along rivers for up to 3 days before they sink. In Latvia, seed has been observed to spread on frozen snow, where it forms a thin ice layer on the surface, and then wind can blow seeds over several kilometres (A. Garkaje, pers. comm., 2020).

EPPO member countries at risk are advised to prepare a contingency plan for the surveillance, eradication and containment of these pests.

This Standard presents the basis of a national regulatory control system for the monitoring, eradication and containment of *Heracleum* spp. and describes:

- elements of the monitoring programme that should be conducted to detect a new infestation or to delimit an infested area;
- measures aiming at eradicating recently detected populations (including an incursion);
- containment measures: to prevent further spread in a country or to neighbouring countries, in areas where the pest is present, and eradication is no longer considered feasible;
- elements to evaluate if eradication or containment has been successful.

Regional cooperation is important, and it is recommended that countries should communicate with their neighbours to exchange views on the best programme to implement in order to achieve the regional goal of preventing further spread of these pests.

For the efficient implementation of monitoring and control at a national level, cooperation between the relevant public bodies (e.g. NPPOs, Ministries of Health, Ministries of Environment, ministries in charge of transport, water management, etc.), as well as with other interested bodies (associations) should be established.

2. Monitoring of *Heracleum* spp.

Owing to their large size, stands and individuals of *Heracleum* spp. are very visible for most of the year and

especially during the flowering period in early summer. During the winter months, the dead stems are often visible as they remain upright. Nevertheless, developing plants (without the umbel) or already treated plants (treated with chemicals or cut/mown) can be difficult to find and staff should be trained to recognize the plants in their vegetative stage (including the very early stage just after germination). Surveyors will often look for large stands; however, they can be present as single individuals scattered along a riverbank, railway line or road verge.

Regular delimiting surveys (according to ISPM No. 6 *Surveillance*; FAO, 2018) are necessary to determine the geographical distribution of these plants and their prevalence. Monitoring should concentrate on areas that are most vulnerable to invasion (abandoned grassland, fringes along watercourses, woodlands, roads and railways, nature conservation areas) and areas susceptible to colonization (adjacent to known infestations, agricultural areas where any of the *Heracleum* spp. have been cultivated or used for apiculture, gardens where it is cultivated, nurseries, within wind dispersal distance of existing stands (i.e. 4 m), within the flood zone of water courses where the species occurs, road or railway borders within 2 km of stands and other high-risk points of entry).

Global position systems (GPS) or photographs (both aerial and from the ground) and the use of drone technology and satellite imagery can assist in surveillance (for examples see Müllerová *et al*., 2005 and Müllerová *et al*., 2017).

3. Eradication of *Heracleum* spp.

Any eradication programme for *Heracleum* spp. in the case of recently detected populations (including an incursion) is based on the delimitation of an invaded area within the country with the application of measures to both eradicate and prevent further spread of the pest. The feasibility of eradication depends on species, the size of the area infested, the habitat type invaded, the density of the population and accessibility of the site, and the resources available (Rajmis *et al*., 2017). Importantly, repeated management measures are required to eradicate populations with all individuals treated. Repeated measures are also needed for several years to exhaust the seedbank (Moravcová *et al*., 2007; Moravcová *et al*., 2018).

Measures are described in detail in Appendix 1 and summarized in a table in Appendix 3.

4. Containment of *Heracleum* spp.

The containment programme for *Heracleum* spp. in the case of established populations is based on the application of measures to prevent further spread of the pest in the country or to neighbouring countries. These measures are described in Appendix 2 and summarized in a table in Appendix 3. There is increasing information concerning success of existing containment initiatives in the EPPO region, e.g. in Ireland (Caffrey & Madsen, 2001), Luxembourg (Krippel & Richarz, 2013), Estonia (Leivits, 2014) and Poland (Klima & Synowiec, 2016).

5. Communication and collaboration

Heracleum spp. are recognizable as a genus and land owners, nature reserve managers, as well as other professions (administration, road and railroad services, garden centres, farmers, gardeners, etc.) should be informed about the threat to natural and managed land, and about preventive measures. In addition, the public should be informed about the threat the species can pose to the natural environment and human health. Integrated management, involving land managers and various management measures, will be more effective and efficient. Regional cooperation is essential to promote phytosanitary measures and information exchange in identification and management of methods. NPPOs can provide land managers and stakeholders with identification guides and facilitate regional cooperation, including information on site-specific management of the species, control techniques and management. Additionally, local/regional authorities can provide members of the public with information concerning any restrictions for the utilization of the species within an area/region.

