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Invasive Plants of Russia: Results of Inventory, Peculiarities of Distribution, and Management Issues

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Abstract—Globalization, the expansion of trade relations, inter- and intracontinental movements of population, the development of transport networks between the countries led to an active settlement of many plant species outside their natural areas. Among such plants, a group of invasive species (those whose distribution has serious environmental, economic, and social consequences) is distinguished. The article contains information about the results of the inventory of invasive species of vascular plants growing in the Russian Federation, as well as an overview of the actions taken in the country to manage the invasive plant species. At present, there are 584 invasive species of vascular plants in Russia; out of them, *Acer negundo*, *Echinocystis lobata*, and *Erigeron canadensis* are the most common. It has to be stated, that until now, both legislative acts regulating the policy in the field of invasive species (legal regulation of phytoquarantine is an exception) and a national strategy for alien species in Russia are absent. The efficient management of biological invasions can work in the case where the general public is aware of the adverse consequences of the invasion of invasive species.

Keywords: alien species, biological invasions, global changes, Russian Federation

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INTRODUCTION

Globalization in combination with the expansion of trade relations, inter- and intra-continental movements of population, and the development of transport networks between the countries led to an active settlement of many plant species outside their natural areas (Lambdon et al., 2008; Dawson et al., 2017; Pyšek et al., 2017; van Kleunen et al., 2019). Such species are commonly called alien; the terms nonindigenous, nonnative, exotic, and adventive plants are less often used (Baranova et al., 2018; Pyšek, 1995; Richardson et al., 2011). At the same time, only a small part of alien species is represented by self-supporting populations; these are so-called naturalized species; among them, a group of invasive species (those whose distribution has serious ecological, economic, and social consequences) is distinguished (Richardson et al., 2011; Blackburn et al., 2019; Pyšek et al., 2020).

It is assumed that on average 10% of plant species from any region are potentially invasive (Dogra et al., 2010). Thus, out of 39100 currently known vascular plant species (*The State*..., 2016), only 3910 are potential invaders. It was established that the centers of species richness of naturalized plants are located on the western and eastern coasts of North America, in Northwestern Europe, South Africa, Southeastern Australia, New Zealand, and India (Pyšek et al., 2017). It is considered that more than 20% of plant species are alien on the continents, while 50% or more are alien on the islands (Rejmanek and Randall, 1994; Dogra et al., 2010). At the same time, the number of naturalized species closely correlates with the number of native species (Pyšek et al., 2017).

At present, there are data on the species richness of alien plants in large regions of the Earth. Thus, 9905 species of alien plants are known in the New World; 7923 species are known in the Old World. At the same time, 9036 species were noted for the temperate zonobiome (in both hemispheres), while 321 species were noted for the Arctic one (Pyšek et al., 2017). At the same time, data on the diversity of alien species at the national or regional levels (required for understanding the causes and mechanisms of the spread of invasive species and developing the methods to control their number) are fragmentary. In this regard, the inventory of invasive species, which is a basis for the development of a strategic long-term plan for the conservation of natural biodiversity and the prevention of their invasion, is of great importance. The problems of "regulating the pathways of the introduction of invasive alien species along with preventing or reducing the rates of their introduction and spread by at least 50%, as well as controlling or eradicating the invasive alien species to eliminate or reduce their effect with special attention to priority species and priority objects," are

formulated in the Global Biodiversity Framework for the period after 2020 (Proposed core monitoring..., 2021, pp. 11–12).

The aim of this study is to find answers to the following questions:

(a) What are the results of the inventory of invasive species of vascular plants growing in the Russian Federation?

(b) What are the peculiarities of their geographical distribution?

(c) What actions are currently being taken in Russia to manage the invasive plant species?

MATERIALS AND METHODS

Territory of Study

The Russian Federation is the largest country in the world by the area (over 17 million km^2), located in Northern Eurasia. Its territory has a length more than 4000 km from north to south (between 81°51′ N and 41°11′ N) and about 10000 km from west to east (between 19°38′ E and 169°0′ W). At the same time, more than 11 million km^2 (or 64% of its entire territory) is located in the zone of the North. In administrative terms, the Russian Federation includes 85 subjects that are united into eight federal districts (FD). Russia has a wide spectrum of physical and geographical conditions; its territory covers by the Arctic, subarctic, and temperate climatic zones. At the same time, the flora of vascular plants in Russia is not rich and is represented by 12500 species (Kamelin, 2007).

