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DISTRIBUTION OF TWO INVASIVE GOLDENROD SPECIES *SOLIDAGO CANADENSIS* AND *S. GIGANTEA* IN LITHUANIA

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Abstract

Karpavičienė B., Radušienė J., Viltrakytė J., 2015: Distribution of two invasive goldenrod species *Solidago canadensis* and *S. gigantea* in Lithuania [Dviejų invazinių rykštenių rūšių – *Solidago canadensis* ir *S. gigantea* – paplitimas Lietuvoje]. – Bot. Lith., 21(2): 125–132.

Two North American goldenrods, *Solidago canadensis* and *S. gigantea,* are listed among invasive species posing the greatest threat to species and ecosystems in Europe. Distribution of non-native goldenrods in Lithuania was studied during field trips conducted in 2012–2015 with additional usage of herbarium data. To date, *S. canadensis* occurs frequently, especially in the eastern part of the country, being the most abundant in Vilnius city, Tauragė district, Vilnius district and Pagėgiai municipalities. *S. gigantea* occurs frequently in the southern part of the country with the highest abundance in Kazlų Rūda municipality. A total area invaded by *S. canadensis* amounts to 1702 ha, and by *S. gigantea* – 411.5 ha. Both species occur mostly in abandoned fields and on roadsides, in communities of ruderal plants of the class *Artemisietea vulgaris.* The current distribution of *S. canadensis* and *S. gigantea* in Lithuania and their competitive potential suggest that these two species are likely to become more common and abundant in the future.

Keywords: invaded habitats, invasive species, *Solidago canadensis*, *Solidago gigantea*.

INTRODUCTION

Biological invasions are a widespread and significant component of human-caused global environmental changes (Vitousek et al., 1997). The spread of invasive species into new territories is considered as one of the major threats to biological diversity and the functioning of invaded ecosystems (Lambdon et al., 2008). An assumption that most invasive species exhibit enhanced performance in their introduced range relative to their native ranges, is not universal (Parker et al., 2013). According to Pyšek et al. (2012) the success of plant species in a new range as well as intensity of impact on resident species richness and productivity depends on species traits, e.g. life form and height – plants taller than 1.2 m are more likely to exert a significant impact than the shorter plants. In this connection, it is not surprising that woody and tall herbaceous plants prevail in the list of invasive species of Lithuania (Anonymous, 2015). Among these, three North American *Solidago* species, i.e. *S. altissima* L., *S. canadensis* L., and *S. gigantea* Aiton are listed. Some authors considered that European populations of *S. canadensis* belong to *S. canadensis* var. *scabra* (Muhl.) Torr. & Gray, which is synonymous with *S. altissima* (Weber, 2001; Sheppard et al., 2006) However, our recent studies on morphological and anatomical characters of goldenrods occurring in Lithuania confirmed the presence of *S. canadensis* and *S. gigantea*, with a high intraspecific variation (Karpavičienė & Radušienė, 2016).

Both non-native goldenrods are rhizomatous perennials, reaching more than two meters in height. *S. canadensis* has rather short rhizomes, leading to compact genet architecture, while rhizomes of *S. gigantea* are up to 20 cm or more in length (Schmid

& Bazzaz, 1987). Due to vegetative propagation, *S. gigantea* can form dense stands, which suppresses the growth of almost all co-occurring species (Jakobs et al., 2004). Numerous wind-dispersed fruits (up to 20 000 fruits per ramet) are essential for the long-distance spread of goldenrods and their successful colonization of unoccupied sites (Werner et al., 1980; Weber, 2000; Weber & Jakobs, 2005).

Solidago canadensis and *S. gigantea* were introduced to Europe as ornamental plants in different centuries: *S. canadensis* in the 17th century and *S. gigantea* in the 18th century (Kowarik, 2003). After a short time from the introduction, they escaped from cultivation and became naturalized in many European countries (Wagenitz, 1979; Weber, 2001; Weber & Jakobs, 2005). In Lithuania, *S. canadensis* was mentioned in 1934 only as cultivated ornamental plant (Dagys et al., 1934), while in 1954, the occurrence of wild populations was noted by Snarskis (1954). According to Gudžinskas (1997), wild population of *S. gigantea* was first recorded in 1977 and both species were distributed diffusely through the whole territory of the country in 1997. Nowadays, *S. canadensis* and *S. gigantea* are listed as invasive posing the greatest threat to species and ecosystems in Europe (Anonymous, 2004). Newly arrived invasive species tend to expand its distribution into its potential range (Dainese & Poldini, 2012). However, there might be large differences between the present and the potential distribution ranges of such species (Gassó et al., 2012). It is believed that the spread of *S. canadensis* and *S. gigantea* has not yet reached its limits and that their range expansion will continue.

