ISSN 2075-1117, Russian Journal of Biological Invasions, 2018, Vol. 9, No. 4, pp. 331–344. © Pleiades Publishing, Ltd., 2018.
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Control of Sosnowskyi's Hogweed (*Heracleum sosnowskyi* Manden.) Invasion on the Territory of the Russian Federation

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Received July 18, 2018

Abstract—The analysis of competitive documentation, contract documents, and technical assignments from 477 government contracts on control of the *Heracleum sosnowskyi* Manden. invasion carried out in 18 Russian regions from 2011 to 2017 is presented. According to the data posted on the official website of the Unified Information System in the field of procurement, 95% of the contracts were signed to destroy *H. sosnowskyi* plants, and the rest were connected with the determination of invaded areas, the development of methods for their elimination, and the supervision of the works carried out. The stands of *H. sosnowskyi* were mapped on an area of 169 000 ha and were destroyed on an area of 18 000 ha. The total cost of the contracts amounted to 314 million rubles. The mowing cost of *H. sosnowskyi* was about 30 000 rubles/ha; the cost for treating thickets with herbicides was 14 500 rubles/ha (median values). The median cost of mapping the *H. sosnowskyi* stands was about 370 rubles/ha. The high variability of the cost of the work was revealed for the contracts with treatment of areas less than 5 ha. The largest scale works on *H. sosnowskyi* eradication were conducted in the Leningrad, Moscow, and Vologda oblasts, where the funds for invasion control were reserved in the regional budgets. In the context of limited funding, systemic work on *H. sosnowskyi* thicket control should be initiated with a pilot project on the territory of one or two settlements, and then this experience should be extended to a larger region. Data on 477 government contracts used in the paper are freely available on the server Zenodo.

Keywords: Heracleum sosnowskyi, invasion, plant thicket eradication, mowing, herbicides, mapping, monitoring, contracts, eradication costs

DOI: 10.1134/S2075111718040045

INTRODUCTION

The invasion of alien plants and animals into new territories followed by an outbreak of their numbers (biological invasions) is attributed to the actual environmental and socioeconomic problems of our time. At the beginning of the 21st century, the potential annual damage from biological invasions on a global scale was estimated at 1.4 trillion USD (Simberloff, 2008; Kettunen et al., 2009; Pimentel, 2011; Bradshaw et al., 2016).

The specificity of agriculture and trade and the development of transport routes significantly affect the risks of individual countries from the expansion of alien species and the role of regions as sources of invasions. Along with significant economic damage, invasions lead to a decrease in biological diversity and pose a threat to food security, which underscores the need for international cooperation in developing and implementing measures to regulate intruders (Paini et al., 2016; Pratt et al., 2017). The calculation of labor and material costs and the development of effective methods for managing invasions are limited by the lack of accurate data in the implementation of measures to reduce their numbers (Wadsworth et al., 2000; Hulme, 2006, 2009; Panetta and Lawes, 2007; Simberloff, 2008; Gren et al., 2009; Pyšek and Richardson, 2010; Pluess et al., 2012; Pergl et al., 2016; Rajmis et al., 2016).

Recently, there has been some progress in the development of fundamental and applied research on biological invasions in Russia (Dgebuadze, 2014), but the solution of practical problems is hampered by the lack of a national strategy to prevent and eliminate the consequences of alien invasions (Senator and Rosenberg, 2016). In our country, the development of regulatory legal acts based on the analysis of phytosanitary risk and potential economic and environmental damage is applied to quarantine plant species (Karmazin, 2013). Potential damage from quarantine pests in Russia is estimated at 600 billion rubles per year, up to 40% of which account for the quarantine species of weeds (Magomedov, 2013; Senator and Rosenberg, 2016).

Some invasive species, for example, a group of giant hogweeds (*Heracleum mantegazzianum*, *H. sosnowskyi*, and *H. persicum*), are also characterized by a high socioeconomic and environmental impact (Nielsen et al., 2005; *Ecology and Management*..., 2007; Dergunova et al., 2012; Pergl et al., 2016; Rajmis et al., 2016). On the territory of Russia, *Heracleum sosnows-*

kyi Manden. was the most widespread (Ozerova et al., 2017; Chadin et al., 2017). In the middle of the 20th century, this Caucasian mountain-forest subalpine meadow species was cultivated in the European part of the Soviet Union and Eastern Europe as a forage crop (Satsyperova, 1984). At the end of the 20th century, *H. sosnowskyi* plants began to spread intensely beyond the boundaries of agricultural lands owing to the capacity for self-sowing. The success of the invasion was caused by the high growth rates of plants, the formation of a thick canopy of thickets, high seed productivity, and the presence of a renewed bank of buds buried 10–15 cm in the soil (*Ecology and Management...*, 2007; Dalke et al., 2015; Panasenko, 2017). For humans, the plant is dangerous, because it is capable of causing an acute phototoxic reaction and burns (Karimian-Teherani et al., 2007; Jakubowicz et al., 2012).

About 20 years have passed between the visible penetration of *H. sosnowskyi* into the territory of populated areas (the 1990s) and the measures of the authorities to destroy it. In 2012, *H. sosnowskyi* was removed from the State Register of Breeding Achievements. In 2015, its green mass and seeds were excluded from the All-Russian Classifier of Products (OK 005-93, Order of the Federal Agency for Technical Regulation and Metrology dated October 22, 2014, no. 1388-st, date of introduction January 1, 2015), and the species was added to the Sector Classifier of Weed Plants of the Russian Federation (supplement no. 384021310). Since 2011, state contracts have been signed to carry out measures to eliminate unwanted thickets of *H. sosnowskyi* in Russia (Procurement Portal..., 2018).

Of topicality are questions on the development of methods for destroying and assessing the effectiveness of measures on the elimination of *H. sosnowskyi* plants in regions and individual settlements (On the Regional Budget..., 2016; On the State Support..., 2016; On the State Support..., 2017; On Alteration the State Program..., 2017; Dalke et al., 2018). Analysis of procurement activities of municipal institutions aimed at eliminating *H. sosnowskyi* will make it possible to assess the cost, scale, and dynamics of the work performed in Russia. On the basis of the data obtained and practical experience, it is possible to propose a strategy for eradicating undesirable thickets of giant hogweed. The study was aimed at a comprehensive assessment of measures to eradicate undesirable thickets of *H. sosnowskyi* based on the analysis of procurement activities in the regions of the Russian Federation.

MATERIALS AND METHODS

Information on procurement related to the implementation of measures to eliminate *H. sosnowskyi* thickets was obtained on the official website of the Unified Information System in the field of procurement of the Russian Federation (Procurement Portal..., 2018). The search of applications was performed using the keyword "hogweed" together with the following conditions: all forms of words; laws—no. 44-FZ, no. 223-FZ, no. 94-FZ; currency—Russian ruble; procurement phase—application submission, commission work, procurement completed, purchase canceled. All keywords were entered in Russian.