Compilation of a List of Invasive Plant Species

The first list of invasive species in Russia was compiled for the Northwest of Russia and includes 22 taxa (Gel'tman, 2003). In 2006, the work on the project "The Black Book of the Flora of Central Russia" began, which resulted in a monograph containing data on 52 of the most aggressive and widespread invasive species on the territory of Central Russia and a "blacklist" of 100 alien plant species that require an urgent study and monitoring for further prevention of invasions (Vinogradova et al., 2006, 2010). Later, the methodological aspects for creating "Black Books" and blacklists for specific regions were developed taking into account the level of aggressiveness of the invasive species and peculiarities of their distribution according to four statuses of invasiveness (Notov et al., 2010), and also numerous blacklists for certain territories appeared (Kravchenko, 2007; Silaeva, 2011; Antonova, 2012; Tremasova et al., 2012; Sagalaev, 2013; Starodubtseva et al., 2014; Panasenko, 2014).

In 2015, the Commission on Invasive Species under the Council of Botanical Gardens of Russia proposed to develop a joint list (blacklist) of invasive plants in Russia. More than 50 researchers from 46 regions of the country were involved in compiling this list (Vinogradova et al., 2015).

Data on the invasive plants growing on the territory of Russia can be found in a database on alien animal and plant species in Russia (Petrosyan et al., 2018). In 2018, the book *The Most Dangerous Invasive Species of Russia (TOP-100)* was published; it contains information on 100 plants and animals that are most dangerous for the ecosystems. For each species, the original maps of natural and invasion areas, invasion corridors and invasion vectors, peculiarities of biology, effect on local species, ecosystems, and humans, and methods of controlling the number are presented (*Samye opasnye*..., 2018).

A complex analysis based on data from 45 subjects of the Russian Federation became the next step in the study of the invasive flora of Russia. The list includes 354 invasive species, but their invasive status was not taken into account (Vinogradova et al., 2018).

In recent years, interest in the problem of biological invasions has grown: the "Black Books of Flora" of Tver oblast (Vinogradova et al., 2011), Siberia (Ebel' et al., 2016), Udmurt Republic (Baranova et al., 2016), Kaluga (Reshetnikova et al., 2019) and Nizhny Novgorod (Mininzon et al., 2020) oblasts, the Far East (Vinogradova et al., 2021), the Republic of Bashkortostan (Abramova et al., 2021), and the Kabardino-Balkarian Republic (Shkhagapsoev et al., 2021) and numerous lists of invasive plant species in individual regions (Supplementary Information C) were published. This made it possible to revise and significantly expand the list of invasive plants growing at the territory of the country.

A current list of the invasive flora of the Russian Federation is given in the Supplementary Information A to this article. The publications that formed the basis of the list are given in the Supplementary Information C. For the ease of use, the sources were grouped by administrative subjects. The list of the species was grouped by federal districts and subjects of the Russian Federation. This approach makes it possible to systematize information in order to develop effective measures of state control for the spread of invasive species.

The present study covers 65 subjects of the Russian Federation (81% of the country's territory): 5 subjects of the Northwestern Federal District, 17 subjects of the Central Federal District, 9 subjects of the Volga Federal District, 3 subjects of the Urals Federal District, 7 subjects of the Southern Federal District, 3 subjects of the North Caucasian Federal District, 10 subjects of the Siberian Federal District, and 11 subjects of the Far Eastern Federal District (Figs. 1 and 2).

Taxonomically close species, the identification of which is associated with certain difficulties (*Reynoutria* × *bohemica*, *R. japonica*, *Elymus trachycaulus*, *E. novae-angliae*, *Helianthus tuberosus* s.l., spe-

