Genesis of the scientific discipline “Invasive Biology” in Russia

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Abstract. This article describes the chronology of scientific papers dealing with invasive biology. The genesis of this new discipline is characterized. The focus is on the study of invasions of plant organisms. The main tasks of the discipline are formulated and results are described. It is shown that over 40 years, single finds of alien plant species have turned into a list of invasive species in Russia, identifying the most significant invasion vectors, and determining the rate of microevolutionary changes in species of the secondary distribution range. The inventory data made it possible to conduct monitoring studies of biological invasions and alien species in general, which will help reduce the economic costs of combating invasive species. However, the dynamics of the invasive component determines the need to continue inventory work, especially in Siberia and the Far East.

1. Introduction
The founder of the science “bioinvasion” (the ability of alien species to expand the secondary distribution range and invade natural ecosystems) is Charles Elton. Discussions about this phenomenon were found in the works by other scientists. Ch. Darwin [1] wrote: “No one can tell untill he tries, whether ... any exotic plant seed freely under culture ... Lastly, when organic beings are placed during several generations under conditions not natural to them, they are extremely liable to vary” (Chapter VIII, p. 234). However, it was C. Elton who generalized the disparate data and used the term “invasion” in the title of his book [2].

Over the past 200 years, the flora and fauna has changed significantly: in some ecosystems, alien (non-native) species that have naturalized in their new homeland outnumber the native ones. Biological invasions threaten the biological diversity of the planet.

It is important to describe how the science on biological invasions was developing in Russia. The focus will be on plant invasion. The purpose is to characterize the genesis of the scientific discipline “Invasive Biology” in Russia on the basis of a chronological study of literary sources.

2. Materials and methods
The materials were literary sources: scientific articles on various aspects of the study of alien and invasive species, conference abstracts, PhD thesis, collections of meetings held in 1989-2020.
3. Results and discussion

3.1 The first stage (1927-1989)

The first scientific article on the fraction of alien plants called the “adventive flora” was written by Nazarov and published in 1927. The author showed that the number of introduced species sharply increases during the decline in agricultural culture and population migration [3]. Herbarium collections of non-native species are scattered, but in the 1970s this group of plants was studied by Tikhomirov and Skvortsov [4]. Since 1983, works by Makarov, Ignatov [5], Bochkin, and Chichev on the findings of alien plant species in Moscow region and Maitulina on alien species in Vologda were published [6].

In 1979, Maitulina guided by Skvortsov began to study biological characteristics of invasive species [7]. Since the term “invasion” was not used, the group was described as “plants belonging to different life forms, with different biology, brought in Russia at different periods and in different pathways. They have one thing in common: they undergo active naturalization and expansion of their secondary distribution range.” In the PhD thesis, the intraspecific variability of *Acer negundo*, *Echinocystis lobata*, and *Conyza canadensis* was studied by the method of creating experimental introduction populations from seeds of different geographical origin. Seeds were collected from the extreme northern (Arkhangelsk, Vologda) to the extreme southern (Ashgabat, Astrakhan) points of the secondary distribution range of species. The amplitude of the clinal variability of biomorphological characteristics of plants was revealed by the gradient of variation of soil and climatic conditions.

Thus, at the first stage of development of the scientific discipline, research objects (alien species and invasive species) were identified and a targeted search for new alien plant species began.

3.2 The second stage (1989-2002)

It is necessary to consolidate fragmented information. In order to coordinate research in Moscow, in 1989, the meeting on “Problems of Studying the Adventive Flora of the USSR” was held. 67 scientists from Ryazan, Tula, Voronezh, Moscow, Ivanovo, Kursk, Magadan and other regions made reports on alien plants [8]. It was proposed to use alien plants as a model for the study of microevolutionary processes.

The “boom” of floristic lists was the work “Abstract of the flora of alien plants of Moscow Region” published in 1990 [9]. It is an example of generalization of data on the flora of various regions.

