Control of Sosnovsky’s hogweed (*Heracleum sosnowskyi Manden.*) in forests using herbicides

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Abstract. The article presents the results of field experiments carried out in the Leningrad Region in 2018 and 2019 with the aim to test the effectiveness of modern herbicides against Sosnovsky’s hogweed and other undesirable herbaceous plants in various types of forest lands: in a clear cutting, spruce plantation, hayfield and on the side of a forest road. The herbicides Magnum (water dispersed granules, 600 g/kg of metsulfuron-methyl), Ancor-85 (water dispersed granules, 750 g/kg of potassium salt of sulfometuron-methyl) and a mixture of Roundup (360 g/l of glyphosate acid) and Ancor-85 were found to be highly effective against Sosnovsky’s hogweed. Magnum stimulates the growth of grasses and is promising for use in areas not occupied by woody vegetation. Anchor-85 is proposed for the care of European spruce (*Picea abies* (L.) Karst.) and Scots pine (*Pinus sylvestris* L.) in the spring.

1. Introduction

Since the 1960s, Sosnovsky's hogweed has been widely cultivated in several regions of the European part of the USSR. It was used mainly as a fodder (silage), as well as a medicinal, starch-containing, honey-bearing and ornamental plant. However, the presence of photosensitizing furcocoumarins in the juice of the above-ground organs of this species resulted in severe dermatitis (often called "burns") when the plant came in contact with human and animal skin, and also negatively affected the health of animals and worsened the quality of agricultural products. For these reasons, Sosnovsky’s hogweed has no longer been grown since the 1980s. However, it was later noted that this species was able to escape cultivation and get out of control, showing a high degree of aggressiveness against local species of phytocenoses. As a result of the cultivation of Sosnovsky's hogweed in the past as a fodder plant, it is now widely spread in the Leningrad, Pskov, Novgorod, Vologda, Tver, Moscow, Ivanovo, Kirov regions, in the Republics of Karelia, Komi, Mordovia, as well as in Belarus, Lithuania, Latvia, Estonia and other countries of Eastern Europe. The areas occupied by Sosnovsky's hogweed in the European part of the Russian Federation continue to increase dramatically. It is believed that Sosnovsky's hogweed annually increases its distribution area by at least 10%, actively crowding out native species and forming single-species communities [1-3].

Thickets of Sosnovsky's hogweed along roads and railways, in and around settlements, on non-cultivated agricultural lands, farms and other objects pose a significant risk to human health. On the lands of these categories, active eradication of Sosnovsky's hogweed has been ongoing for more than 15 years; in a number of constituent entities of the Russian Federation special regional programs are in operation [4]. In Russia, in 2015 Sosnovsky's hogweed received the status of a weed and was included in the “Industry Classifier of Weed Plants” [5].

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This invasive species also spreads actively on the lands of the forest fund: in plantations, on felling sites, in young stands of the natural origin, clearings and hayfields, stands of different ages with a small basal area, and in the most productive forest conditions. As a result of this, in forest plantations the growth of woody plants (primarily coniferous species) is inhibited, their death is observed, and environmental, aesthetic and industrial damage increases due to the growth and dominance of this plant. Biological features of Sosnovsky's hogweed allow the species to successfully compete with many woody plants [6].

The experience of control of Sosnovsky's hogweed has demonstrated that there are various ways to suppress its advance [7-9]. However, practice has shown that the use of only mechanical control measures (mowing, plowing the soil) does not give the required results; Sosnovsky's hogweed regenerates quite quickly from the root and from seeds, actively populating new areas. The real opportunity to destroy Sosnovsky's hogweed and prevent its further spread is currently presented only by a chemical control method, its combination with the mechanical measures, as well as the use of so-called “substitute” crops [10-12]. Employees of the Federal State Institution “SPbNIIILH” developed and patented an effective method for eradication of Sosnovsky's hogweed, consisting of a single treatment of a site occupied by Sosnovsky's hogweed with systemic herbicides with soil activity – preparations based on pyridine derivatives, benzoic and carboxylic acids, and sulfonylurea. The method provides for the subsequent sowing of grass to form a turf cover, preventing the re-growth of Sosnovsky's hogweed from seeds [13]. In order to determine the optimal technological regulations for the use of modern, most effective and environmentally friendly herbicides for the eradication of Sosnovsky's hogweed and associated unwanted plants when creating pine and spruce plantations, as well as when caring for them, special experimental studies are necessary. Methods and technologies for the control of Sosnovsky's hogweed developed for agricultural and industrial lands cannot be applied on the lands of the forest fund without adjustment. Previously developed methods of chemical care for coniferous plantations created by seedlings with open and closed root systems can also not be fully applied against Sosnovsky's hogweed due to its high resistance to herbicides used in forestry, as well as specific biological features (intensive growth, large size and biomass, abundant fruiting, early spring development and the early end of the growing season, aggressiveness towards other types of herbaceous vegetation).

