Selective herbicides to control Sosnowsky's hogweed (Heracleum sosnowskyi Manden.) in pine and spruce plantations

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Abstract. In recent years, in the European part of Russia, massive and extremely negative distribution of Sosnowsky's hogweed (Heracleum sosnowskyi Manden.) on various land categories has been observed. On the lands of the forest fund, there is also a threat of a rapid spread of hogweed, mainly in low-density stands, open spaces, forest plantations, and in fresh clearings. As a result, the growth of woody plants, first of all conifers, is suppressed, their death is observed, and environmental, aesthetic and industrial damage increases. Mechanical measures to combat hogweed are not effective enough and are very laborious. The article presents the results of a field experiment carried out in the Leningrad region in 2019–2020. The aim of the study was to assess the effectiveness of herbicides towards Sosnowsky's hogweed and accompanying herbaceous species, as well as to evaluate their selectivity towards seedlings of Scots pine (Pinus sylvestris L.) and spruce (Picea abies (L.) Karst.). The herbicides studied were Anchor-85, Mortyra, Deimos, Lontrel-300 and Magnum in various combinations and application rates. The herbicides Anchor-85, Mortyra and Magnum showed high efficiency in suppressing Sosnowsky's hogweed, however, only Anchor-85 and Mortyra turned out to be selective enough in relation to conifers.

1. Introduction

Due to the high invasiveness of Sosnowsky's hogweed, it quickly spreads in areas not covered by tall vegetation, rapidly occupies uncultivated agricultural lands, gets established in settlements, and on the road sides. On the lands of the forest fund, there is also a threat of a rapid spread of hogweed, mainly in low-density stands, open spaces, in forest plantations, and in fresh clearings. It spreads, as a rule, from adjacent territories already heavily overgrown with hogweed. This can lead to inhibition of the development and growth, or even death of economically valuable tree species.

It is possible to prevent or limit the distribution of hogweed on the lands of the forest fund thanks to measures aimed at destroying this plant in adjacent territories already occupied by it [1]. Most authors, both Russian and international, believe that with a massive spread of hogweed, mechanical control measures do not ensure its complete suppression. The most effective method of hogweed control is the chemical method [2, 3].

There is a number of studies describing the effect of herbicides on hogweed in areas with its massive distribution. The most effective herbicides and their mixtures are based on glyphosate (Roundup, Glyphos, etc.), picloram (Thordon), clopyralid (Lontrel), dicamba (Banvel), imazapyr (Arsenal), triclopyr (Garlon), as well as sulfonylureas (chlorosulfuron, metsulfuron -methyl,
sulfometuron-methyl, triasulfuron, prosulfuron, flazasulfuron) [4–14]. To achieve the maximum effect in elimination of hogweed, as well as to further limit its spread, some researchers believe that it is necessary to introduce "replacement" crops [15–17]. In this regard, it is promising to use selective herbicides that have an effect on dicotyledonous plants, including hogweed, but not toxic or slightly toxic to grasses. In the Russian Federation, selective herbicides Lontrel-300 (active ingredient clopyralid), Deimos (active ingredient dikamba), Mortira (active ingredient tribenuron-methyl), Magnum (active ingredient metsulfuron-methyl) and others have been registered and used in agriculture against dicotyledonous weeds on loans, hayfields and cereal fields [18, 19]. However, the data on the effectiveness of these herbicides against Sosnovsky's hogweed are limited. In particular, there are no experimental data on their use in forestry and their selectivity in relation to conifers.

Therefore, the main goal of the present study was to determine the biological effectiveness of selected herbicides and their mixtures in eradication of Sosnovsky's hogweed and other types of undesirable herbaceous plants, as well as their selectivity in pine and spruce plantations created by seedlings with a closed root system (CRS).