The objective of the present study was to determine the distribution of *S. canadensis* and *S. gigantea* in Lithuania, and to estimate their invasion extent, trends and habitat preferences using field research and herbarium data.

MATERIALS AND METHODS

Field studies were conducted throughout the territory of Lithuania in 2012–2015. The location, geographic coordinates, habitat and population area together with assessment of anthropogenic impact were recorded for each examined site. Sites were separated by at least 1 km. Specimens of *S. canadensis* and *S. gigantea* were deposited at the Herbarium of the Institute of Botany of the Nature Research Centre (BILAS) in Lithuania.

Areas occupied by the populations of *S. canadensis* and *S. gigantea* were measured using area measure tool (available on the web page http://www.maps.lt). Places occupied by populations consisted of a single clonal clump were excluded from the measurements. Furthermore, additional data from the Herbaria of Vilnius University (WI) and the Institute of Botany of the Nature Research Centre (BILAS) were used. Distribution maps were created applying the national grid system (Gudžinskas, 1993). All localities found in the same square were marked as one point.

Plant communities were characterized based on 42 vegetation plots of 16 m² size made using the Braun-Blanquet method (Braun-Blanquet, 1964). We used paired invaded and non-invaded plots that are similar in soil physical characteristics, to quantify effects of invasion on soil chemical composition. The selection of plots was performed after Hejda et al. (2009). The soil samples were collected at a depth of 5–10 cm from each plot of the 19 invaded and non-invaded plot pairs and analysed as described in the previous paper (Karpavičienė & Radušienė, 2016).

The variations and differences of habitat characteristics between invaded and non-invaded sites were assessed using descriptive statistics and the Wilcoxon matched pairs test. Statistical analyses were performed using the *STATISTICA* 10.0 (StatSoft Inc.) software.

RESULTS AND DISCUSSION

Solidago canadensis occurs frequently in Lithuania, especially in the eastern and southern parts of the country (Fig. 1). During field studies, 381 records of *S. canadensis* were reached, and 63.8% of these concern the sites, where a single plant was noticed (Table 1). To date, *S. canadensis* covers an area of 1702 ha. The largest areas occupied by populations of this species were found in the territory belonging to Vilnius city municipalities: 234 ha in Račkūnai and Užukampis, and 195 ha in Dobrovolė. The most invaded areas are Vilnius city, Tauragė district, Vilnius district and Pagėgiai municipalities (Table 2).

Table 1. Number of records (n) and size of area occupied by *Solidago canadensis* and *S. gigantea*

Group of area size	*S. canadensis*				*S. gigantea*			
	n	Part, %	Total area, ha	Mean area, ha	n	Part, %	Total area, ha	Mean area, ha
single plant	243	63.8	–	–	226	62.1	–	–
< 0.05 ha	45	11.8	–	–	57	15.7	–	–
0.05–2 ha	41	10.7	49.5	1.2	51	14.0	54.2	1.1
2–5 ha	17	4.5	65.0	3.8	12	3.3	34.1	2.8
5–10 ha	12	3.1	92.0	7.7	9	2.5	59.2	6.6
10–50 ha	14	3.7	341.5	24.4	8	2.2	189.0	23.6
50–150 ha	6	1.6	565.0	94.2	1	0.2	75.0	75.0
150–250 ha	3	0.8	589.0	196.3	0	0	0	0
Total	381	100	1702.0	18.3	364	100	411.5	5.1

Table 2. Occurrence of *Solidago canadensis* and *S. gigantea* in Lithuanian municipalities. Number of sites (N) and area of occupancy (A), ha

