North American species of Solidago as ornamental plants and a source of promising raw plant materials

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Abstract. A review of the role of ornamental horticulture as a vector of phytoinvasions is presented on the example of North American species of Solidago: S. canadensis L., S. gigantea Ait and S. graminifolia (L.) Salisb. The first two species were originally cultivated as ornamental plants. With changes in environmental conditions, their range expanded to the north and east of the Eurasian continent, and the lag phase lasted 100-150 years. At the end of the XX century, their secondary range covered all the Eurasian regions, they were transformed into invasive plants and were listed in the Top 100 most threatened and aggressive species that are introduced into natural phytocoenosis and pose a threat to the environment. The secondary range of S. graminifolia is represented by several scattered localities, its lag phase ends, this species is recognized as invasive only in Poland. It has now become evident that alien species can be used as new resource plants. The study of secondary metabolites composition of species of Solidago makes possible the disbursement of a wide range of flavonoids, triterpene saponins, organic acids, and various terpene compounds in their composition. The authors believe that a detailed study of the phytochemical properties and many other widespread invasive species is required in order to identify new plant resources.

1. Introduction

The use of plants for decorative purposes goes back to ancient times. Archaeological evidence shows that many plant species have been introduced to areas outside their natural range, and a number of them have formed stable populations without human assistance. [1] Most of these species have relatively small secondary ranges [2] and do not cause significant environmental and economic damage. However, some alien species have become invasive, they affect local species and can cause significant damage to local ecosystems [3-5]. The introduction of alien species has sometimes occurred unintentionally, but most invasive alien plants have been introduced as ornamental plants in botanical gardens, public green spaces, and infield flower gardens [6, 7].

Due to the needs of economic botany and ornamental gardening, the creation of botanical gardens in the XVII-XVIII centuries contributed to the spread of ornamental plants around the world [8]. The botanical gardens have also played an important role in the collection, evaluation, and dissemination of new agricultural and food crops. It is no wonder that many of the now naturalized and invasive alien plant species were first planted in botanical gardens. Plants of natural flora selected for decorative purposes have a number of characteristics, such as intensive growth, ease of reproduction,
and decorativeness, which contributes to their success in both horticulture and the invasive process. In addition, the environmental changes observed in recent years, in particular, climate warming, contribute to the expansion of the range of invasive plants. Socio-economic changes necessitate the study of invasive plants as potential sources of new bio-products of high added value (various pharmacopoeia drugs, green pesticides). However, it should be borne in mind that in most cases these plants grow on disturbed lands, near roads and landfills. Therefore, toxic substances contained in soils can have a negative impact on the composition of biologically active compounds in invasive plants. The study of the stages of introduction and invasion of various alien species and possible ways of their further use will make it possible to transform invasive species into valuable sources of biologically important components.

Some of the most common alien species in Europe are species of the genus *Solidago*, which naturally grow in North America between 26° and 45° north latitude, reaching 65° north latitude in western Canada and Alaska.

The purpose of this article is to characterize a paradigm shift in the evaluation of the North American species of *Solidago* and their "transformation" from ornamental plants to valuable species.

2. Materials and methods

Literary sources were used as materials: scientific articles on the introduction of species of the *Solidago* genus, on various aspects of studying the invasion processes of these species, as well as on the study of the composition of biologically active plant compounds.

3. Results and Discussion

The name of the *Solidago* genus derives from two Greek words: "solid" – "firm, resistant" and "ago" – "act, do" (translated from Latin "Solidago" means "to heal, to safe"); medieval doctors used the native in Europe S.virgaurea S.virgaurea in the treatment of the bladder, kidneys and for wound healing [9]. In the Russian-language literature, especially popular science, the species of the *Solidago* genus are called "goldenrod" and "golden-rod".

3.1 North American goldenrods as ornamental plants. Species of the *Solidago* genus are among the first ornamental plants introduced from North America to Europe; they were introduced to England in 1645 [10]. The following species appeared on the continent approximately at the same time: *S. canadensis* L. approximately in 1735, *S. gigantea* Ait. and *S. graminifolia* (L.) Salisb.*S. graminifolia* (L.) Salisb. - approximately in 1758 [11] and began to be actively used in decorative floriculture. These species were popular because of their unpretentiousness, easy cultivation, late flowering, originality and variety of inflorescence forms (in the process of plant growth, inflorescences from dense ones gradually become elongated, spreading and more openwork). Unfortunately, there are no data on the appearance of goldenrods in monastic and public gardens in Russia.