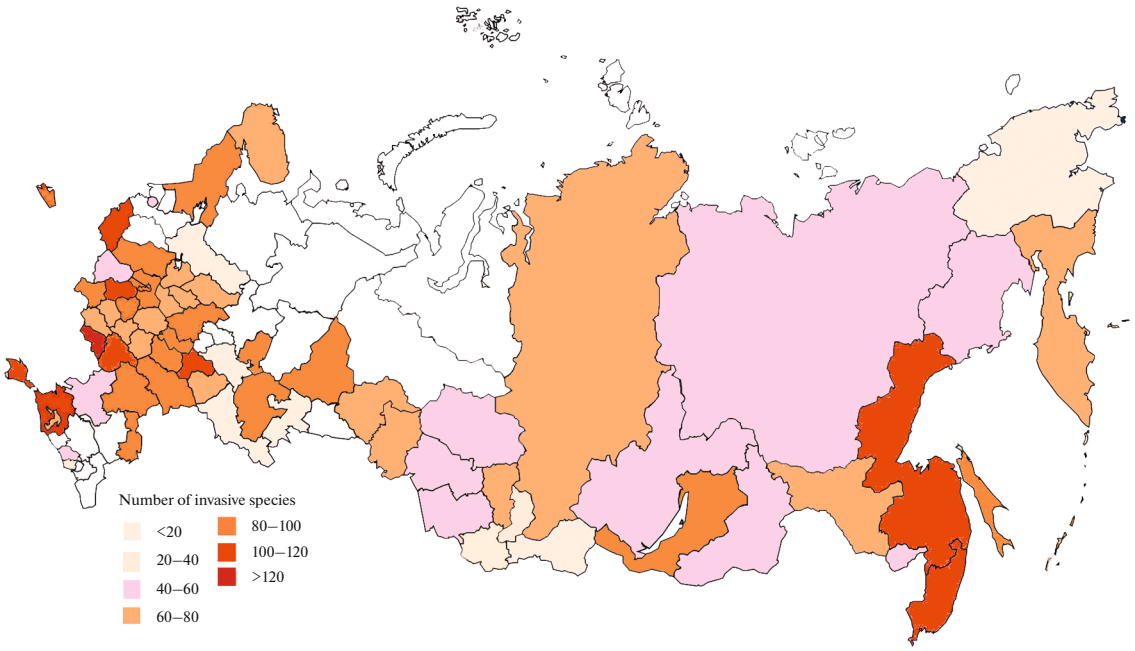

Fig. 1. Total number of invasive plant species in the administrative subjects of the Russian Federation.

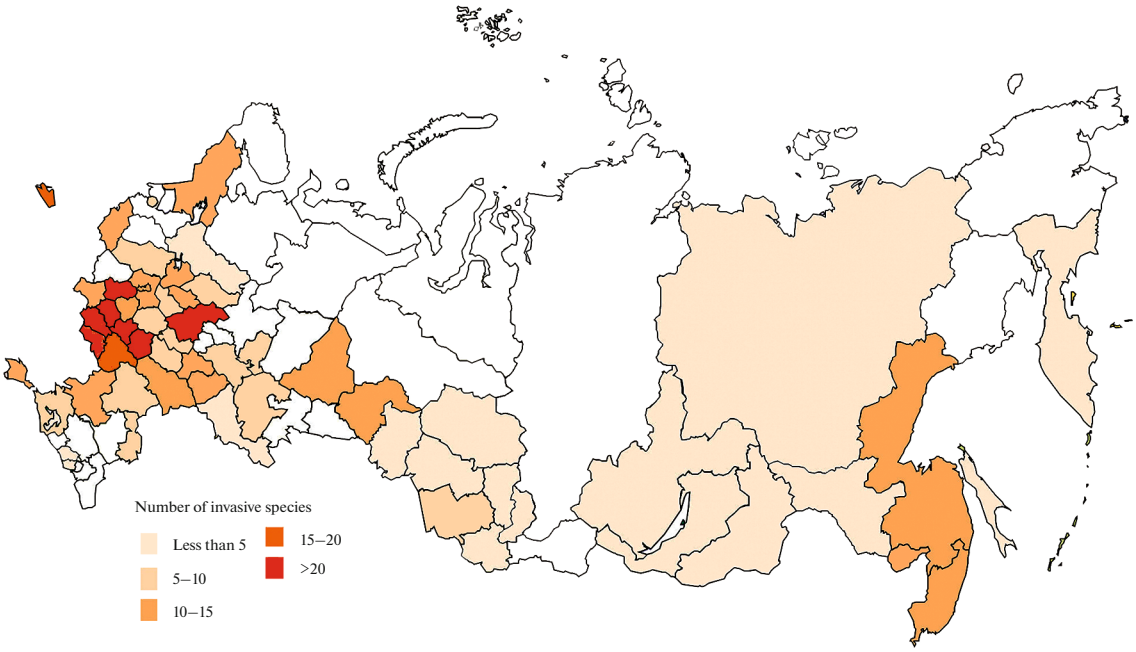

Fig. 2. Number of invasive plant species with the status 1 in the administrative subjects of the Russian Federation.

cies of the genera *Symphyotrichum*, etc.), are included in the list in their wide sense. This is associated with the fact that the control of such species should be part of the state policy in the field of environmental protection, and the methods of control of these closely related species are identical, regardless, for example, of the structure of the basket wrap and other small morphological traits.