Municipality	*S. canadensis*		Municipality	*S. gigantea*	
	N	A		N	A
Vilnius city	35	817.8	Kazlų Rūda	146	295.0
Tauragė district	17	328.5	Vilnius city	27	44.0
Vilnius district	39	236.5	Šakiai district	59	25.8
Pagėgiai	19	142.0	Vilkaviškis district	20	22.1
Rokiškis district	17	56.0	Kaunas district	26	9.5
Kaunas city	31	45.5	Vilnius district	45	3.0
Anykščiai district	10	23.5	Kaunas city	15	1.0
Ukmergė district	11	19.0	Pagėgiai	9	4.7
Kaunas district	14	10.5	Trakai district	9	4.4
Biržai district	10	9.0	Tauragė district	5	1.0
Trakai district	7	6.0	Klaipėda city	3	1.0

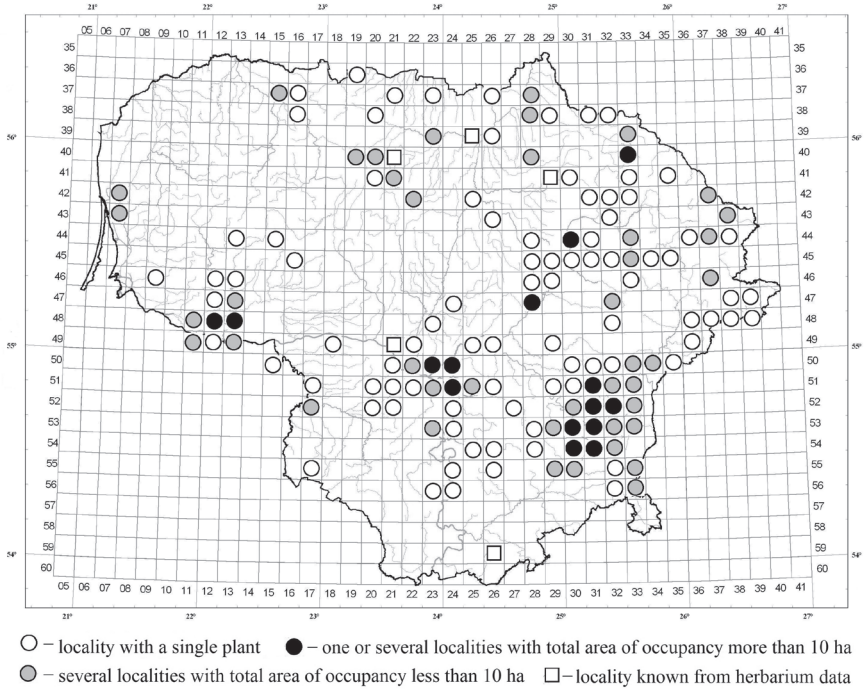

Fig. 1. Distribution of *Solidago canadensis* in Lithuania

S. gigantea occurs frequently in the southern part of Lithuania, being rarely recorded in the northern part of the country (Fig. 2). The largest area of its occupancy is in Kazlų Rūda municipality (Table 2). The number of records and percentage of sites with a single plant and small populations of both species are very similar (Table 1). However, the assessment of total and mean areas occupied by *S. gigantea* populations reveals that they are much smaller than those of *S. canadensis*. All records made in northern Lithuania include a single plant or small sparse populations. Meanwhile, *S. gigantea* is widespread and abundant in the neighbouring Kaliningrad region, where *S. canadensis* is quite rare (Gubareva et al., 1999). Further north, in Latvia, *S. gigantea* occurs only in a small territory within Riga and surrounding towns. *S. gigantea* is rare in Estonia, while *S. canadensis* is widespread in Latvia and distributed sporadically in Estonia (Gudžinskas et al., 2003; Priede, 2008). There are two possible explanations of such differences in distribution between these two species. Firstly, a shorter time span for colonization: *S. gigantea* was introduced to Europe more than 100 years later than *S. canadensis* (Weber, 2001) and became naturalized considerably later. The initial phase of expansion of *S. canadensis* in Latvia was around 1950, while of *S. gigantea* by the end of the 1980s (Priede, 2008). Similar differences are recorded between *S. canadensis* and *S. gigantea* in time of naturalization in Lithuania (Snarskis, 1954; Gudžinskas, 1997). Secondly, the differences in latitudinal extent of potential distribution of both *Solidago* species in Europe: according to Weber (2001), *S. gigantea* almost reaches its northern limit of potential distribution, which does not spread as northward as distribution of *S. canadensis.*