Outside of culture, these species were first recorded in the 1850s, and the exponential growth in the number of their spontaneous populations began in 1870-1900 [11]. According to herbarium collections, *S. canadensis* was recorded as an introduced plant in the Moscow region in 1863, in the Tula region — in 1880, in the Kostroma region — in 1882 [12]. According to the literature, the falling out of cultivation of *S. canadensis* was first observed by V. Ya. Tsinger in the book "Collection of information about the flora of Central Russia" [13]: "Sometimes it is bred in gardens and is often found almost in the entire region brought in a completely wild state". Around the same time, D.I. Litvinov in the book "List of plants growing wild in the Kaluga province, indicating useful and harmful" [14] notes that the Canadian goldenrod "is bred in gardens and sometimes goes wild, for example, it was found on the bank of the Oka near the railway bridge close to the station Aleksin". Schmalhausen I.F. in the book "Flora of Central and South Russia, Crimea and the North Caucasus" [15] describes the distribution of this species as follows: "It is sometimes found wild. Poland, St. Petersburg". Later, D.P. Syreishikov in the "Illustrated flora of the Moscow province" (1910) notes *S. canadensis* as "observed as wildings in the old parks but not often" [16]. Then, V.N. Voroshilov and his co-authors in the book "Keys to Plants of the Moscow Region" [17] noted that *S. canadensis* "is
bred in gardens as an ornamental, sometimes goes wild”. The process of further distribution of *S. canadensis* is poorly studied, and it is hardly possible to restore the real picture of its settlement today [18].

*S. gigantea* was first cultivated in the London Botanic Gardens. It was soon recorded in gardens and nursery gardens of continental Europe, but the origin of these initial populations remains unknown. The species began to disperse approximately 100 years later: the first mention of self-dispersal of *S. gigantea* in Germany dates back to 1832, in Austria – 1857, in the UK it was found wild in 1916. Based on herbarium samples and literature sources, it can be argued that the expansion rate was about 910 km²/year [19]. It is hardly possible to specify the exact date of species appearance in Russia since it was poorly distinguished from *S. canadensis*. In European Russia, one of the first herbarium collections was made in Voronezh in 1868. In Siberia, in the Tomsk region, it was found in 2007, and it is also indicated for the Kurgan region [20].

In contrast to *S. canadensis* and *S. gigantea*, *S. graminifolia*, which appeared simultaneously with them, has a disjointive secondary range in Europe. The species distribution area is limited to small, isolated areas without apparent signs of expansion. In the UK, it is marked on 29 sites (covering 10×10 km), most of which are located in the southern part of the country. Sporadic populations have also been found in Austria, the Czech Republic, Finland, France, Germany, Holland, Italy, Slovakia, Poland, Romania, Switzerland, and Ukraine [21]. It is found in various habitats: on the river banks, on moist meadows, fields and roadsides, in parks around old castles [22]. It is registered in Lithuania and Belarus [23]. In Russia, this species is found only in botanical gardens; data on its growth in Abkhazia [24] refer to the old collection of N.I. Vavilov, who brought more than 50 different species of goldenrod from America to the Sukhumi nursery garden, only three of which are currently left (but not *S. graminifolia*).

It is known that the settlement stage of introduced plant species and the creation of a sufficient number of founder populations, as well as genetic adaptation to a new environment, is preceded by the so-called lag-phase - the time interval between the date of cultivation beginning and the date of mass withdrawal from the culture [25]. The colonization rate of new territories by species depends on both environmental and anthropogenic factors. According to E. Weber [11], the lag phase of *S. canadensis* and *S. gigantea* in Europe was about 100 years. In Russia, this period was about 150 years [20]. For *S. graminifolia*, the lag phase has been going on for 250 years and it cannot be said that it has finished yet. Active settlement of this species continuous only in Poland.

Currently, in European gardens, mainly varieties of goldenrods of hybrid origin are cultivated: ‘Baby Gold’, ‘Baillard’, ‘Dzintra’, ‘Fruhgold’, ‘Golden Dwarf’, ‘Golden Shower’, ‘Goldjunge’, ‘Goldenmosa’, etc. They are less likely to naturalize than “pure” species.

### 3.2 North American goldenrods as invasive species.

At the end of the XX century, the rapid invasion of *S. canadensis* and *S. gigantea* into the natural phytocenosis of Europe was began. *S. canadensis* is found in 39 European countries, it naturalized in 28 ones [26] and is classified as a species capable of transforming natural ecosystems, reducing biological diversity (=transformers). In Russia, the area of the Canadian goldenrod occupies the European part (it is found in 39 regions, in 37 it was naturalized), the south of Siberia, Kamchatka, and the south of the Far East.

*S. gigantea* is distributed in 35 European countries from northern Spain to Eastern Europe and from Northern Italy to southern Scandinavia (from 42 to 63° north latitude), it was naturalized in 25 countries, and its further expansion is expected eastward [26]. In Russia, it settled on the European territory (recorded in 32 regions, naturalized in 26), in the south of Siberia and the Far East (in the Khabarovsk Territory and Primorye). In the last decade, it has been actively introduced into natural communities. Massive thickets of *S. gigantea* were recorded in the Kaluga, Kursk and Moscow regions. Both species grow on disturbed land, abandoned fields, near roads, in vacant lots, landfills, and sparse forests. *S. gigantea* prefers more humid habitats and generally grows in river valleys [12].