As a result of the search on the status as of November 1, 2017, 568 CSV records were obtained which contained the following requisites: the law; purchase registration number; the way to determine the supplier (procurement location); name of purchase; purchase identification code; lot number; name of the lot; initial (maximum) price of the contract; currency; classification by OKDP; classification according to the All-Russian classifier of economic activities and products (ACEAP); classification according to the ACEAP2; name of the customer; date of placement; update date; stage of purchase; features of placing an order; date of the beginning of submission of applications; application submission deadline.

The analysis of the documentation of each purchase made it possible to determine the maximum possible value of contracts and the actual value of the contracts concluded; to determine the region of the Russian Federation and settlements where the purchases were made, the area where the work was planned, and the method of eradication of *H. sosnowskyi* thickets; and to calculate the cost of work per one hectare.

Duplicates, records of contracts that were not concluded or completed, and purchases with missing records of the area of the processed sites were deleted from the general data set. After selection, the sample size was reduced to 477 contracts. For the analysis of the data, descriptive statistics and regression analysis were used. The parameters "initial contract price," "area," and "protocol price per area" according to the Shapiro–Wilk criterion had a distribution different from normal, so the median, the range, and the minimum and the maximum value were used to describe the sampling. The set of data on procurement for the elimination of *H. sosnowskyi* thickets used in this study is placed in the repository Zenodo (2018).

RESULTS

According to the official website of the Unified Information System in the field of procurement of the Russian Federation in the period from 2011 to 2017, works on eradication of *H. sosnowskyi* thickets were carried out in 18 regions of the Russian Federation: Vladimir, Vologda, Ivanovo, Kaliningrad, Kirov, Kostroma, Leningrad, Moscow, Murmansk, Nizhny Novgorod, Novgorod, Perm, Pskov, Sverdlovsk, Tver, Tula, and Yaroslavl oblasts and in the Komi Republic. During this period, 477 contracts for various types of work were concluded (Procurement Portal..., 2018). On the basis of the analysis of the competitive documentation, the works performed were divided into two

Table 1. Descriptive statistics of contracts for eliminating and mapping the *Heracleum sosnowskyi* plant thickets in the Russian Federation (2011–2017) according to the official website of the Unified Information System in the field of procurement of the Russian Federation (Procurement Portal..., 2018)

Indicator	Contract initial price, rubles	Protocol price, rubles	Area, ha	Protocol price calculated for area, rubles/ha
All types of work (group 1 + group 2)*				
Size of sampling	477	477	473	473
Mean value	925852	657740	395	45597
Mean error	102989	60620	260	5109
Median	365000	249036	14	17598
Minimum	21100	14957	0.1	19
Maximum	30886071	10554688	121229	1105584
Range	30864971	10539731	121229	1105565
Sum	441631170	313741982	186623	21567288
Group 1				
Size of sampling	454	454	454	454
Mean value	936089	665466	39	47460
Mean error	107554	63398	4	5305
Median	370487	245893	13	18479
Minimum	25262	18618	0.1	653
Maximum	30886071	10554688	794	1105584
Range	30860809	10536070	794	1104931
Sum	424984210	302121363	17811	21546785
Group 2				
Size of sampling	23	23	19	19
Mean value	723781	505244	8885	1079
Mean error	242305	122509	6492	446
Median	363055	356409	737	371
Minimum	21100	14957	2	19
Maximum	5000000	2300000	121229	7478
Range	4978899	2285043	121227	7459
Sum	16646960	11620619	168812	20503

Protocol price—price after summarizing and concluding a contract with the service provider; area—the area of the territory where the work was carried out in accordance with the terms of reference.

* Group 1—elimination of *H. sosnowskyi* thickets by chemical and mechanical methods; group 2—work on inspecting the territory and mapping the thickets, development of methods for their destruction, and monitoring of work performed.

groups (Table 1). The first group (95% of the total amount) included contracts for the destruction of plants (hereinafter, group 1), the second group (5%) included contracts related to the identification of the area of thickets, the development of methods for their destruction, and monitoring of work (hereinafter, group 2).

The groups differed significantly in the area of work: group 1—17800 ha; group 2—168800 ha. The range of areas between individual contracts reached several orders of magnitude (from 0.1 to 794 ha in group 1 and from 2 to 121229 ha in group 2). The median value of the area in group 1 was 13 ha; in group 2, it was 737 ha. The initial price of the contracts of the two groups totaled about 442 million rubles. After the auctions, the total value of contracts fell by 30% and amounted to 302 million rubles for group 1 and 12 million rubles for group 2. In four contracts of group 2, there were no data on the area of work sites.

The cost of performing work in terms of unit of area varied greatly. For group 1, the median cost of the works was 18500 rubles/ha, while the range exceeded 1 million rubles/ha (Table 1). The greatest variability of the cost of works (coefficient of variation of 145%) is noted in contracts with the area of the cultivated territory less than 5 ha.

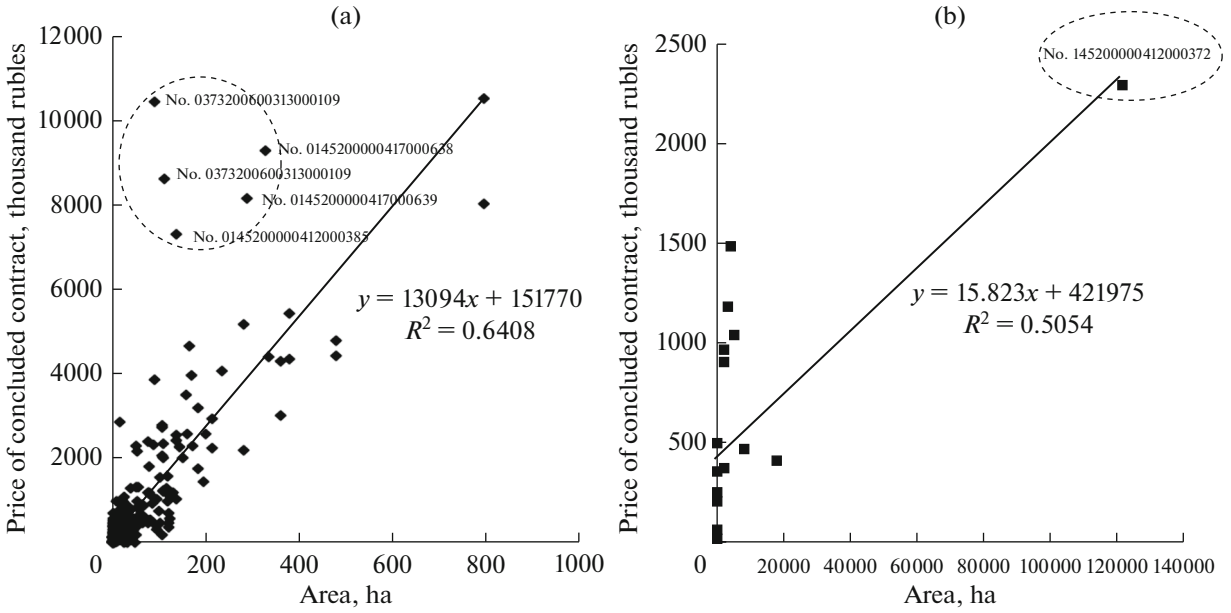

Fig. 1. Dependence of the prices of concluded contracts on the territory where the elimination ((a) group 1, 454 contracts) and mapping and monitoring ((b) group 2, 19 contracts) of *Heracleum sosnowskyi* plants were conducted on the territory of Russia (2011–2017). Dotted lines indicate contracts that deviate significantly from the median values of the sampling.