It should also be noted that the fight against Sosnovsky's hogweed on the road sides, in settlements, and on agricultural lands cannot provide a long-term effect as long as there are sources of Sosnovsky's hogweed seeds on the lands adjacent to the forest fund, as this species is reinstated quickly enough by seed. Since the spread of this invasive plant is already taking on the scale of environmental disasters, the control of Sosnovsky's hogweed should be carried out simultaneously in all categories of contaminated lands, including forest ones.

The aim of the present research was to study the effectiveness of spraying forest areas contaminated with Sosnovsky's hogweed by herbicides and assess their selectivity with respect to pine and spruce. To our knowledge, such study has been conducted for the first time.

2. Methods and Materials

Field experiments were carried out in the Gatchinsky district of the Leningrad region, which belongs to the Baltic-Belozersky taiga region of the taiga zone, in 2018 and 2019. Four field experiments were carried out. Options for the use of herbicides, dates of treatments and results are given in tables 1-5. In the experiments, herbicides allowed for use in Russia were applied [14].

Experiment 1 was performed in a four-year old clear-cutting in a bilberry type of forest growing conditions, sod-podzolic light loamy soil with a humus content in the A1 horizon of 2.8%; experiment 2, in a 10-year old spruce plantation in an acidic type of forest growing conditions, sod-podzolic light loamy soil with a humus content in the A1 horizon of 3.9%, drained; experiments 3 and 4, in a haymaking field and on the side of a forest road in the bilberry type of forest conditions, the soil was sod-podzolic, light loamy with a humus content in the A1 horizon of 3.9%, drained. In experiment 1, the size of the experimental plot was 25 m² (5×5 m), five replications; in experiments 2-4, 100 m².
(20×5 m), two replications. In all experiments spraying was carried out with a Solo manual backpack sprayer with a spray volume of 300 l/ha.

The biological effect of herbicides on herbaceous vegetation was determined by measuring the reduction (in percent) of the projective cover of herbaceous species in relation to the control (without treatment), for which 30 temporary reference areas of 1×1 m for each type of experiment were established.

In experiments 1, 3, and 4, the following types of grasses dominated: Calamagrostis arundinacea (L.) Roth, Calamagrostis epigeios L., Avenella flexuosa (L.) Drejer, Deschampsia cespitosa (L.) Beauv., Agrostis capillaries L., Heracleum sosnowskyi Manden., Veronica officinalis L., Chamaenerion angustifolium (L.) Scop., Cirsium heterophyllum (L.) Hill, Aegopodium podagraria L., Anthriscus sylvestris (L.) Hoffm., Angelica sylvestris L., Hypericum perforatum L., Fragaria vesca L., Potentilla erecta (L.) Raeusch., Trifolium pratense L., and Pulmonaria officinalis L.

In experiment 2, the following species dominated: Calamagrostis arundinacea (L.) Roth, Avenella flexuosa (L.) Drejer, Deschampsia cespitosa (L.) Beauv., Agrostis capillaries L., Jungus spp. L., Carex spp. L., Veronica officinalis L., Heracleum sosnowskyi Manden., H. sibiricum L., Chamaenerion angustifolium (L.) Scop., Cirsium heterophyllum (L.) Hill, Aegopodium podagraria L., Angelica sylvestris L., Anthriscus sylvestris (L.) Hoffm., Urtica dioica L., Filipendula ulmaria (L.) Maxim., Hypericum perforatum L., Fragaria vesca L., Convallaria majalis L., Potentilla erecta (L.) Raeusch., Pulmonaria officinalis L., and Vicia cracca L.