Latin names of plants and last names of the authors of taxon are mainly given according to the database Plants of the World Online.[1] The distribution of the species by the families is given according to the classification of the phylogenetic group IV of angiosperms (Chase et al., 2016).

[1] http://plantsoftheworldonline.org.

Invasive Status

The distribution of the species according to the categories of their invasive status is traditionally performed according to the estimation of the level of aggressiveness of such species and the peculiarities of their distribution (Notov et al., 2010). Depending on the degree of expression of the main characteristics, the species were combined into groups with different statuses.

Status 1, transformer species that are actively introduced into natural and seminatural (natural–anthropogenic) communities; change the appearance of ecosystems; disrupt the succession relationships; act as edificators and dominants, forming single-species thickets of significant area; and displace and (or) prevent the renewal of natural flora species.

Status 2, alien species actively spreading and naturalizing in disturbed seminatural and natural habitats.

Status 3, alien species that are currently spreading and naturalizing in disturbed habitats; in the course of further naturalization, some of them will apparently be able to invade seminatural and natural communities.

Status 4, potentially invasive species that are able to regenerate in places of introduction and manifested themselves as invasive species in adjacent regions.

RESULTS

Inventory Results

At present, the invasive flora of Russia is represented by 584 vascular plant species from 87 families (Supplementary Information A). The most common invaders (according to the number of administrative subjects in which they were registered) were established: *Acer negundo* (is found in 60 subjects out of 65), *Echinocystis lobata* (57), *Erigeron canadensis* (54), *Impatiens glandulifera* (53), *Amaranthus retroflexus* (53), *Helianthus tuberosus* (52), *Lepidium densiflorum* (50), *Hordeum jubatum* (49), *Solidago canadensis* (49), *Matricaria discoidea* (48). For comparison, the most common invasive plants in the world are as follows: *Lantana camara*, *Calotropis procera*, *Pontederia crassipes* (*Eichhornia crassipes*), *Sonchus oleraceus*, *Leucaena leucocephala*, *Centaurea solstitialis*, *Acanthospermum hispidum*, *Galinsoga parviflora*, *Lonicera japonica*, *Cenchrus purpureus* (*Pennisetum purpureum*) (Pyšek et al., 2017). The list of the most common invasive plants in the world is compiled from the materials contained in the CABI Invasive Species Compendium),[2] in the ISSG Global Invasive Species Database,[3] and in the Invasive Plants of the World Database (Weber, 2003). This list is far from complete and does not cover the entire diversity of invasive plant species, since the studies are conducted not in all regions of the world and invasive plants were identified not in all regions. However, today this is the only analytical generalization carried out on a global scale.

Not all invasive species that are the most widespread in Russia are simultaneously the most aggressive. Although some of these species were registered in most regions, they have a low invasive status. Nevertheless, one-fifth of invasive species (107 out of 584) have the status 1 (transformer species) in any of the federal districts. Such a high index draws attention to the need for urgent control of biological invasions at the legislative level. *Elodea canadensis* is the only species registered in all federal districts with the status 1 (transformer species). *Acer negundo* and *Echinocystis lobata* are recognized as transformer species in seven federal districts. Another five invasive plant species have the status 1 in six federal districts and two species have this status in five federal districts (Table 1). Other transformer species are not so widespread (Fig. 3).

The blacklist of invasive species in Russia is quite labile and undergoes changes and additions: new aggressive alien plants annually appear; the invasive status of already detected species changes (unfortunately, more often upwards). Thus, only recently was an active distribution of *Cardamine occulta* noted across the territory of the European part of Russia (Leostrin and Maiorov, 2019). The invasive populations of *Thladiantha dubia* were registered in many regions (Kuluev et al., 2019). In the Asian part of Russia, *Wolffia arrhiza* was discovered, which successfully winters and formed extensive thickets with an area of hundreds of square meters in the floodplain reservoirs of the Ob River (Kipriyanova et al., 2021).

Currently available data make it possible to conduct monitoring studies of biological invasions and alien species; however, high dynamics of the invasive component determines the need to continue the inventory works, especially in poorly studied regions.