The cost of performing work in group 2 also varied significantly: at a median value of 400 rubles/ha, the sample spread was 7500 rubles/ha (Table 1).

The growth in the size of the areas where the contracts for the destruction of thickets of hogweed or cartography were executed followed the increase in the prices of contracts (Fig. 1). Between these indicators, a close positive correlation was established: for group 1 contracts, the Spearman correlation coefficient R was 0.69 ($P < 0.001$), and for group 2, it was 0.83 ($P < 0.001$). The price of a signed contract was linear, depending on the area of the territory where work to destroy or map the thickets was carried out (Fig. 1). Five contracts executed on the territory of Moscow and Leningrad oblasts significantly exceeded the median value of the cost of sampling and the limits of the confidence interval of 95% (Fig. 1a). The linear dependence of the price of mapping work on the area of the plots was determined by the indicators of contract no. 0145200000412000372. According to its terms of reference, the area of monitoring the *H. sosnowskyi* thickets in Leningrad oblast amounted to 121229 ha, and the cost of works was 2299999 rubles. (Fig. 1b).

In 309 contracts of group 1, plants were treated with herbicides; mowing was used in 191 contracts; mechanized tillage was used in 25 contracts. Mowing of *H. sosnowskyi* thickets, together with other methods of their elimination, was carried out with the fulfillment of 64 contracts. Treatment with herbicides without additional control measures was carried out in 263 contracts. Mechanized soil cultivation under *H. sosnowskyi* plants was performed either in combination with mowing or together with the treatment of plants with herbicides. The terms of reference of 13 contracts of group 2 included works on mapping of thickets; 8 contracts were associated with monitoring the results of the work performed.

Analysis of group 1 contracts, in which only one method of plant eradication was provided, made it possible to compare the cost of chemical treatment and mowing of *H. sosnowskyi* thickets (Table 2). The median cost of mowing was about 30000 rubles/ha, which was two times higher than the cost of treating the thickets with herbicides.

During the period from 2011 to 2017, the number of annual contracts for the destruction of *H. sosnowskyi* increased fivefold (to 131 contracts per year), and the number of mapping and monitoring activities remained approximately the same and did not exceed five contracts per year (Fig. 2). The total price of contracts to destroy hogweed significantly varied from 10 to 70 million rubles/year without an explicitly expressed trend (Fig. 2). The median cost of performing work under the contracts of group 1 per unit area had a clear tendency to decrease and reached 15600 rubles/ha in 2017 (Fig. 3). The annual costs for mapping and monitoring did not exceed 4 million rubles (Fig. 2). Over a period of seven years, the total area of sites on which works to eliminate the thickets of plants was carried out increased 6-fold and was 4000 ha in 2017. On the contrary, the total area of sites where mapping and monitoring of *H. sosnowskyi* thickets was performed was characterized by negative dynamics (Fig. 4).

Table 2. Descriptive statistics of the cost of works on the elimination of *Heracleum sosnowskyi* plants per unit area of sites, rubles/ha (2011–2017)*

Indicator	Chemical treatment	Mowing	Mapping	Monitoring
Size of sampling	263	127	11	8
Mean value	25064	67873	1161	966
Mean error	4589	10749	699	562
Median	14486	29767	371	380
Minimum	653	1134	19	191
Maximum	1105584	822222	7478	4587

* The groups of contracts where only one type of work was provided are described.

From 2011 to 2017, the median value of one contract in group 1 changed insignificantly, except for 2013, when 44 contracts for a total of 67 million rubles were completed in Leningrad and Moscow oblasts (Fig. 5a). In group 2, the median value of one contract amounted to 356000 rubles. Over the years, the value of this indicator varied unevenly (Fig. 5).

The study of the frequency of use of various methods of elimination shows that, during the period from 2011 to 2017, the number of contracts involving the use of chemical methods for the elimination of *H. sosnowskyi* increased by an order of magnitude, and the frequency of application of mechanical methods (mowing, plowing) changed little (Fig. 6). The number of contracts of group 2 performed during the year varied from one to five without pronounced dynamics.

Analysis of the available data has made it possible to compile a cost map for the eradication of the *H. sosnowskyi* thickets in the regions of Russia (Fig. 7). Leningrad, Moscow and Vologda oblasts, which account for 90% of all processed areas and 80% of all costs, lead in the implementation of contracts (Figs. 8a, 8b). The median cost of works per unit area of thickets in these regions was close to the median of the general sampling (25817 rubles/ha). The greatest cost of treating a unit of *H. sosnowskyi* thickets (90000–150000 rubles/ha) was recorded in Murmansk oblast, Perm krai, and Ivanovo oblast (Fig. 8c). In Tula, Yaroslavl, and Sverdlovsk oblasts, similar work was estimated at 8000–12000 rubles/ha.

The analysis of contracts made it possible to compare the costs in the regions using different methods for the destruction of *H. sosnowskyi* thickets. For this purpose, samplings of contracts in which the plants were eliminated exclusively by mowing (127 contracts) or only using herbicides (263 contracts) were used. The regions of the Russian Federation were ranked in descending order of costs for mowing *H. sosnowskyi*. The top three included Moscow and Vologda oblasts and the Komi Republic (Table 3). The median cost of mowing a hectare of *H. sosnowskyi* plants in Murmansk, Leningrad, and Ivanovo oblasts was 4–9 times higher than the median value (30000 rubles/ha) of the entire sampling (Table 3).

