Effective combination of management methods suppresses invasive Jerusalem artichoke

H Švehláková1*, B Turčová1, T Rajdus1, P Plohák1 and J Nováková1

1Department of environmental engineering, Faculty of mining and geology, VSB – TU Ostrava, 17. listopadu 2172/15, 708 00 Ostrava – Poruba, Czech Republic

Abstract. The main intention of our research is to determine an effective method to suppress invasive plant populations of Helianthus tuberosus spreading uncontrollably in the territory of the Poodří Protected Landscape Area (PLA) in the Czech Republic. This article brings together the results of selected management methods from 2017-2019 (mechanical, chemical and their combination) and their effect on the growth and reproductive characteristics of Helianthus tuberosus as well as the biodiversity of the local habitats. The combination of mowing and application herbicide based on clopyralid, fluroxypyr and MCPA proves to be the most effective. The partial results have been published before [1,2]. We present a complete research overview of the Helianthus tuberosus disposal.

1. Introduction
The Poodří Protected Landscape Area (PLA) is located in Czech Republic in the Moravian-Silesian Region. In 1993, the area was included in the world important wetlands of the Ramsar Convention, it also belongs to the European important bird areas (IBA) and important plant areas (IPA). Poodří PLA is also one of the worlds and European bird area in the frame of NATURA 2000.
In this research, we monitor invasive plant species Jerusalem artichoke (Helianthus tuberosus), that is capable of rapid and successful reproduction, especially vegetative reproduction by tubers or rhizomes. It also reproduces generatively (seeds), but rarely in the Czech Republic [3, 4]. These invasions significantly reduce the biological diversity of the area as they culminate in large monodominant phytocoenosis with minimum of plant species.

2. Materials and methods
The research area is located in the Poodří PLA, cadastral territory Proskovice and Stará Ves nad Ondřejnicí. It is composed of 12 experimental areas, H1-H10 were established in 2016 and next two (H11, H12) in 2017. The experimental areas range in size from 50 to 100 m² and have square or rectangular shape. The location of the experimental areas corresponds to typical habitats of Jerusalem artichoke- sunny riverbank vegetation (H3, H4, H9, H10, H11, H12), partially shaded riverbank vegetation (H2, H5, H8), meadow (H1) and alder forest (H6, H7). Every year, a representative square of 1m² was marked out on each monitoring area, on which growth and reproduction characteristics of Helianthus tuberosus were monitored (stem height, number of seeds per plant, number of individuals per m², number of fertile individuals per m², number of seeds in fertile plants).

The following interventions were performed on experimental areas:
- The mowing – mechanical mowing once or twice per season
- Digging tubers up – manual extraction of tubers by spade at the end of the vegetation season
• Post-emergence application of herbicides – active substances of herbicides: triclopyr 60 g/l, fluroxypyr 20 g/l (GARLON NEW); pelargonic acid (HERBISTOP); clopyralid 20 g/l, fluroxypyr 40 g/l and MCPA 200 g/l (BOFIX)
• Management combinations – mowing + application of herbicide

The values of the Shannon - Wiener diversity index H and equitability E and coverage of all occurring species were determined on the experimental areas [5]. The reference area H10 was left to its life cycle and development and serves for final comparisons of the effectiveness of individual management methods applied to other research areas. The basic ecological parameters of particular areas are shown in Table 1.

**Table 1. Basic ecological parameters.**

| Study area | Biotope    | Sunlight  | Humidity |
|------------|------------|-----------|----------|
| H1         | meadow     | sunny     | humid    |
| H2         | riverbank  | penumbra  | humid    |
| H3         | riverbank  | sunny     | humid    |
| H4         | riverbank  | sunny     | humid    |
| H5         | riverbank  | penumbra  | humid    |
| H6         | alder forest | shade | humid    |
| H7         | alder forest | shade | humid    |
| H8         | riverbank  | shade     | humid    |
| H9         | riverbank  | penumbra  | humid    |
| H10        | alluvium   | penumbra  | humid    |
| H11        | riverbank  | sunny     | humid    |
| H12        | riverbank  | sunny     | humid    |

3. Results

3.1. Biodiversity evaluation
A total of 84 species were recorded on individual experimental areas. Except of invasive *Helianthus tuberosus* (occurrence on all surfaces), these other invasive species were found *Solidago canadensis* (H2 – H9, H11), *Parthenocissus inserta* (H8, H9, H11, H12), *Conyza canadensis* (H1, H3 – H7, H9), *Reynoutria japonica* (H11), *Impatiens parviflora* (H6, H10) and these expansive species: *Calamagrostis epigejos* (H2 – H5, H8, H10 – H12), *Cirsium arvense* (H6, H8). No protected species (according to the law 395/1992 Sb. or Red List) was recorded on the experimental areas [6].