A management programme would require the activities of the different stakeholders involved to be coordinated for increased efficiency. Citizen science projects may be implemented to encourage landholders and other citizens to report sightings of the three species.

6. Acknowledgements

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References

Andersen UV & Calov B (1996) Long-term effects of sheep grazing on giant hogweed (*Heracleum mantegazzianum*). *Hydrobiologia* **340**(1-3), 277–284.

Bērziņš A, Oļukalns A, Lapiņš D, Lejiņš A, Spricina A, Gavrilova Ģ & *et al*. (2003) Distribution of Hogweed (Heracleum) in Latvia. *LLMZA, Agronomijas Vēstis* **5**, 86–93. (In Latvian; abstract in English).

Caffrey JM & Madsen JD (2001) The management of giant hogweed in an Irish river catchment. *Journal of Aquatic Plant Management* **39**, 28–33.

EMPHASIS project (2016) *Guidelines for sustainable IPM control of weeds*. http://www.emphasisproject.eu/deliverables.php?page=8

EPPO (2009) Datasheet on *Heracleum mantegazzianum, H. sosnowskyi* and *H. persicum*. *EPPO Bulletin/Bulletin OEPP* **39**, 489–499.

EPPO (2020) *EPPO Global Database*. https://gd.eppo.int/ [accessed 25 March 2020].

European Union (2017) Invasive alien species of Union concern. European Commission. http://ec.europa.eu/environment/nature/pdf/IAS_brochure_species.pdf [accessed 30 May, 2018].

FAO (2018) International Standards for Phytosanitary Measures, ISPM 6. Guidelines for surveillance. Produced by the Secretariat of the International Plant Protection Convention, Rome, Italy.

Fremstad E & Elven R (2006) The alien giant species of Heracleum in Norway. *NTNU Norges Teknisk-Naturvitenskapelige Universitet Vitenskapsmuseet Rapport Botanisk Serie* **2**, 1–35.

Holm B (2005) *Biology, distribution and control of invasive Heracleum species*. Master thesis. Estonian Agricultural University, Tartu (EE).

Kabuce N & Priede N. (2010) NOBANIS – Invasive Alien Species Fact Sheet – Heracleum sosnowskyi. Online Database of the European Network on Invasive Alien Species – NOBANIS www.nobanis.org [accessed on 25 November, 2018].

Klima K & Synowiec A (2016) Field emergence and the long-term efficacy of control of *Heracleum sosnowski* plants of different ages in southern Poland. *Weed Research* **56**, 377–385.

Krippel Y & Richarz F (2013) Verbreitung und Management von Heracleum mantegazzianum Somm. et Lev. (Apiaceae, Spermatophyta) in der Obersauerregion in Luxemburg. *Bul-letin de la Société des naturalistes luxembourgeois* **114**, 3–13.

Laiviņš M & Gavrilova Ģ (2003) Heracleum sosnowskyi in Latvia: sociology, ecology and distribution. *Latvijas Veģetācija* **7**, 45–65 (In Latvian; abstract in English).

Leivits M. (2014) *Estimation of the efficacy of hogweed control for the period 2006–2013*. Environment Agency report in Estonian.

Lucey J (1994) Records of the giant hogweed, *Heracleum mantegazzianum* Sommier and Levier, along southern Irish rivers and streams with a revised distribution map for the region. *Bulletin of the Irish Biogeographical Society* **17**(1), 2–6.

Moravcová L, Pyšek P, Krinke L, Müllerová J, Perglová I & Pergl J (2018) Long-term survival in soil of seed of the invasive herbaceous plant *Heracleum mantegazzianum*. *Preslia* **90**, 225–234.