2. Methods and Materials

To achieve the above goal, on August 27, 2019, in the Gatchinsky district of the Leningrad region, an experiment was set up according to generally accepted methods [20, 21]. The experimental plot was located in an oxalis type of forest growing conditions and heavily overgrown with hogweed. The herbicides registered for use in forestry and agriculture on the territory of the Russian Federation were used: Anchor-85 (VDG, 750 g / kg sulfometuron-methyl, potassium salt), Magnum (VDG, 600 g/kg metsulfuron-methyl), Lontrel-300 ( BP, 300 g/l clopyralid), Deimos (VRK, 480 g/l dicamba acid), and Mortyra (EDG, 750 g/kg tribenuron-methyl) [19]. The experiment comprised eight variants of herbicide application, with different application rates and in different combinations, as well as a control variant without treatment. There were two replications. The area of the experimental plot was 25 m². Spraying was carried out on May 7, 2020. A hand-held knapsack sprayer "Solo" was used for the treatment. The flow rate of the working fluid was 300 l/ha. In addition to hogweed, herbaceous vegetation was represented by species typical for these forest growing conditions. Monocotyledonous species were represented by Calamagrostis purpurea (Trin.) Trin. s. 1., Dactylis glomerata L., Phleum pretense L., Eletrigia repens (L.) Nevski, Deschampsia caespitosa (L.) Beauv., and Agrostis capillaries L. The following dicotyledonous species were present: Chamaenerion angustifolium (L.) Scop., Rubus idaeus L., Cirsium arvense (L.) Scop., Aegopodium podagraria L., Anthriscus sylvestris (L.) Hoffm., Urtica dioica L., Filipendula ulmaria (L.) Maxim., and Hypericum perforatum L.

On the day of treatment, adult hogweed specimens were in the phase of a 15–25 cm tall rosette, and hogweed seedlings were 4–16 cm tall in an amount of 50–60 specimens/m². Other types of unwanted herbaceous plants were 6–10 cm tall, in the rosette and tillering phases. There was no unwanted woody vegetation.

On August 27, 2019, seedlings of Scots pine (Pinus sylvestris L.) and spruce (Picea abies (L.) Karst.) with closed root systems were planted. The planting material was sown in 2018 and grown in one rotation in Plantek-81 cassettes. Planting was carried out manually using Kolesov's sword without mechanical tillage. We planted 60 specimens of each species per variant of the experiment (30 specimens per plot). The planting step was 30 cm. In total, 540 pine seedlings and 540 spruce seedlings were planted in the experiment. During the growing season of 2020, the state of conifers and the effectiveness of herbicides for control of hogweed and other types of herbaceous plants were surveyed three times.

3. Results and Discussion

According to the results of the first survey carried out in June, the greatest efficiency of suppression (70%) of all types of herbaceous vegetation was recorded in variant 7 where a mixture of herbicides (Magnum, 25 g/ha + Deimos, 2 l/ha + Lontrel-300, 0.6 l/ha) was used (table 1). A slightly lower level of biological efficiency was recorded in variants 2 (Anchor-85, 100 g/ha + Mortyra, 25 g/ha) and 3.
(Mortyra, 25 g / ha + Deimos 2 l / ha), 57% and 64%, respectively. The lowest efficiency (24%) was observed in variant 5 (Deimos 2 l/ha + Lontrel-300, 0.6 l/ha). One month after chemical treatment, the largest percentage (68–77%) of suppression of hogweed was observed in variants 3, 4 and 7, and the lowest (30%), in variant 5. When the effect of herbicides on undesirable monocotyledonous species was considered, in variants 3–6 an active growth of these species was observed, and the total projective soil cover exceeded the control values by 2–4 times. This is due to the fact that selective herbicides which suppress only dicotyledonous species were used in these mixtures. When applied in its pure form, Magnum as well as a mixture of Magnum, 25 g/ha + Deimos, 2 l/ha + Lontrel-300, 0.6 l/ha did not cause an active growth of grass species during the first reporting period, although these herbicides are known to suppress dicotyledonous species.

According to the results of the second inventory, the best suppression of all types of herbaceous vegetation was observed in the variants where Anchor-85 was used in its pure form or in a mixture with Mortyra. In other variants of the experiment where selective herbicides were used an active growth of grass species was observed. Thus, in variant 3, the projective soil cover of grass species increased almost by seven times compared to the control. The effectiveness of suppressing hogweed in variants 1, 2, 4, 7, and 8 was relatively high and amounted to 74–84%. The worst result was observed in variant 5, where at the time of inventory the projective soil cover of hogweed was 71%.