Chemical methods of elimination were most intensely used in Leningrad, Moscow, and Tula oblasts,

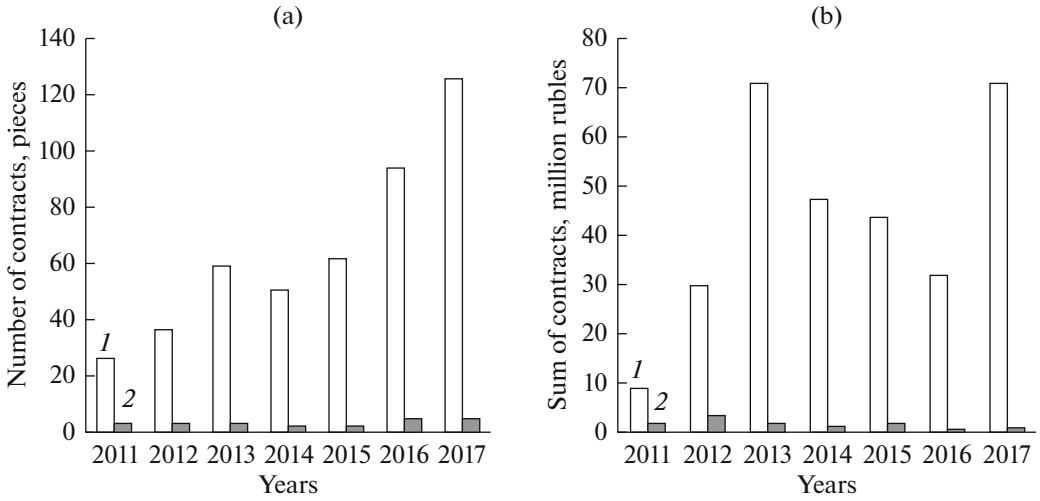

Fig. 2. Number (a) and total price (b) of contracts concluded for eliminating (*1*—group 1, 454 contracts) and mapping and monitoring (*2*—group 2, 23 contracts) of *Heracleum sosnowskyi* plants on the territory of Russia (2011–2017).

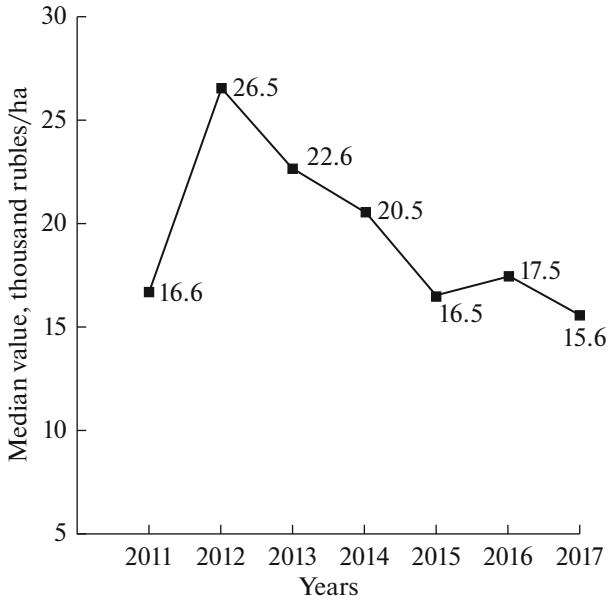

Fig. 3. Dynamics of the median price of contracts for eliminating *Heracleum sosnowskyi* plants calculated per unit of land area in Russia (454 contracts, 2011–2017).

where 14000 ha of *H. sosnowskyi* thickets were treated (Table 4). The greatest costs of using herbicides per hectare were noted in Murmansk oblast (150000 rubles/ha); the lowest costs were in Tula oblast (11000 rubles/ha).

DISCUSSION

The intentional introduction of *H. sosnowskyi*, which led to the local spread of the plants on the territory of the farms in certain regions and then to the uncontrolled expansion, was of primary importance in the formation of the modern secondary range of the species in Russia (Ozerova and Krivosheina, 2018). *H. sosnowskyi* running wild in the European part of Russia began in the 1980s; the first finds of the species outside agrocoenoses in Siberia were noted only in 2005 (Ebel et al., 2018). Currently, *H. sosnowskyi* plants are noted in 54 regions of the Russian Federation (Chadin et al., 2017).

Systematic government procurement for the implementation of contracts on the elimination of undesirable thickets of *H. sosnowskyi* have been carried out since 2011. Between 2011 and 2017, such contracts were carried out in 18 regions of Russia (Fig. 7) in which the species had rapid propagation (Ozerova and Krivosheina, 2018). In the next decade, we can assume an active infestation of *H. sosnowskyi* in the territory of Siberia. At the moment, the situation is extremely favorable for taking preventive measures and suppressing single foci of the spread of *H. sosnowskyi* (Ebel et al., 2018).

In world practice, route studies, remote sensing data of the Earth, modeling of the distribution boundaries (*Heracleum*..., 2009; Pyšek et al., 2012), and specialized Internet resources for collecting data on places of plant growth are used to estimate the secondary range of giant hogweed (About Cow-Parsnip, 2018a).

Assessment of the extent and limits of *H. sosnowskyi* invasion within the territory of the Russian Federation was carried out in a number of studies (Afonin et al., 2017; Ozerova et al., 2017; Panasenko, 2017; Chadin et al., 2017; Dalke et al., 2018; Ozerova and Krivosheina, 2018). According to the data provided in the documentation of the executed contracts, about 190000 ha overgrowing with *H. sosnowskyi* plants were found on the territory of Russia (Table 1). The bulk of the surveys were carried out in Leningrad oblast. In most cases, the areas of cartographic plots did not exceed 5000 ha (Fig. 1b), except for contract

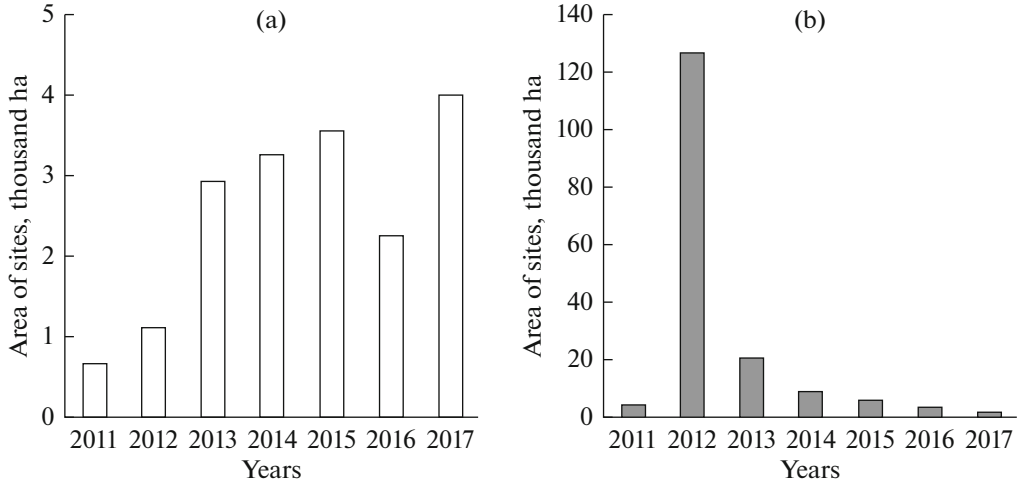

Fig. 4. Areas of work for eliminating ((a) 454 contracts) and mapping and monitoring ((b) 19 contracts) of *Heracleum sosnowskyi* thickets on the territory of Russia (2011–2017).