Peculiarities of Geographical Distribution

The species diversity of invasive species depends on climatic conditions, population density, and the area of the urbanized territory of some regions (González-Moreno et al., 2014; Essl et al., 2019). For the territory of Russia, such patterns have not yet been detected because of the lack of a single list of invasive plants; however, previously (Vinogradova et al., 2018), significant differences in the representation of life forms between the European, Siberian, and Far Eastern biogeographic regions were established; at the same time, perennial herbaceous plants were predominant in the Far East, while shrubs were predominant in the European part of Russia.

The conducted study allowed us to make a conclusion that the invasive species of vascular plants are distributed unevenly across the federal districts. In the

[2] http://www.cabi.org/isc.
[3] http://www.iucngisd.org/gisd.

Table 1. The most common and aggressive species of invasive flora in Russia

Species (family)	Number of subjects of the Russian Federation in which the species is registered	Number of federal districts in which the species is registered	Number of federal districts where the species has status 1	Primary area
Elodea canadensis (Hydrocharitaceae)	45	8	8	North American
Acer negundo (Sapindaceae)	60	8	7	North American
Echinocystis lobata (Cucurbitaceae)	57	8	7	North American
Solidago canadensis (Asteraceae)	49	8	6	North American
Bidens frondose (Asteraceae)	42	8	6	North American
Erigeron canadensis (Asteraceae)	54	8	6	North American
Heracleum sosnowskyi (Apiaceae)	40	7	6	Caucasian
Lupinus polyphyllu (Fabaceae)	43	7	6	North American
Impatiens glandulifera (Balsaminaceae)	53	8	5	South Asian
Erigeron annuus (Asteraceae)	40	6	5	North American

Southern Federal District, 263 species were registered; in the Northwestern, 229; in the Central, 228; in the Volga, 226; in the Far Eastern, 142; in the Ural, 134; in the Siberian, 116; in the North Caucasian, 66 species (Figs. 1 and 2). The distribution of species by the invasive status categories for each federal district is given in the Supplementary Information B.

The largest number of invasive species was registered in Belgorod oblast (125), Krasnodar (119) and Primorsky (113) krais, and Pskov oblast (113). The attention is drawn to the fact that the largest number of invasive species was registered in the regions with not the highest floristic diversity. This can probably be explained by the fact that the compilers of the lists followed the recommendations of European authors on compiling a list of 100 most dangerous alien species (Genovesi and Scalera, 2007). At the same time, not all alien plant species are invasive. In addition, the required number of invasive plants is found not in all regions, and where, nevertheless, the list includes 100 species, the impression of some artificiality of it is created (such lists include archeophyte species that, although they are found in abundance in seminatural habitats, have a low invasive potential, for example, *Lactuca tatarica* and *Sisymbrium loeselii*, and ephemerophytes, for example, *Euphorbia peplus*, or colonophytes).

Lists of invasive plant species are absent for 17 administrative subjects. Among them, there are floristically rich regions (the Republics of Dagestan and Ingushetia, the Karachay-Cherkess Republic, Stavropol krai), as well as regions with a high anthropogenic load (Leningrad oblast and the Chuvash Republic). Data are fragmentary for six more subjects

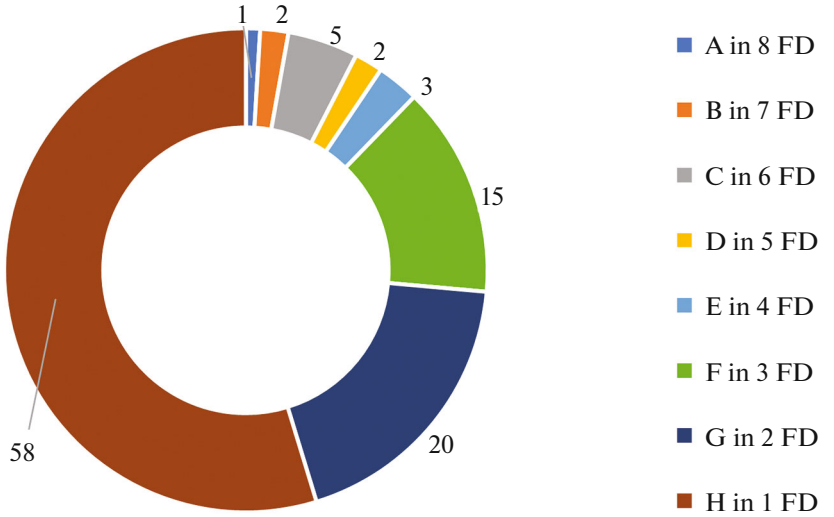

Fig. 3. Number of transformer species (the highest invasive status) by federal districts (FD).