Moravcová L, Pyšek P, Krinke L, Pergl J, Perglová I & Thompson K (2007) Seed germination, dispersal and seed bank in *Heracleum mantegazzianum*. In *Ecology and management of giant hogweed (Heracleum mantegazzianum)*(eds. Pyšek P, Cock MJW, Nentwig W & Ravn HP), pp. 74–91. CAB International.

Müllerová J, Brůna J, Bartaloš T, Dvořák P, Vitková M & Pyšek P (2017) Timing is important: unmanned aircraft vs. satellite imagery in plant invasion monitoring. *Frontiers in Plant Science* **8**.

Müllerová J, Pyšek P, Jarošik V & Pergl J (2005) Aerial photographs as a tool for assessing the regional dynamics of the invasive plant species *Heracleum mantegazzianum*. *Journal of Applied Ecology* **42**, 1042–1053.

Nielsen C, Ravn HP, Nentwig W & Wade M (eds.) (2005) *The Giant Hogweed Best Practice Manual. Guidelines for the management and control of an invasive weed in Europe*. Forest and Landscape Denmark, Hoersholm, **44** pp. https://www.semanticscholar.org/paper/The-Giant-Hogweed-Best-Practice-Manual-Guidelines-Ole-Hattendorf/4179657063d24f568be967eb133dcf1d04271110 (accessed May 2009).

Pergl J (2019) Information on measures and related costs in relation to species included on the Union list: *Heracleum mantegazzianum, Heracleum sosnowskyi*, *Heracleum persicum*. Technical note prepared by IUCN for the European Commission.

Pyšek P, Cock MJW, Nentwig W & Ravn HP. (2007a) *Ecology and management of giant hogweed (Heracleum mantegazzianum)*. CAB International, Wallingford (GB), 324 pp.

Pyšek P, Cock MJW, Nentwig W & Ravn HP (2007b) Master of all traits: can we successfully fight giant hogweed? In *Ecology and management of giant hogweed (Heracleum mantegazzianum)*(eds. Pyšek P, Cock MJW, Nentwig W & Ravn HP), pp. 297–312. CAB International.

Rajmis S, Thiele J & Marggraf R (2017) A cost-benefit analysis of controlling giant hogweed (*Heracleum mantegazzianum*) in Germany using a choice experiment approach. *NeoBiota* **31**, 19–41.

Sachajdakieicz I, Medrzycki P, Wójcik M & Pastwa J (2014) Wytyczne dotyczacw zwaiczania barszczu sosnowskiego (*Heracleum sosnowskyi*) I barszczu mantegazziego (*Heracleum mantegazzianum*) na terenie Polski. The General Directorate for Environmental Protection, Poland, 148 pp.

Tiley GED, Dodd FS & Wade PM (1996) *Heracleum mantegazzianum* Sommier & Levier. *Journal of Ecology (Oxford)* **84**(2), 297–319.

Tiley GED & Philp B (1992) Strategy for the control of giant hogweed (*Heracleum mantegazzianum*) on the river Ayr in Scotland. *Aspects of Applied Biology* **29**, 463–466.

Treikale O, Vanaga I, Priekule I, Gurkina J & Pugacheva J (2005) Re-establishment of biological diversity after *Heracleum* spp. control in riverside Vaive (Gauja national park). *Acta Biologica Universitatis Daugavpiliensis* **5**(2), 113–124.

Appendix 1. Eradication programme

The national regulatory control system involves four main activities:

(1) Surveillance to fully investigate the distribution of the pest;
(2) Containment measures to prevent the spread of the pest;
(3) Treatment and/or control measures to eradicate the pest when it is found;
(4) Verification of pest eradication.

Eradication depends on effective surveillance to determine the distribution of the pest and containment to prevent spread while eradication is in progress. Eradication measures must be verified by surveillance to establish if attempts and measures have been successful.

Staff in charge of the control of the plants should be warned about the health risk associated with these species and should avoid touching the plants with bare skin and prevent ultraviolet (UV) light from reaching exposed skin. All body parts should be covered with protective clothing, synthetic water-resistant material being preferred since cotton and linen fibres soak up the plant sap and can be penetrated by plant hairs. Gloves with long sleeves should be worn, and when cutting the plants, protective glasses must be used to prevent drops of plant sap entering the eyes (Nielsen *et al*., 2005). After control, clothes should be taken off and rinsed in order to avoid skin coming in contact with the sap of *Heracleum* spp. that may be on the clothes.