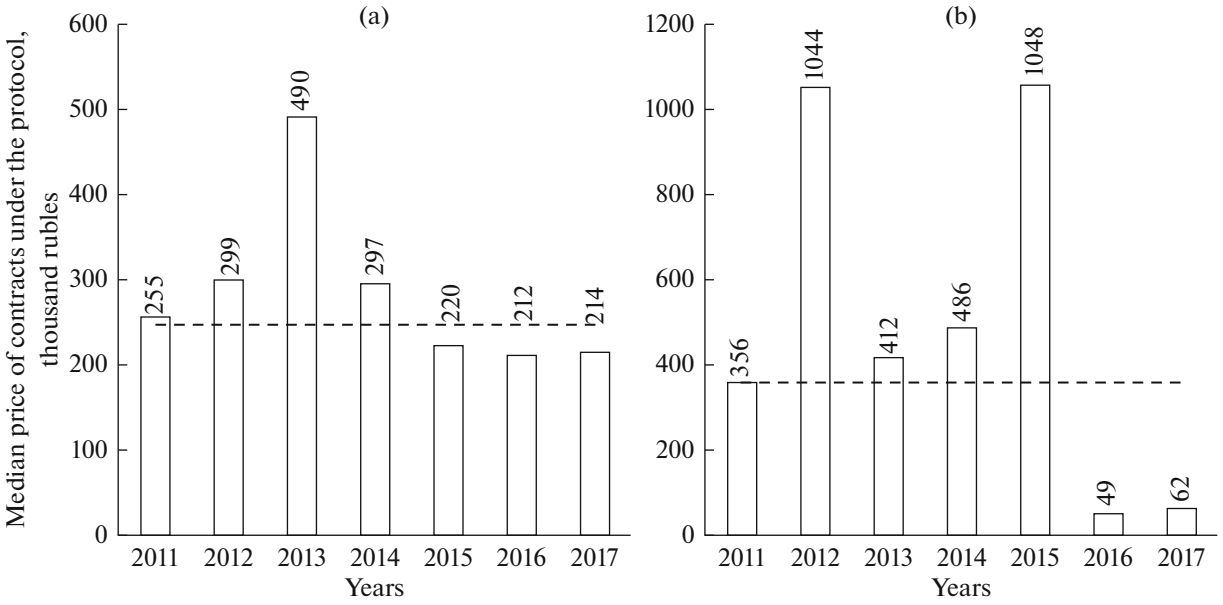

Fig. 5. Dynamics of the prices of works for eliminating ((a) group 1, 454 contracts) and mapping and monitoring ((b) group 2, 23 contracts) of *Heracleum sosnowskyi* thickets on the territory of Russia (2011–2017). Dotted line—the median value for the entire sampling.

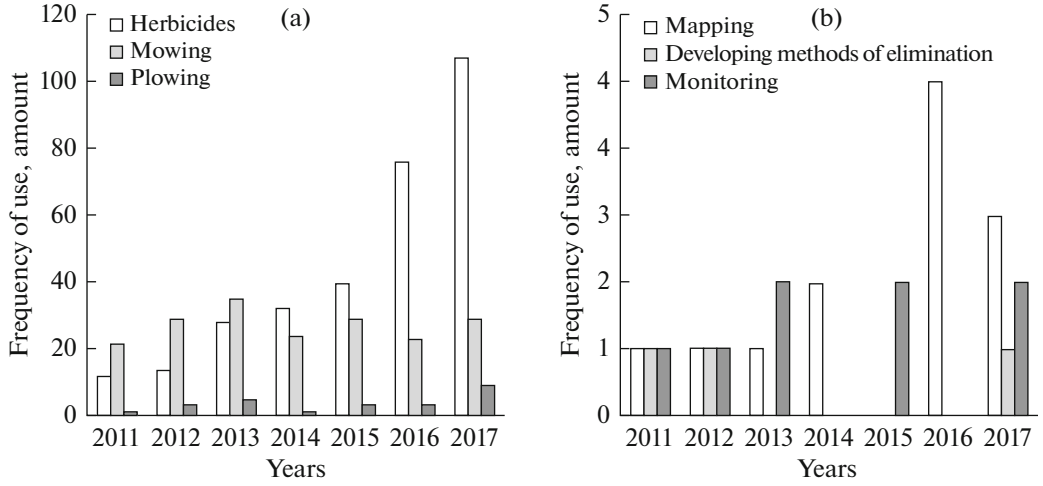

Fig. 6. Frequency of use of different methods for eliminating *Heracleum sosnowskyi* thickets ((a) 454 contracts); mapping, developing methods, and monitoring the work ((b) 23 contracts) on the territory of Russia (2011–2017).

no. 0145200000412000372 on the monitoring of *H. sosnowskyi* undergrowth over an area of more than 120000 ha. The median cost of implementation of works on mapping the thickets of plants amounted to about 370 rubles per 1 ha of the mapped territory (Table 1).

Publications of accurate map data of places of *H. sosnowskyi* on the territory of Russia are limited. About 1300 ha of *H. sosnowskyi* thickets were found in the urban district of Domodedovo, Moscow oblast (Identification and Delineation..., 2014). In 2014, about 8000 ha of thickets were mapped in Moscow oblast (contract no. 0348300277514000038). Later, the total area of *H. sosnowskyi* invasion in Moscow and Moscow oblast was estimatd at 16500 ha (Myshlyakov and Artemova, 2017). On the territory of Syktyvkar (Komi Republic), mapping was carried out and the geographical coordinates of 283 ha of *H. sosnowskyi* thickets were determined (Dalke et al., 2018).

Since 2015, the species *H. sosnowskyi* has been included in the Sector Classifier of Weed Plants, but the damage or costs for its elimination in Russia until recently have not been determined. The classification of *H. sosnowskyi* as a weed plant made it possible to