(Vologda, Rostov, and Smolensk oblasts, as well as the Republic of Tatarstan and Orenburg and Chelyabinsk oblasts, which are well studied in floristic terms).

Issues of Management of Invasive Plant Species in Russia

Since the distribution of invasive plant species negatively affects the state of the environment, it is necessary to pay special attention to the issues of controlling their numbers and dispersal. Previously, a brief overview of the sources of legislative regulation of biological invasions in Russia was presented (Senator and Rozenberg, 2017). Unfortunately, we have to state that so far both legislative acts regulating the policy in the field of invasive species (legal regulation of plant quarantine is an exception) and a national strategy for alien species are absent in Russia. Moreover, none of the normative acts relating to alien species contain any interpretation of the concepts (alien species, invasive alien species, biological invasion) or specific regulations devoted to the control of the import, use, and distribution of alien species on the territory of Russia (Netsvetova, 2022). We note that the legislations, for example, of the Republics of Moldova, Belarus, and Ukraine operate with the concept "invasive alien plant species," which corresponds to the established international practice in this field (Tulina, 2019). It should also be noted that namely the legislative acts provide a legal basis for the efficient management of biological invasions (Tulina, 2019; Lodge et al., 2006; Baquero et al., 2021). It is also important to emphasize that the very absence of laws is a factor contributing to the spread of invasive species (Richardson et al., 2003).

Federal Law no. 492-FZ "On Biological Safety in the Russian Federation" accepted on December 30, 2020, which establishes the basis for the state regulation in the field of providing the biological safety in the Russian Federation and determines a complex of measures aimed at protecting the population and protecting the environment from the effects of hazardous biological factors, at the prevention of biological threats, and at the creation and development of a system for monitoring biological risks, is focused on pathogenic biological agents (microorganisms, viruses, prions, toxins) and contains no information about alien plants. This situation is of a concern, since the biological invasions are currently considered as one of the types of biological pollution (Tulina, 2019).

In the Strategy and Plan of Actions for the Conservation of Biological Diversity in the Russian Federation (*Strategiya i Plan*..., 2014) that provide for the implementation of measures in 2015–2020, the identification and ranking of invasive alien species and pathways of their introduction and spread are designated as one of the national targets; for the priority species, this includes the implementation of management or eradication measures. To estimate the implementation of this task, the following set of indices was distinguished:

(a) the total number of detected alien species categorized by the main taxonomic groups and habitats;

(b) the portion of detected alien species (% of the total number of fauna and flora species);

(c) the total number of detected invasive alien species categorized by the main taxonomic groups and habitats;

(d) the portion of detected invasive alien species (% of the total number of detected alien species);

(e) the portion of detected invasive alien species for which the control and eradication measures are implemented (% of the total number of detected invasive alien species);

(f) the portion of invasive corridors on which the control is established and measures are implemented to regulate the introduction of alien species.

We have to state that the set tasks (particularly, points "a" and "b") are not completely realized. The development of a general list of alien plant species is complicated (Vinogradova et al., 2015), first, owing to taxonomic disagreements in the interpretation of the scope and nomenclature of a number of taxa. Second, the same taxon can be native in the European part of the country and alien in the Asian part (or vice versa). The lists of alien species of local territories are compiled for the regions covering about 80% of the area of the country (Vinogradova et al., 2021). According to the published data, 1203 alien plant species currently grow in Russia (Essl et al., 2019). This is a greatly underestimated number, since the diversity of alien plants is 1354 species just in the Moscow region (Maiorov et al., 2020). If we take into account the fact that the number of naturalized species ranges from 2000 to 3500 on all continents (with the exception of Antarctica) (Pyšek et al., 2017), as well as the hypothesis that more than 20% of plant species are alien on the continents (Rejmanek and Randall, 1994; Dogra et al., 2010), according to our estimations, this index is at least 3000 species in Russia.