The possible methods for treatment and control may depend upon the environment in which they may be applied. The presence of protected, endemic and other native species should be considered as well as the breeding seasons of fauna, the fragility of the ecosystem and any existing regulations.

1. Surveillance

A delimitation survey should be conducted to determine the precise distribution of the pest. Infested areas and adjacent

areas that might receive seed should be monitored. Particular attention should be given to high-priority habitats (i.e. interconnecting habitats that have previously been recorded to harbour *Heracleum* spp.) such as connecting waterbodies and transportation networks (roads and railways) close to any infested areas.

2. Containment measures

Preventive measures include the prohibition of sowing, growing, planting and trading of *Heracleum* spp., and unintentional transport of seeds through the transfer of soil material, human activity and by vehicles should be avoided. Movement of soil from infested sites should be prohibited. Equipment and machinery should be cleaned to remove soil before moving to an uninfested area. Due to the very high likelihood of spread of seeds along rivers, it is important to ensure that upstream infestations are dealt with before attempting eradication further downstream (Caffrey & Madsen, 2001).

3. Treatment and control programme

A key objective of *Heracleum* spp. control is to prevent individual plants from producing viable seeds which can become incorporated into the seed bank or spread to other areas. This usually means preventing the adult plants from flowering and setting seed for a period long enough to exhaust the seed bank. As *H. persicum* is polycarpic, due to repeated flowering over several years it might take longer to control this plant (Fremstad & Elven, 2006).

Due to the persistent seedbank of *Heracleum* spp., (up to 7 years) and the persistence of existing plants, the area under eradication usually does not decrease during the initial eradication process. Studies in Estonia have shown that the density of the population starts to clearly decrease in the third year of eradication (using chemical control and cutting) with a 43–63% decrease compared to nontreated populations (Leivits, 2014).

Any treatment should start early in the growing season and continue as long as regrowth is observed. Regular treatment of plants, especially on field edges and along roads, water courses, etc., reduces the possibility of spread of plants to new localities. Treatment of the species along water courses should be considered high priority due to its effective dispersal along this pathway. Chemical and mechanical control (e.g. root cutting) are the two most effective treatment measures for eradication (e.g. Pyšek *et al*., 2007b; Klima & Synowiec, 2016)

The combination of multiple weed control strategies (e.g. chemical + mechanical control) is advised as it can increase the success of management (Tiley & Philp, 1992; Leivits, 2014; Klima & Synowiec, 2016).

When undertaking any large-scale management actions (e.g. grazing, mowing, ploughing), it is necessary to monitor and manage the edge and neighbouring areas, and the remaining individuals should be eradicated to prevent repeated reinvasion.

Chemical control

It should be highlighted that the availability of products containing active substances will vary nationally and other products may be available and effective. Indications of the approved uses for each active substance may be incomplete. Products should be used following the instructions on the label and in line with the relevant plant protection product regulations. Before using a product, it must be verified that the type of application which will be adopted (foliar or rosette treatment, stem injection) follows the manufacturer's instructions on the label. In addition, the use of herbicides in, for example, fallow fields or in the vicinity of water could be restricted by national legislation, which should be consulted before any herbicidal application. Policies often aim to reduce the amount of pesticides and protect groundwater from herbicides.

A range of herbicides can be used to kill *Heracleum* spp. A single application of herbicide may be sufficient, However, repeated applications or applications in combination with other techniques may be required depending on the herbicide's effectiveness and new seedling recruitment. Careful monitoring of should be carried out post application.

It is recommended to treat plants early in spring (when the rosette has reached at least 20 cm in diameter) as this is the most effective period to apply herbicides and the plants are easily accessible. A follow-up spray approximately 3–4 weeks after the initial application can be performed to target new seedlings. New plants will often quickly grow to replace those that have been controlled. According to the need, additional control should take place. A second application may be replaced by mechanical control (e.g. mowing or cutting). Monitoring the success of management techniques during the first years of control is recommended to ensure no plants are able to set seed.