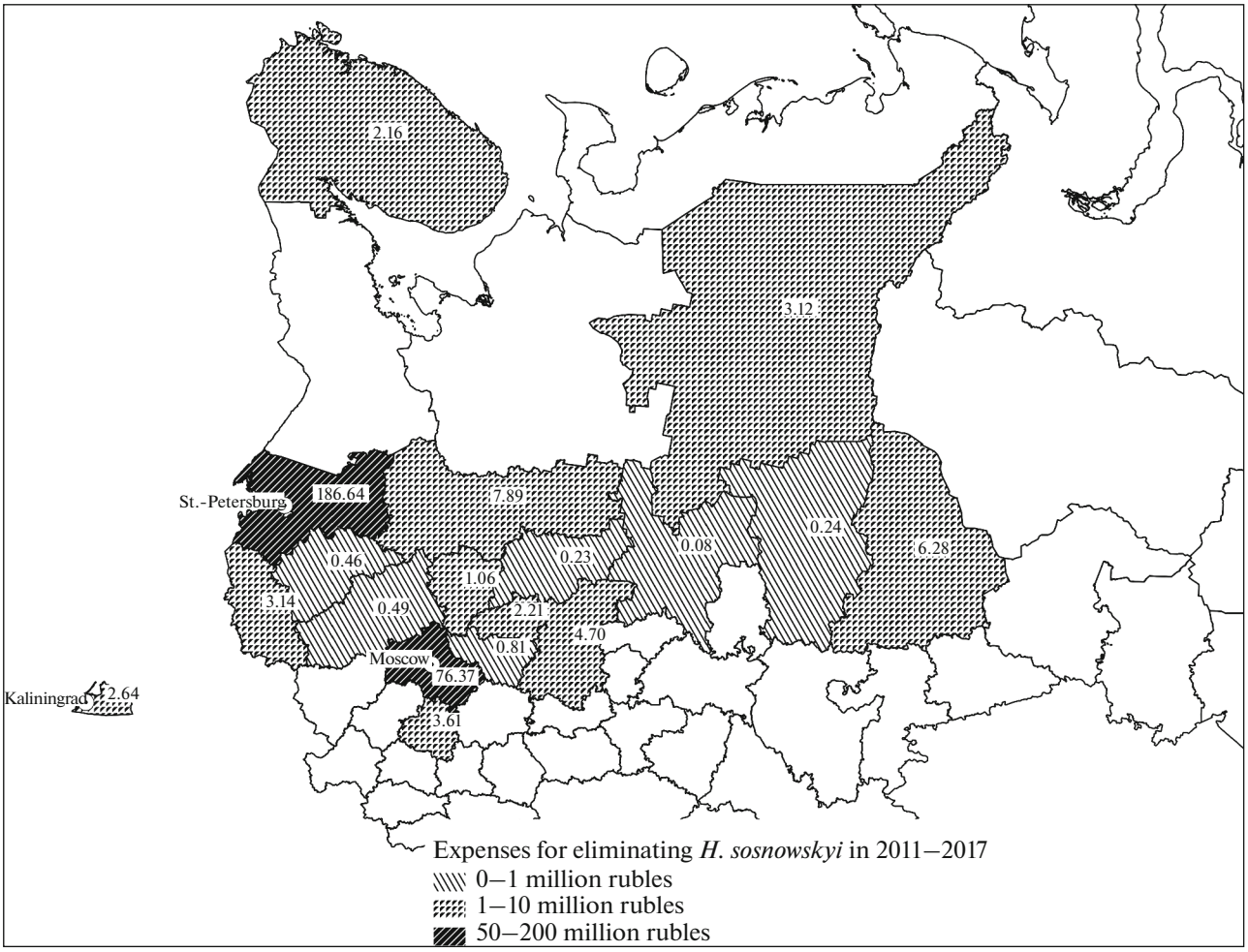

Fig. 7. Expenses for eliminating *Heracleum sosnowskyi* thickets in the regions of Russia in the period of 2011–2017. ((Procurement Portal..., 2018), 454 contracts for eliminating plants using mechanical and chemical methods.) The boundaries of the regions are given according to the data of the Rosreestr and GIS-Lab.info.

allocate budget funds for eliminating the thickets of the species in Leningrad, Moscow, Vologda, Kirov, and Kaliningrad oblasts (About Cow-Parsnip, 2018b). State support positively influenced the total number and dynamics of activities in Leningrad and Moscow oblasts, where, according to the contracts from 2011 to 2017, 15700 ha were treated, which amounted to 88% of the total area of work on elimination of *H. sosnowskyi* in Russia (Fig. 8a).

The cost of *H. sosnowskyi* elimination depended on the method of treatment of the territory (mowing, chemical treatment, plowing) and varied significantly in different regions. In recent years, the median cost of destroying the thickets in terms of the area of work performed has stabilized at the level of 16000 rubles/ha (Fig. 3). In most regions of the Russian Federation, these costs corresponded to the median of the general population (Fig. 8c). It is interesting to note that the greatest variability in the cost of work was noted in the cases where the area of the thickets did not exceed 5 ha (coefficient of variation 145%). With the increase in the area of work, their relative value in the calculation for the area of the site was reduced. High variability of the cost of works to control the invasion of giant hogweed is typical of other countries. In Denmark, the average annual cost of invasive control amounted to 10000 Euros with a span from 50 to 60000 Euros between municipalities. In Scotland, the destruction of thickets of giant hogweed in an area less than 1 ha is estimated from 1 to 30 working hours; in areas from 9 to 19 ha, the working time varied from 1600 to 10800 h (*Ecology and Management*..., 2007).

According to our data, the annual costs for the elimination of *H. sosnowskyi* in Russia amounted to 10 to 70 million rubles (Fig. 2), or from 0.07 to 0.5 rubles per capita. In Sweden, such expenses were significantly higher and reached 73 million SEK per year, or 8 SEK (equivalent to 30 rubles) per person (Gren et al., 2009). In Germany, the cost of controlling hogweed infestation ranged from 0.0005 (Rajmish et al., 2016)