The Shannon - Wiener diversity index reaches an average value of 1.9 ± 0.34 with a minimum of 1.3 (H4) and a maximum of 2.4 (H8) on all experimental areas. The value of equitability reaches an average 0.6 ± 0.08, the maximum is 0.8 (H8), the minimum 0.5 (H4). It means that these habitats are relatively poor in species.

The biodiversity expressed by the Shannon - Wiener diversity index is shown in the Figure 1.
Helianthus tuberosus reaches the coverage level 4 of Braun – Blanquet scale on areas H1, H2, H3, H4, H6, H7, H9, H10, H11 and coverage level 3 on areas H5, H8, H12. An indirect ratio of Helianthus tuberosus and H’ coverage values can be observed from the data (Figure 2). Except for areas H1, H10 and H12, it occurs in codominance with another invasive species Solidago canadensis with a coverage of + to 2.

3.2. Growth characteristics and vegetative reproduction
Evaluated growth characteristics - number of shoots per m², number and weight of tubers per m² are clearly listed in Table 2.

The values from the reference area (H10), where no management methods were performed, show that there was a slight increase in the amount of above-ground vegetation (+ 5%) and a massive increase in underground biomass within 1 year. There was an increase of up to more than 200% in number of tubers per m², their weight has increased by 82%. It can therefore be assumed that in the case of zero management, there will be a gradual increase in the abundance of Helianthus tuberosus and the suppression of other, especially native species, due to intensive reproduction by tubers.

The combination of mowing 2x per season + 1x application of herbicide BOFIX during spring can be considered as the most effective because Helianthus tuberosus was almost completely removed in the first year after the interventions.

The application of herbicide BOFIX (H4, H7) can also be evaluated as a very effective method. There was a decrease in the number of shoots by 98% and the number and weight of tubers by 96% -100% in 2018. In the following year (2019), the number of shoots decreased by 98% -100% and the number and weight of tubers by 96% -100%.

The combination of mowing + application of herbicide GARLON - NEW is also effective. This management was started in the spring of 2018 on area H12 where the number of tubers was reduced by 60% and the weight of tubers by 91% in autumn 2018. In 2019, the number of tubers decreased by 81%, their weight by 93%, the number of shoots by 92% compared to the original state.

The combination of mowing + application of herbicide HERBISTOP containing pelargonic acid on areas H5, H8 also led to a reduction in above ground and underground biomass, however, the efficiency was lower as shown in the Table 3. The number of shoots was decreased by 33% (H8) and 48% (H5), the number of tubers by about 30% in both areas, the weight of tubers was decreased by 60% to 67% during 2017-2018. The number of shoots decreased by 94% (H5) and 25% (H8) during 2018-2019. There was a slight increase in the number of shoots on area H8 in 2019. The number of tubers decreased overall by 43% (H8) and 65% (H5) and the weight of tubers by 64% (H8) to 84% (H5).
The application of herbicide HERBISTOP appeared to be promising and suitable for the content of the active substance, which is of natural origin and leaves no residues. The number of tubers decreased by 38% and their weight by 78% in 2017. The number of shoots decreased by a total of 34%, the number of tubers by 54%, but their weight increased by 5% in 2018. However, there was a significant increase in the number of shoots per m² (+243%) and also an increase in the number and weight of tubers (by 224% and 304%) in 2019. This trend was monitored and confirmed in 2020 as well. HERBISTOP was therefore evaluated as unacceptable for use without supplementation by a mechanical method.

Regular mowing twice a year (H1) leads to a slow and constant decrease in the amount of above-ground and underground biomass. After the 1st mowing (2017), the number of individuals decreased by 9%, the number of tubers by 16% and the weight of tubers by 22%. In 2019, the total number of shoots decreased by 39%, the number of tubers by 48% and the weight of tubers by 65%.

Digging tubers up (H3, H9) is a very effective method, in all monitored parameters there was a reduction of 99% - 100% in the 1st year of management. However, manual digging is very demanding and not suitable for large areas. In addition, digging disrupts the vegetation cover and soil, which can lead to erosion or invasion of other problematic species (Solidago canadensis and Calamagrostis epigejos in our case).
Table 2. Growth characteristics and vegetative reproduction.