By the end of the growing season, the best suppression of all types of unwanted vegetation was recorded in variants 1 and 2: 92% and 84%, respectively. In variant 8 (Magnum, 100 g/ha), there was a slight increase in efficiency. In the rest of the experimental variants, it significantly decreased, mainly due to the growth of grass species. It was not possible to achieve complete suppression of hogweed in any of the experimental variants. In variants 1, 2, 7 and 8, the highest degree of suppression of hogweed was recorded, 81–97%. In all other variants, by the end of the growing season it significantly decreased and was below the acceptable level (10–64%). According to the results of the first inventory of pine seedlings planted before the chemical treatment, their condition was good only in variants 1 and 2, where Anchor-85 was used in its pure form or in a mixture with Mortyra (table 2). Moreover, while in variant 1 there was a slightly larger amount of damaged seedlings in comparison with the control, in variant 2 their number was even lower. In variant 8, 76% of pine seedlings did not have any signs of damage one month after the chemical treatment. In all other variants, the number of damaged and dead seedlings exceeded 60%. In variants 1 and 2, the state of spruce seedlings was good by the time of the first inventory and did not differ in any way from the control; not a single seedling with herbicide-specific damage was found. In all other variants, a large number of damaged seedlings was observed; in variant 8, only 8% were classified as “undamaged” (“healthy”).

By the time of the second inventory, in the part of the plantation treated by Anchor-85 and its mixture with Mortyra the condition of pine seedlings remained the same as in the first inventory. A somewhat higher percentage of slightly damaged seedlings in the part of the plantation where Anchor-85 was used in its pure form can be explained by the stress from planting, since a visual examination of seedlings did not reveal any damage associated with the use of herbicides. In variant 4, the percentage of healthy seedlings increased slightly, but the increase from 36% to 42% could not be considered substantial. In all other variants, the condition of pine deteriorated significantly. In the variants where the mixture Mortyra, 25 g/ha + Deimos, 2 l/ha was used, the percentage of dead seedlings increased by more than four times since the first inventory, and in the variant with Magnum, 100 g / ha, by more than two times. In addition, in many variants of the experiment, the number of seedlings that suffered damage of varying degrees increased substantially. For example, in variant 7 after the first inventory, 34% of the seedlings were classified as healthy, and after the second inventory, only 9%. According to the results of the second survey, spruce seedlings in variants 1 and 2 continued to show high survival rates; 92% and 91% of the seedlings, respectively, were classified as healthy. In other variants of the experiment, their condition continued to deteriorate. After applying the mixtures Mortyra, 25 g/ha + Deimos, 2 l/ha and Mortyra, 25 g/ha + Deimos, 2 l/ha + Lontrel-300, 0.6 l/ha, the number of spruce seedlings classified as “undamaged”, decreased by 2–2.5 times compared with the results of the first inventory. On plots treated with Magnum (100 g/ha) and its
mixture with Deimos and Lontrel-300, the number of dead seedlings increased fourfold compared to the numbers recorded during the first inventory.

**Table 1.** The effect of herbicides on hogweed and other types of undesirable herbaceous vegetation in a field experiment carried out in a pine and spruce plantation (treatment carried out on May 7, 2020).