On the day of treatment (May), adult specimens of Sosnovsky's hogweed were in the phase of the rosette, 10–25 cm high; seedlings of Sosnovsky’s hogweed were 3–7 cm high in amount of 10–20 individuals/m². Other types of unwanted herbaceous plants were in the phases of the rosette and tillering, 8-20 cm high. In experiment 1, natural regeneration of European spruce (Picea abies (L.) Karst.) and Scots pine (Pinus sylvestris L.), 2–4 years old, 5–25 cm high, without signs of growth on the day of treatment was noted.

3. Results and Discussion

In experiment 1, performed in a four-year old clear-cutting with self-seeding of pine and spruce, a mixture of herbicides (Roundup, 4 l/ha + Anchor-85, 100 g/ha), applied in the first ten days of May provided fast and effective suppression of Sosnovsky's hogweed as in seedling phase, and in the phase of the rosette throughout the growing season, 86-100% (table 1). At the same time, herbicides effectively suppressed a wide range of other dicotyledonous and monocotyledonous undesirable plants, 96-100%. Anchor-85 (100 g/ha) was also quite effective, but it acted more slowly in all groups of herbaceous species, including Sosnovsky's hogweed (79-97%). Magnum (100 g/ha), in terms of its effect on Sosnovsky's hogweed and other dicotyledonous species, was similar to Anchor-85 (100 g/ha), but it caused active growth of monocotyledonous species, primarily grasses. Pine and spruce showed high resistance to Anchor-85 when treated before the start of the active growth, which makes this herbicide the most promising for the control of Sosnovsky's hogweed in coniferous plantations (table 2). Acceptable (satisfactory) resistance to the mixture of herbicides (Roundup, 4 l/ha + Anchor-85, 100 g/ha) was demonstrated by seedlings of spruce, and low (insufficient), by seedlings of pine. Magnum (100 g/ha) did not possess the necessary selectivity with respect to pine and spruce even when used before the start of the active growth of conifers (table 2).

In experiment 2 performed in a 10-year old plantation of spruce, a mixture of herbicides consisting of Roundup, 4 l/ha + Anchor-85, 100 g/ha, as well as Anchor-85 (100 g/ha) and Magnum (100 and 200 g/ha) effectively suppressed Sosnovsky's hogweed, ensuring its elimination by the end of the season by 95-100% (table 3). Magnum caused the increase in the number of grasses by several times in comparison with the control.

In all experiments, some dicotyledonous species partly survived: Chamaenerion angustifolium (L.) Scop., Angelica sylvestris L., Aegopodium podagraria L., Convallaria majalis L. and Hypericum perforatum L.; in experiment 2, some monocotyledonous species also survived, including Calamagrostis arundinacea (L.) Roth, Avenella flexuosa (L.) Drejer, and Deschampsia cespitosa (L.)
Table 1. The effect of herbicides on Sosnovsky’s hogweed and other undesirable herbaceous vegetation in a four-year old clear cutting (experiment 1, treatment on 08.05.2019).

| Type of experiment | Date of inventory | Projective cover of herbaceous plants, % | Suppression efficiency towards herbaceous plants, % |
|--------------------|-------------------|------------------------------------------|--------------------------------------------------|
|                    |                   | total | Sosnovsky’s hogweed | dicotyledons | grasses | all species | Sosnovsky’s hogweed | dicotyledons | grasses |
| 1. Roundup, 4 l/ha + Anchor-85, 100 g/ha | 10.06.19 | 6 | 4 | 2 | 0 | 93 | 86 | 96 | 100 |
|                       | 13.07.19 | 3 | 2 | 1 | 0 | 97 | 94 | 98 | 100 |
|                       | 16.08.19 | 1 | 0 | 1 | 0 | 99 | 100 | 98 | 100 |
| 2. Anchor-85, 100 g/ha | 10.06.19 | 12 | 6 | 4 | 2 | 86 | 79 | 91 | 83 |
|                        | 13.07.19 | 6 | 4 | 1 | 1 | 94 | 89 | 98 | 93 |
|                        | 16.08.19 | 3 | 1 | 2 | 0 | 97 | 97 | 96 | 100 |
| 3. Magnum, 100 g/ha   | 10.06.19 | 31 | 8 | 5 | 18 | 64 | 71 | 89 | 97 |
|                        | 13.07.19 | 29 | 5 | 2 | 22 | 70 | 86 | 96 | 97 |
|                        | 16.08.19 | 39 | 2 | 2 | 35 | 58 | 94 | 96 | -169 |
| 4. Control             | 10.06.19 | 86 | 28 | 46 | 12 | - | - | - | - |
|                        | 13.07.19 | 98 | 35 | 49 | 14 | - | - | - | - |
|                        | 16.08.19 | 92 | 32 | 47 | 13 | - | - | - | - |