| Control       | Study area | 2017   | 2018     | 2019  |
|---------------|------------|--------|----------|-------|
| Without control | H10        | 186    | 196      | +5%   | -     |
|                | H2         | 97     | 297      | +200% | -     |
|                | H11        | 1021   | 1860     | +82%  | -     |
| Mowing + Bofix | H9         | 61     | 0        | -100% | 0-100%|
|                | H11        | 25     | 0        | -100% | 0-100%|
|                | H4         | 106    | 0        | -100% | 0-100%|
| Bofix          | H7         | 174    | 0        | -100% | 0-100%|
|                | H4         | 128    | 0        | -100% | 0-100%|
|                | H5         | 24     | 1        | -96%  | 1      |
|                | H7         | 71     | 13       | -98%  | 0      |
|                | H5         | 34     | 0        | -100% | 0-100%|
|                | H8         | 177    | 0        | -100% | 0-100%|
|                | H9         | 136    | 71       | -48%  | 8      |
|                | H9         | 31     | 21       | -32%  | 11     |
|                | H6         | 76     | 25       | -67%  | 12     |
|                | H5         | 24     | 16       | -33%  | 18     |
|                | H8         | 14     | 10       | -29%  | 8      |
|                | H6         | 28.1   | 11.2     | -60%  | 10.1   |
| Bofix          | H7         | 12     | 10       | -29%  | 8      |
|                | H7         | 28.1   | 11.2     | -60%  | 10.1   |
|                | H6         | 89/55  | -38%     | -54%  | 92     |
| Mowing +       | H6         | 920/265| -71%     | 66%   | 953    |
| Herbistop      | H12        | 56     | 37       | -34%  | 89     |
|                | H12        | 56     | 37       | -34%  | 89     |
|                | H6         | 186    | -15      | -92%  | -      |
| Mowing +       | H12        | 144/58 | -60%     | 27    |
| Garlon new b   | H3         | 144/58 | -60%     | 27    |
|                | H12        | 144/58 | -60%     | 27    |
|                | H3         | 1877/173| -91%    | 123   |
|                | H3         | 1877/173| -91%    | 123   |
|                | H12        | -      | 15       | -92%  | -      |
| Digging        | H9         | 386    | 5        | -99%  | -      |
|                | H9         | 288    | 5        | -99%  | -      |
|                | H9         | 386    | 5        | -99%  | -      |
|                | H11        | 541    | 8        | -99%  | -      |
|                | H11        | 208    | 189      | -9%   | 127    |
| Mowing         | H11        | 111    | 93       | -16%  | 58     |
|                | H11        | 107    | 83.4     | -22%  | 37     |
|                | H11        | 107    | 83.4     | -22%  | 37     |

a Measurement and counting of individuals and tubers in spring and autumn 2017, then in autumn 2018.

b Measurement and counting of individuals and tubers in spring and autumn 2018, then in autumn 2019.

3.3 Generative reproduction

We recorded flowering of Helianthus tuberosus in 2018 on one third of the areas (H4, H6, H7, H10) and in 2019 only on the area H10. We monitored the number of flowering individuals and the total number of anthodia (see Figure 3). It is evident from the data that in 2019 individuals bloomed only on the area without intervention (H10), while the number of flowering individuals and the number of capes were essentially the same as in 2018. No plants bloomed on the areas with interventions in 2019.
Seeds were collected and counted from mature anthodia in the autumn 2018 and 2019 (see Figure 4). The largest number of seeds was produced on reference area H10 in both years, while in 2019 2.5 times more seeds were produced with approximately the same number of anthodia. Flowering plants on the remaining areas produced seeds only in 2018.

In June 2020, 10 randomly selected seeds from 2019 (the seeds were temperature stratified in the winter of 2019/2020) were planted in pots and grown in outdoor conditions. A total of 5 individuals grew up, reaching a height of up to 80 cm, but none of them developed a flower.

4. Discussion
The results confirm the conclusions of previous research that use of the combined method 2x mowing + application of herbicide is optimal [1,2]. The most effective results were obtained using an herbicide based on clopyralid, fluroxypyr and MCPA (commercial preparation BOFIX). Similar conclusions have already been reached by Wall and Friesen [7] or Schittenhelm [8]. Later, however, highly effective
management using glyphosate prevailed, but its use is currently limited due to its possible carcinogenicity [9] as well as the growing resistance of many weed species [10,11]. In the following seasons, after application of glyphosate, Švehláková [1] recorded the occurrence of several extremely tall, intensely flowering Jerusalem artichoke individuals with massive underground biomass. Only application of BOFIX herbicide proved to be effective in reduction of above-ground and underground biomass. The disadvantage of this method is higher difficulty and higher consumption of herbicide, which is easier and more economical to apply to pre-mown areas. It also affects flowering and seed production not before the second year of management. On the areas treated with BOFIX (H2, H7), the return of some meadow species was recorded already in first year of management.

Combination of mowing + application of herbicide based on triclopyr and fluroxypyr (GARLON NEW) is also relatively effective. It should be emphasized that its application must be preceded by mowing, or application in spring, because in the case of higher plants with a defoliated lower part of the stem, it is not effective [1].

The application of an herbicide based on pelargonic acid (HERBISTOP) did not prove successful, there was a big increase in the monitored growth parameters in the 2nd year of management. Its effectiveness can be increased by combination with mowing, but the results do not reach the quality of herbicides containing clopyralid or triclopyr and fluroxypyr.