According to the bio-geographical forecast for three species of the *Solidago* genus in Europe [11], the potential range of *S. graminifolia* does not differ significantly from the potential ranges of *S. gigantea* and *S. canadensis*. The last two species have not reached the limits of their distribution yet,
and for *S. graminifolia*, a significant difference between its current real and potential ranges has been revealed, so natural and climatic conditions do not prevent it from becoming an invasive species over the same vast territory. However, *S. graminifolia* is still considered invasive only in Poland [22]: its first samples were collected within the current borders of Poland in 1885, and after 125 years the range of the species increased by about 100 times (from 3 km² to 300 km²).

The active dispersal of North American *Solidago* species is facilitated by the biological and ecological characteristics of the species. The species have an unprecedented wide ecological plasticity and can grow on both waterlogged rich soils, poor dry soils, and even on construction debris. They are characterized by very high seed productivity: under favourable conditions, a single generative shoot produces up to 19 thousand seeds. The seeds are easily carried by the wind, but most of the seeds remain on the stem during the winter. Seed germination can reach 100% [12]. They are also capable of vegetative reproduction. Due to clonal growth, they form dense thickets and quickly become the dominant secondary successions. The number of shoots in the thickets of Canadian goldenrod can reach 309 pcs/m². For the giant goldenrod, from 5 to 55 rhizomes are formed in one ramet during the growing season. The large number of buds on the rhizomes allows the plants to quickly re-grow after damage. The number of growth buds on the rhizomes of *S. gigantea* is 10 times higher than that of *S. canadensis*. In addition, the rhizomes of *S. gigantea* are on average much longer; thus, the species can cover larger areas and expand the size of the area captured by the population in a relatively shorter period of time. Shoot density in the clone is 30-170 pcs/m². In recently abandoned fields, individual clones are often easily distinguishable and reach a diameter of 2-5 m. Large old clones can consist of 1 thousand ramets. The long rhizomes of *S. gigantea* are easily fragmented and can be carried by water currents, which contributes to the rapid invasion of the species along riverbanks [27]. The rhizomes of *S. graminifolia* are distinguished by an even greater number of dormant buds (3-4 per 1 cm of rhizomes, i.e. almost 10 times more than that of *S. gigantea*).

Invasive goldenrod species cause significant environmental damage and reduce the biological diversity of natural ecosystems. In this regard, they are included in the EPPO list of invasive species: countries, where *S. canadensis* and *S. gigantea* grow, are recommended to take measures to eliminate them. They are included in the Black Books of the flora of Central Russia [12], Siberia [28] and the Far East [29]. They are included in the TOP 100 most aggressive species of Russia [20]. Special measures are being developed to combat invasive species of the *Solidago* genus, including mechanical (mowing twice a year in May and August, digging up the soil) and chemical (the use of herbicides glyphosate, picloram, imazapyr) methods. However, herbicides are effective only for the most sensitive young plants with a height of no more than 10-15 cm [21].

3.3 North American goldenrods as valuable plants. Views on invasive species have changed somewhat over time. It is noted that in the secondary range they have larger sizes than in their homeland and form massive (usually single-species) thickets. By the area of the occupied territory, invasive species, especially in anthropogenic disturbed habitats, practically do not differ from native species, and their resource potential is quite high. In addition, invasive species have a high chance of becoming new resource plants, since a significant part of them are "refugees from the culture" and have economically valuable characteristics [30]. The main problem with the use of invasive species is the almost complete lack of information about their biological features in the secondary range, in particular about the dynamics of chemical accumulation and its dependence on the habitat and the plant development phase. Even with literature data provided on the biochemistry of a particular species in its natural range, they can not always be applied to the same taxon unit growing in the secondary range due to significant micro-evolutionary changes in plants under new soil and climatic conditions.

The next problem is that the stocks of invasive species in various regions of the secondary range have not been identified yet. But there is no need to determine scientifically-based volumes of annual harvesting and develop rational systems for the exploitation of thickets since it is advisable to remove all the biomass of alien species from phytocenosis, and not to preserve their natural reserves [31].
4. Conclusion

Thus, on the example of North American species of the Solidago genus, a change in views on the plant introduction problem is demonstrated. Initially, almost all more or less ornamental alien species were involved in cultivation, and in the course of deliberate introduction, their secondary range increased almost limitlessly. However, when these species began to "escape" from the culture and enter natural ecosystems, it was recognized that alien invasive species cause significant economic and environmental damage and reduce natural biodiversity. The plants began to be reduced, and the botanical gardens were urged to treat the introduction more carefully and accurately control the settlement of plants. Currently, we observe the third change of views, when invasive species are beginning to be considered as valuable plant raw materials, and dozens of scientific articles are published daily to study the phytochemical characteristics of alien species.

Thus, the study of secondary metabolites composition of Solidago species makes possible the disbursement of a wide range of flavonoids, triterpene saponins, organic acids, and various terpene compounds in their composition. Therefore, the species of the Solidago genus are promising plant raw materials.

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