The history of invasive goldenrods in Lithuania is analogous to that in Latvia (Priede, 2008). In both countries uncontrolled invasion of *S. canadensis* and *S. gigantea* was closely related to the political and economic changes after the re-establishment of the independence in 1990s, when many of the former cultivated kolkhoz fields and urban areas were abandoned and poorly managed. Both invasive species were introduced as ornamental plants and are still commonly cultivated in gardens and parks. Therefore, naturalized populations of *S. canadensis* and *S. gigantea* are found in the neighbourhood of collective gardens, villages, homesteads and cemeteries quite often. Consequently, the cities, especially their outskirts, act as the main centres of dissemination. However, some of the heavily invaded sites do not meet these regularities, because they are located far away from the cities. It is highly probable that abundant spreading of *S. gigantea* into Kazlų Rūda and

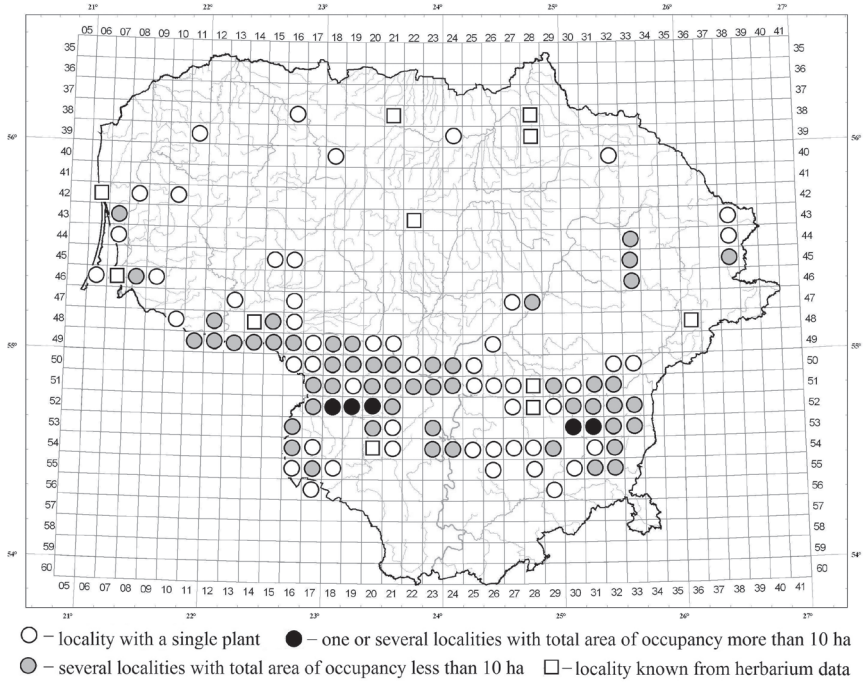

Fig. 2. Distribution of *Solidago gigantea* in Lithuania

Vilkaviškis district municipalities occurred along the railway from the neighbouring Kaliningrad region. According to Gusev (1974), *S. gigantea* was already widespread in Kaliningrad region in 1974. In the similar position, near the railway and motor way from Kaliningrad region, are the sites in Tauragė district and Pagėgiai municipalities, which are heavily invaded by *S. canadensis*. However, this species is rare in Kaliningrad region (Gubareva et al., 1999), and the pathways of its arrival at the corresponding sites are still unclear.

Generally both invasive *Solidago* species occur in abandoned fields and on roadsides, and less frequently in other human-affected places or natural habitats (Fig. 3). However, a slight disparity in habitat differentiation between them is noticeable: *S. gigantea* occurs relatively more frequent on roadsides and in shrubberies than *S. canadensis* does (Fig. 3). Some published sources referred that in Europe *S. gigantea* prefers moist to mesic sites (i.e. roadsides, forest edges, old fields, grasslands, wetlands, and riversides), while *S. canadensis* occurs at semi-dry and dry sites (Weber & Jakobs, 2005; Geir et al., 2008). Presented habitats are very similar to those in which *S. canadensis* and *S. gigantea* usually thrive in their native range in North America (Croat, 1972; Werner et al., 1980; Semple & Cook, 2006). Unfortunately, our study did not confirm such difference in habitat preferences between these two species. The differences may be explained by the fact that the investigations were carried out in a relatively small territory of Lithuania. On the other hand, according to Hejda et al. (2009), invasive neophytes occur in a wider range of habitats in the invaded range than they do in their native range.