The results of the study of microevolution in the 20 most aggressive alien plant species were summarized [10]. It was shown that microevolutionary processes in self-pollinators and cross-pollinating species proceed differently. In the first case, a genotype develops in the initial invasive population adapted to various climatic conditions, but morphologically homogeneous. In the second case, classical natural selection is observed. It contributes to the intraspecific variability of the biomorphological characteristics of plants.

Thus, the second stage is characterized by numerous lists of “adventive floras” and identification of patterns of microevolution of alien species in the secondary distribution range.

3.3 The third stage (2003-2014)

After a long break, in 2003, in Tula, the conference “Problems of Studying Adventive and Synanthropic Flora in the CIS Regions” was held. Geltman used the concept “invasive species” and presented the first list of invasive species (for the North-West of Russia). He also emphasized the need for a more detailed study of this group [11].

At this time, a growing wave of threats from alien species caused a need for joint efforts and adoption of fundamental documents. The document “Towards an EU Strategy on Invasive Species” aimed at developing policies and measures to create an early warning system for threats from invasive species (COM resolution 2008, paragraph 789) was adopted. According to one more document *Aichi Biodiversity Target 9*, «by 2020, invasive alien species and pathways are identified and prioritized,
priority species are controlled or eradicated and measures are in place to manage pathways to prevent their introduction and establishment» (https://www.cbd.int/invasive/doc/cbd-pathf-brochure-en.pdf.) Regulation EU № 1143/2014: (http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:JOL_2014_317_R_0003). It sets out rules to prevent, minimize and mitigate the adverse impact on biodiversity of the introduction and spread within the Union, both intentional and unintentional, of invasive alien species.

Since 2008, the Russian Journal of Biological Invasions and its Russian-language version (www.sevin.ru/invasjour/) have been published in Russia. They address urgent issues of invasive biology and assess risks of invasion effects on native ecosystems. By 2020, 45 issues have been published. More than a hundred articles were devoted to invasion of plant organisms.

The 2010 and 2012 conferences held in Izhevsk showed that Russian scientists continue to study the alien and synanthropic flora of Russia. In 2012, Vinogradova formulated 9 fundamental tasks of Invasive Biology [12]. The results obtained are as follows.

1) **An inventory of invasive species in Russian regions.** Methodological aspects of the “Black Books” and “black” lists of a region have been developed taking into account the level of aggressiveness and features of distribution of invasive species according to four invasive statuses. The Black Books of the flora of Central Russia [13], Tver Region, the Udmurt Republic and Siberia [14, 15], Nizhny Novgorod and Kaluga Regions [16, 17] were published. According to the unified methodology, lists of invasive species (“black” lists) of the Upper Volga region and the river Sura basin, the Middle Urals, Khabarovsk Territory, Bryansk and Voronezh Regions were compiled [18-23]. Information on invasive activities can be obtained from the book “Alien Flora of Moscow and Moscow Region” (2012).

2) **Identification of biological characteristics of invasive species**, which is important for the most aggressive species (with invasive status 1 and 2). Of particular interest are works in which wild and non-wild species are compared in terms of traits that make it possible to predict whether a species is invasive. Similar studies were conducted for species from the genera *Conyza*, *Galega*, *Robinia*, *Lupinus*, and *Caragana*.

3) **Comparative analysis of the invasive status of closely related alien species.** A methodology for the analysis was developed in 2014 on the example of the Leguminosae family

4) **Study of micromorphological characters of invasive species and assessment of their significance for taxonomy.** Diagnostic keys have been developed to identify species from the genera *Solidago*, *Bidens*, *Conyza* [24], *Aronia* by their micromorphological characteristics.

5) **Identification of naturalized species in botanical gardens.** Guided by the resolution of the Congress of European Botanic Gardens (Helsinki, 2009), Vinogradova developed the “Code of Conduct for Botanic Gardens on Invasive Alien Species”, which was adopted by the participants of the conference on biodiversity conservation (Yaroslavl, 2011) and approved at the First Organizing Congress of the Council of Botanical Gardens of the CIS countries under the International Association of the Academy of Sciences (Moscow, 2013). An analysis of the invasive potential of cultivated, weed and alien plants found on the territory of the botanical gardens was carried out at the GBS RAS and the botanical garden of Moscow State University [25], the botanical gardens of Tver, Voronezh and Kaliningrad universities [26-28].