Herbicides considered effective for the control of *Heracleum* spp. include glyphosate (considered to be the most effective herbicide for these species), triclopyr, imazapyr and different sulfonylureas, which can be applied early in the growing season for best effect. Possible effects on successional crops or plant species or environment (e.g. soil) should be considered.

Repeated application of herbicide may be needed for high levels of control. Klima & Synowiec (2016) detail for *H. sosnowskyi* that herbicide spraying for 5 years (three times during each vegetative season) using a mixture of glyphosate and flazasulfuron (1260 g of glyphosate per hectare and 50 g of flazasulfuron) was required for total control.

Single annual chemical application has been assessed in Belgium to control *H. mantegazzianum* (E. Branquart, pers. comm., 2020). Glyphosate (360 g L^{-1}) was sprayed early

in the growing season (May) in four experimental plots of 20 m^2 which were heavily colonized by *H. mantegazzianum* at a concentration of 7.5 L ha^{-1} (2.7 kg a.i. ha^{-1}). Three months post application, plant density decreased by 83% from an initial density of 4.9 individuals per square metre to a final density of 0.85 individuals per square metre, from which most originated from secondary seed germination. A final plant density of 3.9 individuals per square metre was recorded from control plots. Scarce dwarfed plants (<50 cm in height) bearing very small flowers were observed in sprayed plots, at a density of 0.03 individuals per square metre (Fig. 2). These residual plants can easily be destroyed by mechanical techniques to avoid any seed production.

Fig. 2 Dwarfed *H. mantegazzianum* regrowing after a spring glyphosate application (EPPO Global Database: image courtesy: E. Branquart).

As part of an EU-funded project (EMPHASIS, 2016), the following herbicides were shown to give effective control (no flowering) on *H. sosnowskyi* in Latvia with a single treatment: tribenuron-methyl 75 Water Dispersible Granule (WG) 15 g ha^{-1} + metsulfuron-methyl 200 WG 30 g ha^{-1} + 100 mL nonionic surfactant with 200 L ha^{-1} and tribenuron-methyl 75WG 15 g ha^{-1} + triasulfuron 20 WG 35 g ha^{-1} + 200 mL nonionic surfactant with 200 L ha^{-1}. It is important to ensure that herbicides are applied at the correct time and the application covers all plants and all surface areas of the plants to achieve best results.

Individual plants at the rosette stage can be treated using an applicator impregnated with the herbicide and covering the *Heracleum* spp. rosette on the surface of the emerging leaves with the active substance. For individual plants which have developed the main shoot, chemical control may be used by applying the herbicide into the mown stalk or by injecting it. Stem injections should be performed with a syringe and injected into the flower-bearing part of the stem. The amount of herbicide to be injected should be in accordance with the area of ground shaded: 4.5 mL for 3 m^2 ground shaded (Bērziņš *et al*., 2003).

Information regarding time requirements to apply different methods can be found in Nielsen *et al*. (2005) and Klima & Synowiec (2016).

Mechanical control

Mechanical control for eradication can be performed in different ways.

Root cutting is effective but labour intensive (Pergl, 2019) and is recommended for single plants or small stands (<200 plants) (see Figs. 3 and 4). It is usually performed with an ordinary spade or a hoe (for smaller plants) and takes place in early spring with a repeated treatment in mid-summer. The roots must be cut at least 10 cm below ground level otherwise the plants may regrow. Cut parts of the plants are either destroyed or left to dry.

Hand-pulling (using protective gloves) is effective with young seedlings or young plants (e.g. growing in moist conditions where it is easy to pull them out) but is impractical with larger plants.

Fig. 3 Using a handheld cutting tool to cut the roots (EPPO Global Database: Image courtesy: Contrat de Rivière Amblève).

Fig. 4 Removal of root system from the ground (EPPO Global Database: Image courtesy: Contrat de Rivière Dyle).

Mechanical cutting may be used for eradication purposes for small populations where the management can be very intensive (see mechanical cutting section in Appendix 3).

Ploughing of the soil at a depth of 20–30 cm depth in agricultural fields can bury the seeds at depths which will significantly reduce their ability to germinate. Digging or ploughing to destroy the crown (below 10 cm soil depth) can completely kill the plant (Bērziņš *et al*., 2003; Nielsen *et al*., 2005). Rototilling and harrowing will cut the roots into pieces, preventing the regrowth of old plants and the establishment of young plants. The ploughing treatment should be selected according to the characteristics of the agricultural land. The measures should be repeated until the stands are eliminated.