Based on vegetation plots, 60 species of vascular plants were registered in the company of *S. canadensis* and 43 species in the company of *S. gigantea* (Table 3). The most constant species in the communities invaded by *S. canadensis* are *Artemisia vulgaris*, *Achillea millefolium*, *Calamagrostis epigejos*, *Dactylis glomerata*, *Vicia cracca*, and *Taraxacum officinale*, which were found in more than 50% of plots. In the communities invaded by *S. gigantea*, the most frequent are *Artemisia vulgaris*, *Elytrigia repens*, *Calamagrostis epigejos* and *Urtica dioica*. *Artemisia vulgaris*, the most common species, was recorded in 75 and 93.3% of plots invaded by *S. gigantea* and

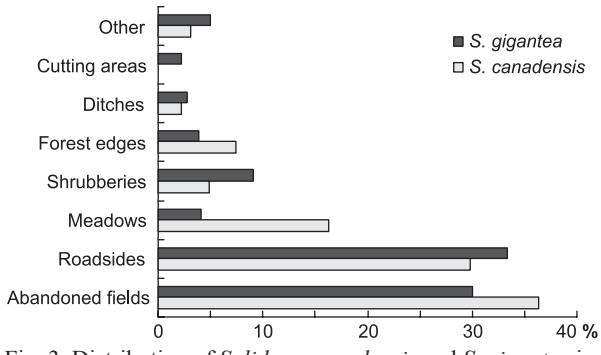

Fig. 3. Distribution of *Solidago canadensis* and *S. gigantea* in various habitat types in Lithuania

Table 3. The most frequent species associated with *Solidago canadensis* and *S. gigantea*. Frequency of species is reported as the ratio (%) of the species entries in releves

Species	Frequency and abundance*	
	A	B
Solidago canadensis	$100^{2–5}$	$16.7^{1–2}$
Solidago gigantea	$6.7^{+–1}$	$100^{2–5}$
Artemisia vulgaris	$93.3^{+–3}$	$75.0^{+–2}$
Achillea millefolium	$86.7^{+–2}$	$33.3^{+–2}$
Dactylis glomerata	$73.3^{+–3}$	$25.0^{+–1}$
Calamagrostis epigejos	$73.3^{+–2}$	$50.0^{+–2}$
Vicia cracca	$70.0^{+–1}$	$41.7^{+–2}$
Taraxacum officinale	$66.7^{+–2}$	8.3^{+}
Agrostis capillaris	$46.7^{+–2}$	8.3^{1}
Erigeron strigosus	$46.7^{+–2}$	$16.7^{+–1}$
Equisetum arvense	$46.7^{+–2}$	8.3^{+}
Mentha arvensis	36.7^{+}	25.0^{+}
Rumex acetosa	$36.7^{+–1}$	.
Solidago virgaurea	$33.3^{+–1}$	8.3^{+}
Silene pratensis	$33.3^{+–1}$	16.7^{+}
Trifolium repens	$33.3^{+–1}$	.
Cirsium arvense	$30.0^{+–2}$	$25.0^{+–1}$
Phleum pratense	$30.0^{+–2}$	$16.7^{+–2}$
Poa angustifolia	$30.0^{1–2}$	$33.3^{+–2}$
Elytrigia repens	$26.7^{+–2}$	$58.3^{+–2}$
Senecio jacobaea	$26.7^{+–1}$	16.7^{+}
Veronica chamaedrys	$23.3^{+–1}$	$25.0^{+–1}$
Convolvulus arvensis	16.7^{+}	$25.0^{+–1}$
Rubus idaeus	7.7^{1}	$41.7^{+–1}$
Urtica dioica	3.3^{+}	$50.0^{+–2}$
Chamerion angustifolium	3.3^{+}	25.0^{+}
Lysimachia vulgaris	3.3^{+}	33.3^{+}

* – Frequency of species is reported as the ratio (%) of the species entries in releves; only species with ratio above 20% at least in one column are shown; superscript figures denote values of plant abundance after Braun-Blanquet (1964); A – plant communities with predominant *S. canadensis*; B – plant communities with predominant *S.gigantea*