Table 2. Condition of pine and spruce seedlings by category (% of the total number on the day of treatment) in a four-year old clear-cutting (experiment 1, treatment on 08.05.2019).

| Type of experiment | Date of inventory | Pine | Spruce |
|--------------------|-------------------|------|-------|
|                    |                   | without damage | weak damage | severe damage | dead | without damage | weak damage | severe damage | dead |
| 1. Roundup, 4 l/ha + Anchor-85, 100 g/ha | 10.06.19 | 11 | 89 | 0 | 0 | 86 | 14 | 0 | 0 |
|                       | 13.07.19 | 9 | 72 | 19 | 0 | 85 | 15 | 0 | 0 |
|                       | 16.08.19 | 5 | 71 | 24 | 0 | 81 | 19 | 0 | 0 |
| 2. Anchor-85, 100 g/ha | 10.06.19 | 100 | 0 | 0 | 0 | 98 | 2 | 0 | 0 |
|                        | 13.07.19 | 100 | 0 | 0 | 0 | 95 | 5 | 0 | 0 |
|                        | 16.08.19 | 100 | 0 | 0 | 0 | 96 | 4 | 0 | 0 |
| 3. Magnum, 100 g/ha   | 10.06.19 | 26 | 74 | 0 | 0 | 15 | 85 | 0 | 0 |
|                        | 13.07.19 | 10 | 45 | 45 | 0 | 18 | 48 | 34 | 0 |
|                        | 16.08.19 | 6 | 49 | 45 | 0 | 16 | 50 | 34 | 0 |
| 4. Control             | 10.06.19 | 100 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
|                        | 13.07.19 | 100 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
|                        | 16.08.19 | 100 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
Table 3. The effect of herbicides on Sosnovsky's hogweed and other types of unwanted herbaceous vegetation in a spruce plantation (experiment 2, treatment on 10.05.2019).

| Type of experiment | Date of inventory | Projective cover of herbaceous plants, % | Suppression efficiency towards herbaceous plants, % |
|--------------------|-------------------|----------------------------------------|--------------------------------------------------|
|                    |                   | total | Sosnovsky's hogweed | dicotyledons | monocotyledons | all species | Sosnovsky's hogweed | dicotyledons | monocotyledons |
| 1. Roundup, 4 l/ha + Anchor-85, 100 g/ha | 22.05.19          | 24   | 10 | 10 | 4 | 59 | 55 | 67 | 33 |
|                    | 10.06.19          | 10   | 8  | 2  | 0 | 89 | 82 | 95 | 100 |
|                    | 21.08.19          | 1    | 0  | 1  | 0 | 99 | 100 | 97 | 100 |
| 2. Anchor-85, 100 g/ha | 22.05.19          | 37   | 16 | 17 | 4 | 36 | 27 | 43 | 33 |
|                    | 10.06.19          | 24   | 12 | 9  | 3 | 74 | 73 | 78 | 67 |
|                    | 21.08.19          | 5    | 1  | 3  | 1 | 94 | 97 | 92 | 92 |
| 3. Magnum, 100 g/ha | 22.05.19          | 39   | 18 | 16 | 5 | 33 | 18 | 47 | 17 |
|                    | 10.06.19          | 44   | 14 | 8  | 22 | 53 | 68 | 80 | -144 |
|                    | 21.08.19          | 43   | 2  | 3  | 38 | 53 | 95 | 92 | -217 |
| 4. Magnum, 200 g/ha | 22.05.19          | 35   | 14 | 15 | 6 | 40 | 36 | 50 | 0 |
|                    | 10.06.19          | 31   | 10 | 6  | 15 | 67 | 77 | 85 | -67 |
|                    | 21.08.19          | 26   | 0  | 1  | 25 | 71 | 100 | 97 | -108 |
| 5. Control         | 22.05.19          | 58   | 22 | 30 | 6 | -  | -  | -  | -  |
|                    | 10.06.19          | 94   | 44 | 41 | 9 | -  | -  | -  | -  |
|                    | 21.08.19          | 91   | 39 | 40 | 12 | -  | -  | -  | -  |