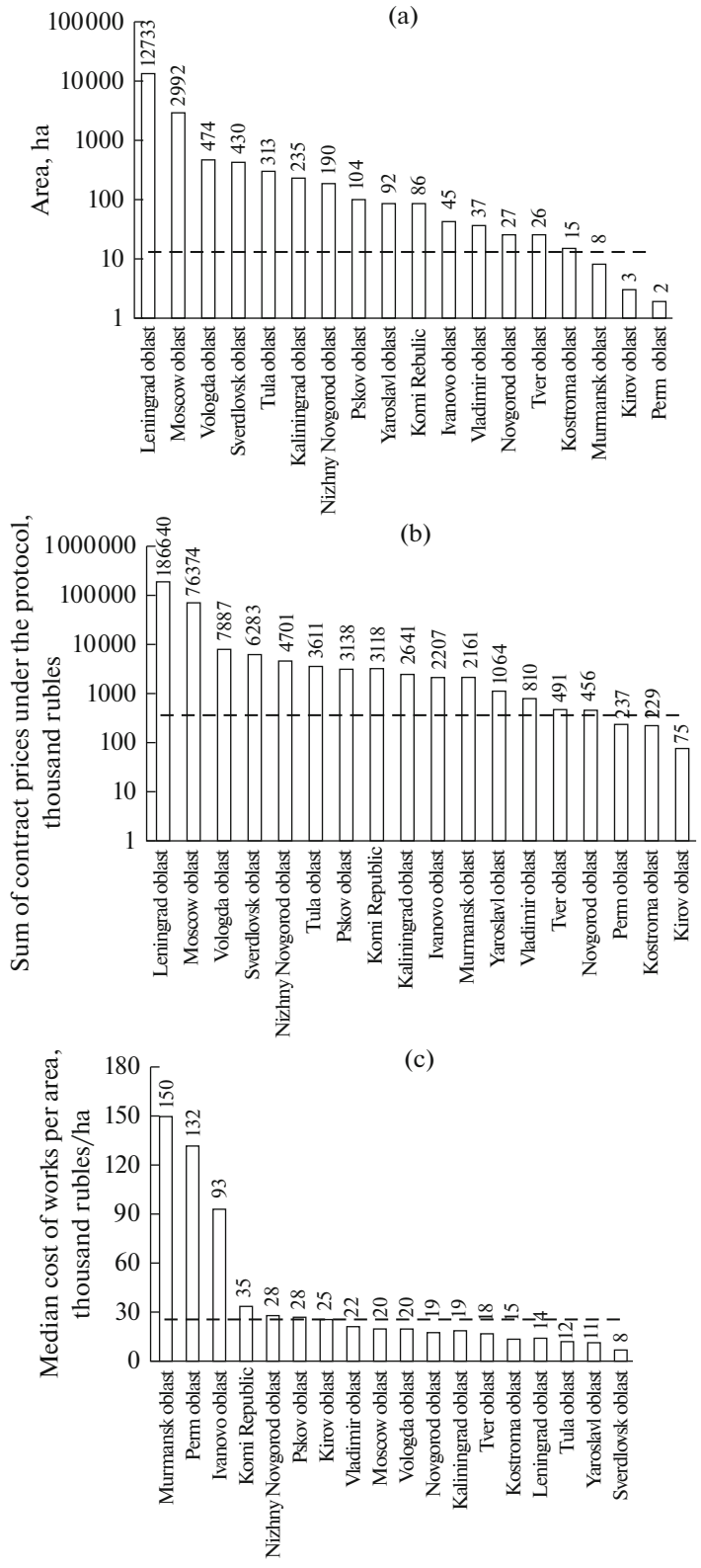

Fig. 8. Areas for elimination of *Heracleum sosnowskyi* thickets (a), sum of contract prices (b), and cost of works per unit area of thickets (c) in the regions of Russia for the period of 2011–2017 (454 contracts for eliminating plants using mechanical and chemical methods). Dotted line—the median value for the entire sampling.

Table 3. Expenses and costs of work on eliminating tickets of *Heracleum sosnowskyi* using mowing in the regions of the Russian Federation (127 contracts,* 2011–2017)

Region of the Russian Federation	Sum of contracts, rubles	Area of sites, ha	Cost of works calculated per area, rubles/ha
Moscow oblast	46426773	1212.1	38301
Vologda oblast	3212032	220.1	14597
Komi Republic	2778457	74.2	37435
Murmansk oblast	1384451	5.6	249451
Sverdlovsk oblast	951498	119.3	7978
Nizhny Novgorod oblast	837760	21.4	39111
Leningrad oblast	687700	2.5	279451
Pskov oblast	491155	16.5	29767
Ivanovo oblast	471688	3.6	131756
Kaliningrad oblast	210576	105.0	2005
Tula oblast	196590	2.7	73906
Kirov oblast	30000	0.3	100000

* Contracts where only the mowing of plants was used.

Table 4. Expenses and costs of work on eliminating tickets of *Heracleum sosnowskyi* using herbicides in the regions of the Russian Federation (263 contracts,* 2011–2017)

Region of the Russian Federation	Sum of contracts, rubles	Area of sites, ha	Cost of works calculated per area, rubles/ha
Leningrad oblast	171929845	12042.1	14277
Moscow oblast	19148824	1504.7	12726
Tula oblast	3182810	295.0	10791
Vologda oblast	3026082	115.0	26324
Nizhny Novgorod oblast	1937471	93.0	20824
Ivanovo oblast	1501811	38.9	38617
Yaroslavl oblast	1063855	92.0	11564
Vladimir oblast	810000	37.0	21892
Tver oblast	490640	26.0	18893
Kaliningrad oblast	370000	16.7	22103
Komi Republic	339198	12.1	27941
Pskov oblast	236446	10.5	22519
Kostroma oblast	229450	15.2	15083
Murmansk oblast	180000	1.2	150000
Novgorod oblast	151007	10.1	14907
Kirov oblast	18618	1.5	12412

* Contracts where only the chemical treatment of plants was used.

to 0.02 Euros (Gren et al., 2009) (equal to 0.04–0.5 rubles) per capita, which is equivalent to the expenses in the Russian Federation.

According to general expenses, the greater part of the work on *H. sosnowskyi* elimination was carried out in the Central and Northwestern Federal Districts of Russia (Fig. 7). In Moscow, Leningrad and Vologda oblasts, about 16000 ha of thickets of plants were destroyed (Fig. 8). As was noted, the most common methods of *H. sosnowskyi* elimination include mowing and the use of herbicides. Analysis of the documentation of concluded contracts showed that, in the period from 2011 to 2017, herbicides were used on a much larger area than mowing (Tables 3 and 4), and the cost of the chemical method was half of the cost of mowing (Table 2). The cost of mowing of *H. sosnowskyi* plants

was comparable to the cost of similar works in Estonia (about 650 USD/ha). It should be noted that, in Estonia, about 30% (609 ha) of undesirable thickets of hogweed were eliminated (Nielsen et al., 2005), but later new invasive sites were discovered, and the plant control program was found to be ineffective.

According to our data, mowing cannot be regarded as an independent and meaningful method of *H. sosnowskyi* elimination. The success of *H. sosnowskyi* invasion is associated with its biological characteristics at the organismic and cenotic levels: high growth rates, formation of thick canopy, high seed productivity and annual renewal of the seed bank, high protection of renewal buds from mechanical damage (*Ecology and Management*..., 2007; Dalke et al., 2015; Maslova et al., 2018). Thickets of hogweed effectively resist the mowing of the aboveground part. Underestimation of this information and a certain inertness in decision making still lead to widespread use of the mowing method to eliminate *H. sosnowskyi*. Nevertheless, in recent years, there has been a gradual decline in the use of mowing for the destruction of *H. sosnowskyi* and a significant increase in the number of contracts providing the use of herbicides (Fig. 6) against a background of a multiple increase in the total number of concluded contracts (Fig. 2). Grants for reimbursement of costs on eliminating *H. sosnowskyi* are provided to the agricultural producers of Leningrad and Kaliningrad oblasts only if they use the effective chemical methods of elimination (On the Regional Budget..., 2016). It is proposed to consider chemical methods to prevent seed formation and spread of new seeds of giant hogweed as a first step in plant elimination strategies. After chemical treatment, it is proposed to form a replacement crop and use mechanical and combined methods of elimination (*Ecology and Management*..., 2007).