Black polythene covers can be used to kill individual *Heracleum* spp. or small stands (Fig. 5). Covering with black polythene prevents the photosynthesis of plants and acts to raise the temperature below the polythene, which can kill plants and seeds. This method should be used at the start of the vegetative period while plants are still small and can be covered with polyethylene tight to the ground. The opaque polythene should be carefully fixed to resist wind effects and should be checked regularly to ensure it is not damaged. This method is considered to be rather expensive. In Latvia, after applying this method for 1 year, all plants died (Pyšek *et al*., 2007a). If there is a persistent seed bank, black polythene covers should stay in place for several years. Once the *Heracleum* spp. have been killed, restoration of the area with native vegetation should be conducted to avoid recontamination.

Fig. 5 Black polythene covering secured to the ground (EPPO Global Database: Image courtesy: E. Branquart).

Disposal

Plant waste generated during the eradication programme should be piled up, and contact with water and with the ground should be avoided if waste contains umbels or seed. Preferably, umbels should be bagged up and disposed of following the recommendations below. It is not recommended to collect and leave material that contains herbicide residues in the environment. It is not recommended to compost any *Heracleum* plant material if seed is included. If necessary, waste can be removed in large sacks. Authorized burning can be performed (ensuring that seeds are not spread by the hot air). The waste could also be burned in an incinerator, but this is very expensive. Alternatively, it could also be removed to an authorized landfill in closed containers in order not to spread seeds and waste should immediately covered once it reaches the landfill. The safety of waste should be carefully evaluated.

4. Verification of pest eradication

Eradication is considered to be achieved when there are no signs of *Heracleum* spp. growth. Since the seeds can survive for some years in the soil, follow-up monitoring should be undertaken for at least 7 years for *Heracleum* spp., corresponding to field observations for not finding viable seeds in fields (Andersen & Calov, 1996).

Appendix 2. Containment programme

In the case of an established population, eradication may be difficult to achieve. Containment measures aimed at preventing further spread of the pest to endangered areas or to neighbouring countries should be applied. While different approaches have been used to manage *Heracleum* spp., an integrated approach is recommended. Following the application of control measures, sowing of native species with good competitive abilities to colonize the gaps in vegetation may be considered (i.e. grass species).

1. Surveillance

Surveillance should be carried out in likely places of introduction of *Heracleum* spp.: urban and semi-urban areas, particularly on disturbed sites such as transportation networks, e.g. railway embankments and roadsides. In addition, surveillance should be conducted along riverbanks/canal sides and in abandoned grassland habitats and agricultural sites. *H. sosnowskyi* has also been recorded as growing in forest habitats and wetlands, such as bogs, and even in acid and alkaline places (EPPO, 2009).

Populations along network corridors (watercourses, highways, power lines) should be managed as a priority to prevent the dispersal of seeds. Special attention should be given to nature conservation areas.

2. Containment measures

As for eradication, treatment to contain the species should start early in the growing season. Chemical control and mechanical control (as described in Appendix 1), as well as mechanical and manual control methods, grazing and integrated control, may be implemented to contain populations of *Heracleum* spp. Applying a combination of different measures may prove more effective.

Mechanical cutting can be effective, but it is important that it is undertaken at appropriate times in the growing season to be effective (Fig. 6). If mechanical cutting is undertaken too early this method is unlikely to provide long-term control as there is rapid regrowth from below ground, and it may also encourage the perennation of flowering shoots which would otherwise die after flowering. Cutting should be postponed until the first green seeds start to emerge on the top flower of generative plants. By that time the plant has practically depleted its resources and control is more effective compared with cutting in the early growing phase (Holm, 2005).

Fig. 6 Mechanical control using large machinery (EPPO Global Database Image courtesy: A. Bērziņš).