Mowing is also less efficient compared to combined methods. The results of our experiment confirm the conclusions of Fehér and Končeková [12] about the need for repeated mowing for a period of 3 years, when the number and vitality of the frames will decrease by about 44%.

The results of the development of generative organs are interesting. The plants bloomed on 4 areas (without intervention, with application of herbicide BOFIX and HERBISTOP) in 2018, in 2019 only on the area without intervention, where, however, they produced 2.5 times more seeds than in the previous season). Denisow et al. [13], Starovoytov et al. [14] states that in the conditions of Central and Western Europe, Jerusalem artichoke seeds do not ripen, or that there is a lack of data on sexual reproduction. Konvalinková [15], however, demonstrated the ability of seed germination in laboratory conditions. In our experiment, 5 individuals grew from 10 planted seeds. Thus, it can be assumed that in warm years, Helianthus tuberosus is able to successfully form viable seeds and multiply generatively. It is also important that the plants produced significantly fewer flowers on the treated areas (except for HERBISTOP sprayed areas) than on areas without management. However, it is still necessary to verify whether the cause is management or whether it is a natural population fluctuation.

5. Conclusion

Helianthus tuberosus is one of the most widespread invasive species in the Czech Republic. It spreads very effectively, especially in the vegetative way, but our experiment shows that in warm years it can create viable seeds and reproduce generatively as well. It is also problematic due to its attractiveness to pollinators, who may prefer it to domestic species. It acts as a factor suppressing native plant species and significantly influencing biodiversity of the landscape.

In the case of point occurrence, the optimal management is digging of tubers in autumn or early spring. If the invaded areas are larger, the management of 2x mowing + application of an herbicide containing clopyralid, fluroxypyr and MCPA after the 1st mowing proved to be effective. Mowing + application of an herbicide containing triclopyr and fluroxypyr can also be recommended, but it is necessary to apply it to young plants with an unfoliated lower part of the stem. Pelargonic acid spraying has proven ineffective and cannot be recommended for Jerusalem artichoke management, but its efficiency can be increased in combination with mowing, where it achieves slightly better results than mowing alone.

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References

[1] Švehláková H, Janíková A, Kupka J, Šotková N and Rajdus T 2017 Possibilities of the management of Helianthus tuberosus species in Poodri PLA (Czech Republic) IOP Conf. Series: Earth and Environmental Science 92

[2] Janíková A, Švehláková H, Turčová B and Stalmachová B 2020 Influence of management on vegetative reproduction of invasive species of Helianthus tuberosus in Poodri PLA IOP Conference Series: Earth and Environmental Science 444

[3] Pladias Databáze české flóry a vegetace 2014–2021 Pladias Available https://www.pladias.cz/.

[4] Mlíkovský J and Stýblo P 2006 Nepůvodní druhy fauny a flóry České republiky ČSOP

[5] Braun–Blanquet J 1964 Pflanzensoziologie: Grundzüge der Vegetationskunde. Wien: Springer-Verlag p 631

[6] Grulich V and Chobot K 2017 Red List of Threatened Species of the Czech Republic Vascular Plants p 178

[7] Wall D and Friesen G 1989 Volunteer Jerusalem Artichoke (Helianthus tuberosus) Interference and Control in Barley (Hordeum vulgare) (Weed Technol.) 3 (1) p 170-172

[8] Schittenhelm S 1996 Competition and Control of Volunteer Jerusalem Artichoke in Various Crops, J. Agron 176 (2) p 103-110

[9] IARC Monographs 2015 evaluation of five organophosphate insecticides and herbicides, IARC Volume 112

[10] Heap I and Duke S O 2018 Overview of glyphosate-resistant weeds worldwide Pest. Manag. Sci 74 p 1040-1049

[11] Singh V, Etheredge L, McGinty J, Morgan G and Bagavathiannan M 2020 First case of glyphosate resistance in weedy sunflower (Helianthus annuus) Pest Manag Sci. p 685-692

[12] Féher E and Končeková L, 2009 Evaluation of mechanical regulation of invasive Helianthus tuberosus populations in agricultural landscape J. Centr. Europ. Agr. P 245-250

[13] Denisow B, Tymoszuk K, and Dmitruk M 2019 Nectar and pollen production of Helianthus tuberosus L. – an exotic plant with invasiveness potential Acta Bot. Croat. 78(2) p 135-141

[14] Starovoytov V, Starovoytova O, Aldoshin N, Mahonina A 2017 Jerusalem Artichoke as Means of Fields Conservation Acta Technol. Agric. 20(1) p 7-10

[15] Konvalinková P 2003 Generative and vegetative reproduction of Helianthus tuberosus, an invasive plant in central Europe ed Child L, Brock J H, Brundu G, Prach K, Pyšek P, Wade P M, Plant invasions: Ecological threats and management solutions p 289-299