Beauv. As in experiment 1, this herbicide caused serious damage to spruce. Anchor-85 and a mixture of herbicides (Roundup + Anchor-85) demonstrated high selectivity for spruce – no external noted damage was.

In experiment 3 carried out in a hayfield which was heavily overgrown with Sosnovsky's hogweed, a mixture of herbicides consisting of Roundup, 4 l/ha + Anchor-85, 100 g/ha, as well as Magnum (100 and 200 g/ha), provided suppression of Sosnovsky's hogweed by the end of the first growing season by 88-99%, and in the second year, by 92-98% (table 4). In the first year, Magnum at the surface density of 100 g/ha stimulated the development of grasses in such a way that their projective cover reached 55%, which was 2.9 times higher than the control value (19%); in the following year, the projective cover of grasses reached 85% (i.e. 3.4 times higher than the control). Magnum at the surface density of 200 g/ha caused some inhibition of grasses in the first one to two months after the treatment.

In experiment 4 carried out on the side of a forest road, a mixture of herbicides consisting of Roundup, 4 l/ha + Anchor-85, 100 g/ha, as well as Magnum (100 and 200 g/ha) provided suppression of Sosnovsky's hogweed by 70-99% during the season, and by 100% at the end of the season (table 5). A mixture of herbicides almost completely (98%) suppressed all types of grasses. By the end of the season, Magnum at the surface density of 100 g/ha caused an intensive development of grasses so that their projective cover reached 75%, which exceeded the control figure (8%) by 9.4 times. As in experiment 3, Magnum at the surface density of 200 g/ha inhibited growth of grass species in the first one to two months after the treatment, and therefore their abundance reached only 45% by the end of the season, although this is still 5.6 times higher than in control.
Table 4. The effect of herbicides on Sosnovsky’s hogweed and other types of undesirable herbaceous vegetation in a forest haymaking field (experiment 3, treatment on 12.05.2018).

| Type of experiment | Date of inventory | Projective cover of herbaceous plants, % | Suppression efficiency towards herbaceous plants, % |
|--------------------|-------------------|------------------------------------------|-----------------------------------------------|
|                    |                   | total | Sosnovsky’s hogweed | dicotyledons | grasses | total | Sosnovsky’s hogweed | dicotyledons | grasses |
| 1. Roundup, 4 l/ha + Anchor-85, 100 g/ha | 12.06.18 | 19 | 15 | 2 | 2 | 81 | 78 | 75 | 91 |
|                                                     | 20.07.18 | 3 | 1 | 1 | 1 | 97 | 99 | 89 | 95 |
|                                                     | 26.06.19 | 10 | 5 | 5 | 0 | 90 | 92 | 44 | 100 |
| 2. Magnum, 100 g/ha | 12.06.18 | 67 | 29 | 3 | 35 | 33 | 58 | 63 | -52 |
|                                                     | 20.07.18 | 66 | 9 | 2 | 55 | 34 | 88 | 78 | -189 |
|                                                     | 26.06.19 | 92 | 5 | 2 | 85 | 8 | 92 | 78 | -240 |
| 3. Magnum, 200 g/ha | 12.06.18 | 54 | 23 | 3 | 28 | 46 | 67 | 63 | -22 |
|                                                     | 20.07.18 | 53 | 6 | 1 | 46 | 47 | 92 | 89 | -142 |
|                                                     | 26.06.19 | 74 | 1 | 1 | 72 | 26 | 98 | 89 | -188 |
| 4. Control | 12.06.18 | 100 | 69 | 8 | 23 | - | - | - | - |
|                                                     | 20.07.18 | 100 | 72 | 9 | 19 | - | - | - | - |
|                                                     | 26.06.19 | 100 | 66 | 9 | 25 | - | - | - | - |