At the moment, it is impossible to completely eliminate undesirable thickets of giant hogweed, so it is necessary to develop options for managing these species and to limit the expansion of their secondary range (*Ecology and Management*..., 2007; Pyšek et al., 2012; Pergl et al., 2016; Rajmis et al., 2016), as well as to draw attention to international cooperation on biological intrusions (Paini et al., 2016; Pratt et al., 2017). According to a number of authors, inadequate coordination between legislation and research and management practices hinders effective counteraction of invasive species in different countries (Pergl et al., 2016). Management of invasions should include a mechanism for early detection and decision making on their elimination, sufficient quantity and efficient allocation of resources to perform the required types of work, and supervision. Elimination should be carried out at the earliest stage of the invasion, when the volume of invasion is relatively small (Wadsworth et al., 2000; Ebel et al., 2018). The condition for successful work is to estimate the frequency of occurrence of new invasions and determine their exact boundaries. For example, in order to successfully control the branched broomrape invasion (*Orobanche ramosa* L.) in Australia, the annual number of new foci should not exceed 50, otherwise the invasion progresses (Panetta and Lawes, 2007). Studying the biology of invasive plant species makes it possible to predict their distribution (Dalke et al., 2015; Chadin et al., 2017) and to improve the quality of management of invasions (Simberloff, 2008). The modeling of biological invasion management strategies shows that successful control of the population of giant hogweed on a regional scale is possible only on the basis of results of studies on spatial distribution of plants, population structure, ontogenesis, and ecological and physiological characteristics (Wadsworth et al., 2000; Dalke et al., 2015; Chadin et al., 2017). On the other hand, a meta-analysis of 136 campaigns on elimination of 75 invasive species showed the success of activities within a territory limited to the size of a settlement or a small region. There are very few reports on successful elimination of invasive species at the level of countries or continents (Pluess et al., 2012). Short-term programs (up to one year) for the elimination of weeds have been found to be ineffective (Wadsworth et al., 2000); long-term work is expected to last for more than 10 years (Panetta and Lawes, 2007; Rajmis et al., 2016).

The accumulated volume of knowledge on the biology of *H. sosnowskyi* (Shumova, 1970; Satsyperova, 1984; Skupchenko, 1989; *Ecology and Management*..., 2007; Dalke et al., 2015; Veselkin et al., 2017) allows us to formulate the basic principles of managing its invasion. In the conditions of limited resources, one should abandon the idea of a one-time, one-stage (for one field season) destruction of all the thickets of the species in the territory of the region. Systemic work on the elimination of *H. sosnowskyi* must begin with the implementation of a pilot project on the territory of one or two settlements (Dalke et al., 2018). To do this, it is necessary (1) to register and map the territories occupied by *H. sosnowskyi* thickets; (2) to classify the territories occupied by *H. sosnowskyi* by types of economic use and degree of danger to the population; (3) to establish the owners of land plots; (4) to identify priority areas for the destruction of plant thickets; (5) to perform work on the destruction of *H. sosnowskyi* at selected sites; (6) to organize supervision for evaluating the effectiveness of the implemented activities; and (7) to create and maintain buffer zones with a width of at least 6 m at the boundaries of sites contacting untreated thickets of *H. sosnowskyi*. Taking into account the experience gained during the implementation of the pilot project, it is necessary to develop a strategy for the destruction of undesirable thickets throughout the region. To reduce the negative consequences of the spread of *H. sosnowskyi* plants, regular propagation of knowledge about this species among the population should be carried out (About Cow-Parsnip, 2018c).

The expediency of destroying *H. sosnowskyi* plants on agricultural land is controversial. Replacing this species with crops is not difficult. The implementation of these activities is limited by the pace of land involvement in agricultural production. At the same time, giant hogweed growing on abandoned lands can lead to an increase in the concentration of mineral elements (K, Mn) and enhancement of nitrogen dynamics in the soil (Vanderhoeven et al., 2005) and slow the overgrowing of fields by arboreal shrub vegetation.

On the territory of Russia, the eradication of undesirable thickets of *H. sosnowskyi* has been carried out for more than seven years, but the absolute majority of the contracts executed during this time did not include complex measures ensuring effective control of the invasion. In contract no. 0106200001317000073, mapping of thickets followed by the development of practical recommendations on the most effective method for controlling *H. sosnowskyi* plants was performed, taking into account the natural and ecological conditions of the Republic of Karelia. The number of works aimed at the destruction of thickets was significantly higher (95% of contracts) compared to mapping and monitoring (5%); in some years, some types of work were not performed (Fig. 6b). On the other hand, a survey of the territory of Leningrad oblast on the growth of *H. sosnowskyi* was blocked in 2014 because of a lag in the pace of the struggle with plants against the rate of survey of the territory. As a result of the implementation of contracts from 2011 to 2017, no more than 10% of the areas of cartographic thickets were destroyed in the region (Fig. 8a).

The fragmentation of measures on mapping and eliminating the thickets, chaotic work, repeated processing on the same site, and the use of ineffective methods of control often make it difficult or even devalue the efforts expended. The effectiveness of the work performed is also reduced by the lack of planning in the short and long term, insufficient consideration of the biological characteristics of the species, and a limited amount of resources. High variability and spread of indicators of concluded contracts and significantly overestimated costs on elimination of *H. sosnowskyi* overgrowth are observed when work is performed on cultivated areas of less than 5 ha.

CONCLUSIONS

Analysis of procurement activities (Procurement Portal..., 2018) showed that, in the period from 2011 to 2017 in the Russian Federation, no less than 477 contracts for the elimination of invasive species *H. sosnowskyi* were completed for a total of 314 million rubles. Mapping of undesirable thickets was carried out on an area of 169 000 ha; work on the elimination of thickets was carried out on an area of 18 000 ha. Fifty-eight million rubles was spent on inefficient and more expensive, in comparison with the use of herbicides, mowing of *H. sosnowskyi* undergrowth.

Systemic work with undesirable thickets of *H. sosnowskyi* must begin with the implementation of a pilot project in a limited area. The project should include a full range of measures ensuring maximum effectiveness of invasive control. Implementation of large-scale projects in the regions of the Russian Federation should be carried out within the framework of a long-term program based on existing data and experience in elimination of the invasion of *H. sosnowskyi*.

ACKNOWLEDGMENTS

This work was supported by the Russian Foundation for Basic Research, project no. 16-44-110694 r_a "Ecological and Physiological Modeling of Geographical Limits of the Spread of Invasive Plant Species by Example of *H. sosnowskyi* in the Taiga Zone of the European Part of Russia," performed on the basis of the Agreement between the Government of the Komi Republic and the Russian Foundation for Basic Research for 2013–2017.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interests. The authors declare that they have no conflict of interest.

Statement on the welfare of animals. This article does not contain any studies involving animals performed by any of the authors.

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Translated by M. Shulskaya