As for the invasive species, the problems formulated in points "c," "d," and "e" are completed (this article just indicates this). According to data from 64 regions of the country, 584 invasive plant species were identified, which is about 10% of the number of alien species. Nevertheless, new invasive species are annually recorded in Russia, so monitoring of their distribution should not only be continued but also strengthened. In addition, the portion of invasive alien species in respect of which the measures of regulation and eradication are carried out is extremely low (no more than 1%!). *Acer negundo* (Nikolaeva et al., 2020) and *Heracleum sosnowskyi* (Kudryavtseva et al., 2009) can be example of such species.

Regarding point "f," it should be said that the list of invasive corridors (invasion vectors) of alien plant

species was developed, but the regulation of the number of alien plants is carried out completely only on agricultural lands and roadsides of highways and railways (as a part of general weed control). The implementation of measures to regulate the introduction of alien species is currently performed only in botanical gardens. In this regard, the publication of the Code of Management of Invasive Alien Plant Species in the Botanical Gardens of the CIS Countries (*Kodeks*..., 2015), developed by the Commission on Invasive Plant Species operating under the Council of Botanical Gardens of the CIS countries under the IAAS, was an important step.

A significant contribution of research institutes (including botanical gardens) to the study of invasive plant species and identification of ways to combat them should be emphasized here. As a rule, namely the employees of these organizations carry out the identification and inventory of the invasive species, identification of sources of introduction and habitats, study of interaction with native species. The results of these works contribute to the understanding of the peculiarities of naturalization, reproduction, and distribution of the invasive species, estimation of their effect on native species, and efficiency of the used control methods.

It should be noted that the efficient management of biological invasions can work in the case where the general public is aware of the adverse effects of biological invasions. Considering that the number of specialists is always limited, it is necessary to take into account the role of the general population (and, first of all, scientific volunteers) in the management of the invasive species. A recent study (Ebel', 2021) demonstrated how "civil science" data can be useful in filling the gaps in knowledge about the distribution of invasive plant species. In just 2.5 years, about 12000 records about 98 invasive and potentially invasive plant species (uploaded by more than 800 observers) were collected in the project "Invasive Plants of Siberia" organized on the iNaturalist platform (Ebel', 2021). In Russia, there are social movements that deal with the problem of the invasion of the *Heracleum sosnowskyi* species (BorshcheViktori, Antiborshchevik, etc.). Being socially significant, the problem of the invasion of Sosnowsky's hogweed causes a great response among the population; therefore, many individuals are involved both in "civil science" projects (aimed at collecting information about Sosnowsky's hogweed) and in the direct control of this species. The experience accumulated by such social movements can be used to involve the volunteers in the control of other invasive species (Shaikina et al., 2022). These and similar projects associated with the early detection of invasive species become very important, since it is almost impossible to prevent the introduction of invasive species.

CONCLUSIONS

At present, the ecosystems modified by anthropogenic impact (which often contain a large number of alien species) predominate over a large territory of the Earth (Vitousek et al., 1987). Russia is not an exception; according to analytical estimations, 3000 alien species of vascular plants grow here. However, despite the intensive studies aimed at modeling potential changes in the distribution of organisms due to climate change and anthropogenic load, there is still great uncertainty in the predictions of what species will develop new regions and habitats and what will be the consequences of their invasion (Pyšek et al., 2020).

Our article contains the most complete list of invasive species of vascular plants growing on the territory of the Russian Federation (Supplementary Information A) with their distribution by categories of the invasive status for each federal district (Supplementary Information B). This list makes a powerful contribution to the studies of invasions and is also a basis for invasive species management and environmental regulation. We note that information on the distribution and number of invasive plant species in Russia is still insufficient; therefore, the collection of data on the number and sizes of populations and, if possible, monitoring the dynamics of alien species can form a basis for predicting their distribution and for developing and successfully implementing a strategy of managing the invasive species.

The absence of attention to the problem of invasive species can lead to significant socioeconomic consequences and cause an irreparable damage to ecosystems. In this regard, it is extremely important to address the issue of biological invasions at the state level and, first of all, the development of a national strategy on alien species and legislative acts regulating the policy in the field of invasive species. The development of common criteria for describing the populations of invasive species and their monitoring, as well as an increase in public awareness of the nature and consequences of the impact of invasive species, should be other important steps.

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COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest. The authors declare that they have no conflicts of interest.

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

SUPPLEMENTARY INFORMATION

The online version contains supplementary material available at https://doi.org/10.1134/S2079086423060130.

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