Table 5. The effect of herbicides on Sosnovsky’s hogweed and other types of unwanted herbaceous vegetation on the side of a forest road (experiment 4, treatment on 17.05.2019).

| Type of experiment | Date of inventory | Projective cover of herbaceous plants, % | Suppression efficiency towards herbaceous plants, % |
|--------------------|-------------------|------------------------------------------|-----------------------------------------------|
|                    |                   | total | Sosnovsky’s hogweed | dicotyledons | grasses | total | Sosnovsky’s hogweed | dicotyledons | grasses |
| 1. Roundup, 4 l/ha + Anchor-85, 100 g/ha | 12.06.19 | 15 | 11 | 4 | 0 | 85 | 87 | 60 | 100 |
|                                                     | 13.07.19 | 5 | 1 | 4 | 0 | 95 | 99 | 56 | 100 |
|                                                     | 16.08.19 | 2 | 0 | 2 | 0 | 98 | 100 | 75 | 100 |
| 2. Magnum, 100 g/ha | 12.06.19 | 56 | 25 | 9 | 22 | 42 | 70 | 10 | -340 |
|                                                     | 13.07.19 | 53 | 5 | 4 | 44 | 45 | 94 | 56 | -529 |
|                                                     | 16.08.19 | 80 | 0 | 5 | 75 | 18 | 100 | 38 | -837 |
| 3. Magnum, 200 g/ha | 12.06.19 | 45 | 21 | 7 | 17 | 54 | 74 | 30 | -240 |
|                                                     | 13.07.19 | 29 | 2 | 2 | 25 | 70 | 98 | 78 | -257 |
|                                                     | 16.08.19 | 49 | 0 | 4 | 45 | 50 | 100 | 50 | -462 |
| 4. Control | 12.06.19 | 97 | 82 | 10 | 5 | - | - | - | - |
|                                                     | 13.07.19 | 97 | 81 | 9 | 7 | - | - | - | - |
|                                                     | 16.08.19 | 98 | 82 | 8 | 8 | - | - | - | - |
The positive results of the application of Roundup + Anchor-85, Anchor-85 and Magnum against Sosnovsky's hogweed are confirmed by data obtained in several regions of Russia and countries of Eastern Europe [8, 11, 14-16]. Previously, high resistance of conifers to Anchor-85 was established [17, 18]. Any literature data regarding the low selectivity of Magnum in relation to pine and spruce was not found. Also, for the first time, we obtained experimental data on the transformation of herbaceous cover after the application of Magnum in forestry.

4. Conclusion
It was found that:
- the use of a mixture of herbicides (Roundup, 4 l/ha + Anchor-85, 100 g/ha) results in a quick and effective suppression of all groups of herbaceous vegetation, including Sosnovsky's hogweed, other dicotyledonous, and also monocotyledonous species;
- the use of Magnum with the surface density of 100 and 200 g/ha results in an effective suppression of Sosnovsky's hogweed and other dicotyledonous herbaceous species; within one season, it results in transformation of a grass cover with the participation of Sosnovsky's hogweed and other dicotyledonous and monocotyledonous grass species into a cover dominated by perennial grasses;
- pine and spruce showed high resistance to Anchor-85 (100 g/ha) when treated in the period before the start of their active growth, which makes this herbicide the most promising for the control of Sosnovsky's hogweed in plantations and young natural conifer stands;
- acceptable (satisfactory) resistance to the mixture of herbicides (Roundup, 4 l/ha + Anchor-85, 100 g/ha) was demonstrated by seedlings of spruce, and low (insufficient), by seedlings of pine. Magnum (100 g/ha) proved to be a non-selective herbicide with respect to pine and spruce even when applied in the period before their active growth;
- Magnum should be considered the most promising herbicide for the control of Sosnovsky's hogweed on forest lands not occupied by woody vegetation, that is, in clear-cuttings, hayfields, and clearings and on the sides of forest roads.

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