6) **Identification of the most invasive communities** where direct removal of invasive species is expected. This work began in 2011. *Adenocaulon adhaerescens* which has spread widely along the paths of the GBS RAS was studied. An attempt to restrain the growth of *Impatiens glandulifera* along the Likhoborka River and *Solidago gigantea* in nearby deposits was made.

7) **Compilation of the glossary.** In 2018, the “The main terms and concepts used in the study of alien and synanthropic flora” was published [29]. Notes have been added to a number of terms, containing the etymology of names and interpretation used in foreign or domestic literature, corresponding to other classifications of alien plant species.

8) **Studying the evolution of the system of consortial relationships of invasive species** with both pathogens and phytophages and pollinating insects, and assessing the role of this factor in the further
4. **Expansion of introduced species.** As part of this task, in 1990-2010, systematic monitoring of phytophages and pathogenic organisms of *Ribes aureum* was carried out. The information suggests that during naturalization, pathogens adapt to alien plants. The duration of this process is determined by environmental conditions, the effect of anthropogenic factors and the age of the plantings. Most phytophages and phytopathogens are also found on other species of the genus *Ribes*. Thus, the hypothesis on the effect of phytophages and phytopathogens on the success of invasions of alien species in the secondary range is correct only at the initial stage of naturalization. In future, phytophages and pathogens of closely related species are actively included in the system “alien species - pathogen”.

9) **Creating a system for online tracking the distribution of invasive species.** This task is remote, only the first steps are being taken to implement it. For example, the site https://www.inaturalist.org/projects/flora-of-russia allows everyone post observations on the occurrence of invasive species in regions.

In the same period, it was noted that many invasive species can become new resource plants, since a significant part of them are “escapees from cultivation”, which possess economically valuable traits. Data on the medicinal, melliferous, food, silage and fodder benefits of invasive species are summarized [30]. The authors suggest collecting invasive species in ecologically clean secondary habitats. Thus, when harvesting invasive species in natural ecosystems, we use significant reserves of economically valuable raw materials and reduce the negative impact of alien plants on the biodiversity of the region.

The symposium “Invasion of Alien Species in Holartic”, the only international event dedicated to alien species and regularly held in Russia, played a crucial role in the development of research on biological invasions. The first symposium - Borok-1 - was held in 2001, the last one (Borok-5) - in 2017. The symposia analyzed causes and patterns of the anthropogenic settlement of species compared to the natural one; the influence of invasive species on the flora and fauna, characteristics of ecosystems were discussed [31].

3.4 **The fourth stage (2015-2020)**

The current stage is characterized by the completion of an inventory of alien and invasive species of Russia. In 2015, the Black-list of invasive plants of Russia was published by 50 scientists from 42 administrative regions. Due to the vast territory of the country, the compilation of a single list was inappropriate. It includes three blocks: the European part of Russia, Siberia and the Far East. 24 alien plant species are present in all the Russian regions.

The database on alien species of animals and plants of Russia has been created and patented, it is available on the Internet [32, 33]. The patterns of distribution of alien plants in different regions of Russia have been identified depending on the anthropogenic load on ecosystems [34]. The book “The Most Dangerous Invasive Species of Russia (TOP-100)” was published, which contains information on 100 species that are most dangerous for ecosystems [35]. For each species, original maps of natural and invasive ranges, invasive corridors and invasion vectors, biology features, effects on native species, ecosystems and humans, abundance control methods are presented.

The data obtained made it possible to conduct monitoring studies of biological invasions and alien species. However, the high dynamics of the invasive component determines the need to continue inventory work, especially in poorly studied regions.

4. **Conclusion**

The rapid emergence of new invasive species and their introduction into natural ecosystems have caused rapid development of invasive biology in Russia. During 40 years, single finds of alien species turned into a list of invasive taxa, specifying the most significant invasion pathways, and determining the rate of microevolutionary changes in species in the secondary distribution range. It is necessary to control the distribution of invasive species in Russia.
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