Mowing techniques

Mowing techniques can be used for large infested and accessible areas. Mowing must be repeated at least two or three times during the growing season for several years otherwise the plants regrow from nutrient reserves contained in the roots and may develop inflorescences. For populations which are small or situated in unsuitable locations for mechanical mowing (e.g. along rivers or slopes), plants can be cut manually. However, it should be noted that mowing is not an efficient method to kill individual plants (see Fig. 7) and may enhance plant density due to reduced intraspecific competition with other plants, but it can efficiently reduce produced seeds and limit the risk of spread to neighbouring areas (Caffrey & Madsen, 2001; Nielsen *et al*., 2005; Pyšek *et al*., 2007b).

Fig. 7 Dense *H. sosnowskyi* regrowth after mowing in Latvia compared to a control area (Image courtesy: Emphasis Project).

Umbel removal

An additional method for smaller populations is to remove the umbels of flowering plants, except for *H. persicum*. Timing is crucial and this should be done at the peak of flowering when the seeds are formed but not yet mature. When the removal of umbels is performed too early (before full inflorescence), regeneration is very vigorous; when performed too late, seeds may be released while removing the umbels. Cut umbels must be destroyed (burned) as soon as possible as seeds may lie on the ground and ripen, even from umbels cut early in the flowering stage. Pyšek *et al*. (2007) showed that 85% of terminal umbels cut off at the beginning of fruit formation and left at a site produce germinable seeds. Cutting the main inflorescences is considered equivalent to mowing the plants three times. If a long-term programme is feasible, only flowering plants can be targeted in subsequent years until the population is depleted (Pyšek *et al*., 2007a). It should be noted that Nielsen *et al* (2005) specify that umbel cutting should be only used as an improvised solution for the control of stands where no attempt of control was conducted earlier in the season.

A special 'hogweed tool' has been developed which consists of a curved saw blade on a long handle that is used to cut the stem while the user stands at a safe distance away from the plant (Nielsen *et al*., 2005).

Another option is to cover *H. mantegazzianum* and *H. sosnowskyi* umbels with textile bags during flowering time (Sachajdakieicz *et al*., 2014). In this way, the seeds are collected in the bags during ripening and the bags are burned afterwards. An advantage of this technique is that the plant may be less likely to produce secondary inflorescences.

After the treatment by cutting or bagging, stands should be checked carefully to ensure that plants do not regenerate and produce viable seeds; regenerating umbels must be destroyed in the same way.

Grazing

Heracleum spp. are not effectively controlled by light grazing. However, intensive grazing, especially by sheep and goats, can be highly effective (Tiley *et al*., 1996). Sheep were found to greatly reduce *Heracleum* spp. after 2 years and completely eliminate it after 7 years when no viable seeds remained in the soil (Andersen & Calov, 1996). The plants may be slightly less palatable to cattle, but grazing by cattle as well as pigs is recommended in Ireland (Lucey, 1994).

Sheep and cattle prefer young and fresh plants. In general, livestock need a period of time to become accustomed to *Heracleum* spp. before they will regularly eat these species. However, the animals develop a preference for *Heracleum* spp. In areas with dense infestation, mowing is recommended to allow the establishment of other plant species, since the grazers are less likely to be negatively affected by eating *Heracleum* spp. if the diet is mixed. Livestock with pigmentation of the bare skin (e.g. black-faced sheep) should be chosen in order to reduce inflammation due to the plants. If symptoms of poisoning in livestock are detected (e.g. skin inflammation), affected animals must be removed from the field temporarily (Nielsen *et al*., 2005).

Grazing pressure should be adjusted according to the density of the stand and to the period of the year. It is recommended to use a dense regime of animals in spring (20–30 sheep per hectare) and when the plants are weakened and most of the biomass has been removed to reduce grazing pressure (5–10 sheep per hectare),

Information regarding time requirements to apply different methods can be found in Nielsen *et al*. (2005).

During the grazing it is necessary to control the site for ungrazed or regenerating *Heracleum* individuals. Such plants have to be managed by mechanical methods such as cutting or root cutting.