| Experimental variant | Survey date | Projective cover of herbaceous plants, % | Suppression efficiency for herbaceous plants, % |
|----------------------|-------------|------------------------------------------|------------------------------------------------|
|                      |             | total | Sosnovsky’s hogweed | dicotyledons | grasses | all species Sosnovsky’s hogweed | dicotyledons | grasses |
| 1. Anchor-85, 100 g/ha | 16.06.20   | 49    | 38 | 7 | 4 | 49 | 58 | -250 | 0 |
|                       | 31.07.20   | 17    | 14 | 3 | 0 | 83 | 84 | 0 | 100 |
|                       | 09.09.20   | 8     | 4  | 4 | 0 | 92 | 95 | -300 | 100 |
| 2. Anchor-85, 100 g/ha+ Mortyra, 25 g/ha | 16.06.20   | 42    | 36 | 3 | 3 | 57 | 60 | -50 | 25 |
|                       | 31.07.20   | 24    | 20 | 2 | 2 | 76 | 78 | 33 | 67 |
|                       | 09.09.20   | 15    | 10 | 2 | 3 | 84 | 89 | -100 | 50 |
| 3. Mortyra, 25 g/ha + Deimos 2 l/ha | 16.06.20   | 35    | 21 | 3 | 11 | 64 | 77 | -50 | -175 |
|                       | 31.07.20   | 67    | 23 | 3 | 41 | 32 | 74 | 0 | -583 |
|                       | 09.09.20   | 91    | 32 | 5 | 54 | 4 | 64 | -400 | -800 |
| 4. Mortyra, 25 g/ha + Lontrel-300, 0,6 l/ha | 16.06.20   | 54    | 29 | 6 | 19 | 44 | 68 | -200 | -375 |
|                       | 31.07.20   | 63    | 35 | 4 | 24 | 36 | 61 | -33 | -300 |
|                       | 09.09.20   | 90    | 52 | 2 | 36 | 5 | 41 | -100 | -500 |
| 5. Deimos 2 l/ha + Lontrel-300, 0,6 l/ha | 16.06.20   | 74    | 64 | 0 | 10 | 24 | 30 | 100 | -150 |
|                       | 31.07.20   | 83    | 71 | 2 | 10 | 15 | 20 | 33 | -67 |
|                       | 09.09.20   | 92    | 79 | 2 | 11 | 3 | 10 | -100 | -83 |
| 6. Mortyra, 25 g/ha + Deimos, 2 l/ha + Lontrel-300, 0,6 l/ha | 16.06.20   | 62    | 51 | 2 | 9 | 36 | 44 | 0 | -125 |
|                       | 31.07.20   | 75    | 50 | 9 | 16 | 23 | 44 | -200 | -167 |
|                       | 09.09.20   | 92    | 61 | 14 | 17 | 3 | 31 | -1300 | -183 |
| 7. Magnum, 25 g/ha + Deimos, 2 l/ha + Lontrel-300, 0,6 l/ha | 16.06.20   | 29    | 24 | 1 | 4 | 70 | 74 | 50 | 0 |
|                       | 31.07.20   | 47    | 21 | 5 | 21 | 52 | 76 | -67 | -250 |
|                       | 09.09.20   | 65    | 17 | 9 | 39 | 32 | 81 | -800 | -550 |
| 8. Magnum, 100 g/ha | 16.06.20   | 52    | 48 | 2 | 2 | 46 | 47 | 0 | 50 |
|                       | 31.07.20   | 40    | 23 | 3 | 14 | 59 | 74 | 0 | -133 |
|                       | 09.09.20   | 32    | 3  | 3 | 32 | 66 | 97 | -200 | -333 |
| 9. Nontreated check  | 16.06.20   | 97    | 91 | 2 | - | - | - | - | - |
|                       | 31.07.20   | 98    | 89 | 3 | - | - | - | - | - |
|                       | 09.09.20   | 95    | 88 | 1 | - | - | - | - | - |

The final count, carried out at the end of the growing season (September 9), four months after the chemical treatment, confirmed high rates of pine survival in variants 1 and 2. In variant 1, at the time
of inventory the number of healthy seedlings was the same as in the control. This was due to the fact, that some of the seedlings that experienced stress from planting moved from the category of "slightly damaged" to the category of "undamaged". On the plots where the mixture Mortyra, 25 g/ha + Lontrel-300, 0.6 l/ha was used, a significant number of seedlings were classified as healthy, due to the fact that some of the previously damaged specimens had recovered. However, this variant cannot be considered successful, since by this time 28% of the seedlings were classified as "dead". In other variants, the number of damaged and dead seedlings increased. For example, in variants 3 and 7, only 6% and 8% of pine seedlings were classified as healthy, respectively.

Table 2. Condition of pine and spruce seedlings by category (% of the total amount on the day of treatment) in a field experiment with herbicides (planting carried out on August 27, 2019; and treatment, on May 7, 2020).