Table 4. Results of the Wilcoxon matched pairs test for soil composition and acidity at the sites invaded (SI) and not-invaded (SN) by *Solidago canadensis* and *S. gigantea*

	S. canadensis				*S. gigantea*			
	Mean SI	Mean SN	Z	p	Mean SI	Mean SN	Z	p
P_2O_5	199.1	161.1	1.6	0.114	163.7	115.8	2.0	0.046
K_2O	161.9	150.4	0.6	0.541	165.3	132.5	1.4	0.173
Humus	3.3	3.3	0.4	0.678	3.8	3.7	0.7	0.500
pH	6.0	6.7	1.8	0.066	5.7	5.1	1.6	0.109

S. canadensis, respectively. Similarly, according to Jakobs et al. (2004), in Europe *S. gigantea* is usually associated with *Artemisia vulgaris*, *Urtica dioica*, *Cirsium arvense* and *Rubus* spp. An association of plants with the predominance of *S. canadensis* or *S. gigantea* is classified as *Rudbeckio-Solidaginetum*, and belongs to the class *Artemisietea vulgaris* (Matuszkiewicz, 2001). In the Ukraine, *S. canadensis* dominates in some communities of the associations *Tanaceto vulgaris-Artemisietum vulgaris* Sissingh 1950, *Convolvulo-Agropyretum repentis* Felföldy 1943 or *Chaerophylletum aromatici* Gutte 1963 (Tokaryuk et al., 2012).

The soil chemical composition varies widely among the *Solidago* species growing sites. However, there are no significant differences in the mean quantities of soil nutrients and acidity between the growing sites of *S. canadensis* and *S. gigantea* (Karpavičienė & Radušienė, 2016). The average concentrations of phosphorus and potassium are slightly higher in the soils of non-invaded plots than in those of invaded. Significant difference is noticeable only for phosphorus content between sites invaded and non-invaded by *S. gigantea* (Table 4). The findings and interpretations of changes in the soil chemical composition are different. According to Chapuis-Lardy et al. (2006), the concentrations of labile phosphorus increase in plots invaded by *S. gigantea*, but according to Zhang et al. (2009), available phosphorus content consistently decreases with *S. canadensis* invasion. Scharfy et al. (2010) indicated that the presence of *S. gigantea* did not influence phosphorus availability in soil. The phosphorus content dependence on soil type and invading plant species was noted by Chapuis-Lardy et al. (2006).

The current distribution of *S. canadensis* and *S. gigantea* in Lithuania and their competitive abilities suggest that they are likely to spread further in the future. Abandoned fields and meadows become the springboard habitats for alien goldenrods. The development of monodominant stands of *S. canadensis* and *S. gigantea* poses the threat to native plant diversity and leads to the creation of homogenized landscape over the large areas.

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INVAZINIŲ NEVIETINIŲ *SOLIDAGO* RŪŠIŲ PAPLITIMAS LIETUVOJE

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Santrauka

Solidago canadensis ir *S. gigantea,* dvi iš Šiaurės Amerikos kilusios rykštenės, yra įtrauktos į sąrašą rūšių, keliančių didžiausią pavojų Europos rūšims ir ekosistemoms. Nevietinių rykštenių paplitimas buvo tirtas 2012–2015 metais visoje Lietuvos teritorijoje vykusių lauko ekspedicijų metu, papildomai naudojant herbariumo duomenis. *S. canadensis* buvo išplitusi beveik visoje teritorijoje, tačiau gausiausia buvo Vilniaus miesto, Tauragės ir Pagėgių savivaldybėse. *S. gigantea* gausesnė buvo pietinėje Lietuvos dalyje, o gausiausia – Kazlų Rūdos savivaldybėje. Bendras plotas, kuriame augo *S. canadensis*, siekė 1702 ha, o *S. gigantea* – 411,5 ha. Abi invazinės *Solidago* rūšys dažniausiai augo apleistuose laukuose ir pakelėse, *Artemisietea vulgaris* klasės ruderalinių augalų bendrijose. Dabartinis invazinių *Solidago* rūšių paplitimas Lietuvoje ir jų konkurencinės savybės leidžia manyti, kad ateityje jos taps dar gausesnės.