Integrated control

In former fields and pastures, integrated control combining mowing/cutting, chemical control, soil cultivation and sowing of grass mixtures has given good results. After management of *Heracleum* spp. by herbicides and/or soil cultivation, grass mixtures should be sown at high densities (4000 emerging seedlings per m^2) and include competitive native grass species included to avoid soil erosion or reinfestation. Examples of suitable grass mixtures can be found in Nielsen *et al*. (2005) and, where feasible, native species should be used. The application of a selective herbicide suitable for broadleaved weeds in a developing grass sward can kill newly emerging seedling of *Heracleum* spp. (Treikale *et al*., 2005).

In natural habitats (e.g. along riversides), herbicide treatments may not be allowed. The creation of a strong plant community is achieved by additional cutting treatments for hogweed (above-ground cutting in spring, and frequent cutting after sowing when new seedlings of *Heracleum* spp. reach 20–30 cm) and increasing sowing rates of grass mixtures. The best grasses for such mixtures are local varieties that are resistant to flooding, well-adapted to the habitat and able to compete with *Heracleum* spp.

As mentioned in the eradication section, when plants are continuously grazed or cut the roots contract, pulling the crown down to about 10 cm below the soil surface.

Tiley & Philp (1992) described an integrated 2-year programme of spraying with glyphosate in April/May (early in the growing season), combined with cutting below ground when or where spraying was not feasible. Large flowering plants are dealt with before vegetative plants.

Mechanical control is suggested to be applied additionally when needed (e.g. when regrowth occurs or where plants or parts of plants have been missed during chemical application). When *Heracleum* spp. are eradicated or contained, dense competition by sown species or regrowth of native species can help to avoid seed germination and the recruitment of new *Heracleum* spp. as they are very light demanding. Therefore, nonselective herbicide (such as glyphosate) treatment should be followed by vegetation renewal to obtain results more quickly. With selective herbicide treatment faster natural renewal is possible.

Biological control

There are no known biological control agents available for these *Heracleum* spp. (Pyšek *et al*., 2007a).

Appendix 3. Summary of management techniques

Management techniques for *Heracleum* spp. are summarized in the table below according to the size of the populations and the habitats in which they can be implemented. A combination of management techniques is advised as it can increase success. Populations should be checked regularly for regrowth of plants.

Size of population	Technique*	Time of year or age of population	Habitat	Effectiveness of treatment	Remarks
Single plants to small stands (<1000 plants)	Root cutting (E, C)	Early spring with a repeated treatment in mid-summer	Any habitat	+++	Labour expensive, but very effective (at least 10 cm below ground level) Monitoring for regrowth is required
	Chemical (E, C)	Early in the season (March–May or until 20 cm diameter)	Any habitat (with limitations around water bodies)	+++	National recommendations on the use of herbicides need to be followed Can be followed by sowing of grass mixture or root cutting
	Black polythene cover (E)	Start of the vegetative period while plants can be covered efficiently (April to the beginning of May) or after mowing	Any habitat	+++	Expensive Check if no damage to the cover Following removal of the polythene, grass seed should be sown to avoid reinfestation
	Hand pulling (E)	Young seedlings	Any habitat	++	Only feasible in certain situations and labour intensive In specific moist soils can work well
	Removal of umbels or covering umbels with bags (C)	At the peak of flowering (when seeds are not mature)	Any habitat	+	For removal of umbels: risk of secondary seed production Take care of removed umbels and seeds – do not spread further (if possible burn them safely)
Large infestations (>1000 plants)	Chemical (E, C)	Early in the season (March–May or until 20 cm long)	Any habitat (with limitations around water bodies)	+++	National recommendations on the use of herbicides need to be followed Can be followed by sowing of grass mixture or root cutting Repeated applications may be required
	Ploughing of the soil (E, C)	Spring and autumn	Agricultural lands	+++	Can be followed by sowing of grass mixture or monocotyledon cultures One of the quickest eradication methods due to its high impact (~3-4 years, Bērziņš *et al.*, 2003)
	Intensive grazing (C)	From the start of the vegetative period when plants start to grow as the animals prefer young and avoid larger plants It may be continued through the summer	Any habitat suitable for grazing	++	In areas densely infested, mowing is necessary to allow the establishment of other species
	Mowing (C)	Two to three times during the growing season	Accessible areas	+	Can be followed by grazing, chemical control or other methods Repeated mowing is required to avoid flower production

*Depicts if the method is suitable for eradication (E), containment (C) or both.