| Experimental variant | Survey date | Pine | Spruce |
|----------------------|-------------|------|--------|
|                      |             | Undamaged | Slightly damaged | Severely damaged | Dead | Undamaged | Slightly damaged | Severely damaged | Dead |
| 1. Anchor-85, 100 g/ha | 16.06.20  | 80 | 13 | 6 | 1 | 92 | 4 | 2 | 2 |
|                      | 31.07.20  | 81 | 12 | 5 | 2 | 92 | 5 | 1 | 2 |
|                      | 09.09.20  | 90 | 5 | 1 | 4 | 93 | 4 | 0 | 3 |
| 2. Anchor-85, 100 g/ha + Mortyra, 25 g/ha | 16.06.20  | 91 | 4 | 3 | 2 | 93 | 4 | 3 | 0 |
|                      | 31.07.20  | 91 | 6 | 0 | 3 | 91 | 6 | 0 | 3 |
|                      | 09.09.20  | 92 | 5 | 0 | 3 | 90 | 5 | 1 | 4 |
| 3. Mortyra, 25 g/ha + Deimos, 2 l/ha | 16.06.20  | 26 | 34 | 34 | 6 | 19 | 10 | 63 | 8 |
|                      | 31.07.20  | 14 | 29 | 31 | 26 | 10 | 12 | 51 | 27 |
|                      | 09.09.20  | 6  | 36 | 23 | 35 | 4  | 14 | 40 | 42 |
| 4. Mortyra, 25 g/ha + Lontrel-300, 0.6 l/ha | 16.06.20  | 36 | 28 | 12 | 24 | 56 | 21 | 11 | 12 |
|                      | 31.07.20  | 42 | 27 | 7  | 24 | 59 | 22 | 7  | 12 |
|                      | 09.09.20  | 58 | 11 | 3  | 28 | 71 | 7  | 8  | 14 |
| 5. Deimos, 2 l/ha + Lontrel-300, 0.6 l/ha | 16.06.20  | 30 | 27 | 14 | 29 | 33 | 18 | 33 | 16 |
|                      | 31.07.20  | 14 | 18 | 37 | 31 | 23 | 24 | 35 | 18 |
|                      | 09.09.20  | 12 | 14 | 39 | 35 | 18 | 36 | 15 | 31 |
| 6. Mortyra, 25 g/ha + Deimos, 2 l/ha + Lontrel-300, 0.6 l/ha | 16.06.20  | 28 | 15 | 29 | 28 | 35 | 12 | 36 | 17 |
|                      | 31.07.20  | 13 | 22 | 34 | 31 | 14 | 40 | 25 | 21 |
|                      | 09.09.20  | 10 | 18 | 41 | 31 | 12 | 43 | 22 | 23 |
| 7. Magnum, 25 g/ha + Deimos, 2 l/ha + Lontrel-300, 0.6 l/ha | 16.06.20  | 34 | 18 | 20 | 28 | 15 | 63 | 19 | 3 |
|                      | 31.07.20  | 9  | 22 | 41 | 28 | 10 | 16 | 62 | 12 |
|                      | 09.09.20  | 8  | 14 | 48 | 30 | 6  | 12 | 64 | 18 |
| 8. Magnum, 100 g/ha | 16.06.20  | 76 | 12 | 6  | 6 | 8  | 19 | 64 | 9 |
|                      | 31.07.20  | 60 | 18 | 8  | 14 | 7  | 26 | 27 | 40 |
|                      | 09.09.20  | 52 | 23 | 9  | 16 | 8  | 17 | 21 | 54 |
| 9. Nontreated check | 16.06.20  | 90 | 6  | 0  | 4 | 94 | 4  | 0  | 2 |
|                      | 31.07.20  | 91 | 1  | 2  | 6 | 93 | 4  | 1  | 2 |
|                      | 09.09.20  | 90 | 2  | 2  | 6 | 93 | 4  | 1  | 2 |
Similarly to pine, spruce was in a good condition and had a high survival rate during the entire growing season only in variants 1 and 2 (table 2). By the time of the final inventory, in variant 4 the number of healthy seedlings increased slightly (up to 71%). In other variants, an increase in the number of damaged and dead specimens was observed during the growing season. The lowest rate were recorded in variant 3, where only 4% of spruce seedlings remained healthy, and 42% died.

4. Conclusion
We found that:
- In a field experiment carried out on a plot heavily overgrown with hogweed, in all experimental variants herbicides acted rather slowly.
- By the end of the growing season, the most effective suppression of hogweed (89–97%) was shown by herbicides in the following variants: Anchor-85, 100 g/ha; Anchor-85, 100 g/ha + Mortar, 25 g/ha; and Magnum, 100 g/ha. The least effective suppression (10–41%) was achieved in the variants with Mortyra, 25 g/ha + Lontrel-300, 0.6 l/ha; Deimos, 2 l/ha + Lontrel-300, 0.6 l/ha; Mortar, 25 g/ha + Deimos, 2 l/ha + Lontrel-300, 0.6 l/ha.
- In all variants of the experiment where Anchor-85 was not used an intensive growth of grasses was observed.
- Only in the variants with Anchor-85, 100 g/ha and Anchor-85, 100 g/ha + Mortyra, 25 g/ha, seedlings of both species were not damaged by herbicides. At the end of the season, after the treatment with Anchor-85 (100 g/ha), the survival rate of pine was 96%, and spruce, 97%. After the treatment with the mixture Anchor-85, 100 g/ha + Mortyra, 25 g/ha, the survival rate of pine was 97%, and spruce, 96%.
- In all other variants (3–8), conifers showed various degrees of damage, which indicates a low selectivity of the herbicides and makes them unpromising for further study and use in pine and spruce plantations.
- The herbicide Mortyra, in view of its relatively high selectivity for pine and spruce, is interesting for further study when caring for these species in plantations.

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