Influence of invasive flora species on the ecosystem of the Russian Far East

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Abstract. For the first time, based on the revision of herbarium collections, the resettlement of alien flora faction species in the Far Eastern Federal District (FEFD) was divided into four stages. Of the 117 invasive species of the Far Eastern Federal District, 47 ones were registered for the first time before the construction of the Trans Siberian railway, i.e. at the turn of the 1900s, 30 - from 1900 to World War II, 29 - from 1940 to 1980, i.e. before the targeted study of the alien flora faction, and 11 - from 1980 to the present. The data on scientists who played a key role in the study of the flora of the Far Eastern Federal District is presented. Seven species are only beginning to invade natural plant communities, 88 species are actively invading natural plant communities and 22 species belong to the “transformers”, which actively invade themselves into natural and seminatural communities, change the physiognomy of ecosystems, disrupt succession links, forming large single-species dense stands and force out and (or) obstruct the reproduction of aborigine species.

1. Introduction
The most important ways of biodiversity conservation are prevention, minimization and mitigation of negative impacts on natural ecotopes from invasive alien species [1]. The revision of alien species is recognized as the primary task, which allows for assessing the degree of disturbance of the territory, characterizing the distribution of alien species and predicting the rate of their dispersal [2-3].

In Russia, revision of alien species is progressing rapidly [4]. In 2020, a list of invasive species (“black” -list) was published for the Far Eastern Federal District (FEFD), covering 40.6% of the Russian area [5]. The list summarizes data on 11 regions of the Far Eastern Federal District: the Amur Region, the Republic of Buryatia, the Jewish Autonomous Region, the Trans-Baikal Territory, the Kamchatka Territory, the Magadan Region, the Primorsky Territory, the Republic of Sakha (Yakutia), the Sakhalin Region, the Khabarovsk Territory, and the Chukotka Autonomous District. At present, an analysis of information on the species included in this list is being carried out, and the database of their herbarium collections is being replenished.

The article is a review of data on invasive alien species in the Far Eastern Federal District and periodization of the stages of their dispersal.

2. Materials and methods
Generalization of literature data on the results of scientific expeditions in the region since the beginning of the 19th century. Revision of herbarium collections in the largest herbarium storage facilities: MHA, MW, LE, MIMB, VBGI, VLA, MAG, SASY.
3. Results and discussion
The “Black” list of the Far Eastern Federal District includes 117 invasive alien species belonging to 99 genera from 32 families. According to the dates of their first recorded finds, four groups of species were identified: 1) found during the first natural scientific expeditions of the 19th century before the construction of the Trans-Siberian Railway; 2) found before World War II, 1900-1940; 3) found before the “boom” of the study of adventive species, 1941-1980; 4) registered in the last decades, 1980-2020.

3.1. Stage 1. The first natural science expeditions of the 19th century.
From the end of the 16th century, detachments of Russian Cossacks began to penetrate into Transbaikalia and the Amur region. They founded small fortified settlements there. By the beginning of the 19th century, Russia had already developed the lands in the basins of the Lena, Aldan, Kolyma and Anadyr rivers, the coast of the Okhotsk Sea, Kamchatka and the Kuril Islands. However, the expansion to the Far East continued. Herbarium labels collected lack dates of collection or names of collectors, and the decoding of the labels is like an investigation. The oldest herbarium specimen (1792) was collected by I. Sivers (1762-1794). In 1790, he was assigned to an expedition equipped by the Medical College for the botanical and resource study of Siberia and traveled from the Urals to Dauria. Almost half of the old collections (21 species) belonged to N.S. Turchaninov (1792-1863). For several years (1830-1834), he was a member of the Academy of Sciences as "a scientist traveler from Altai to the Eastern Ocean". Sometimes only Inter Jacutiam et Ochotiam is listed on the labels, but in most cases both the date and place of collection can be discerned.

The Russian Geographical Society, created in 1845, played an important role in organizing geographical expeditions to explore Eastern Siberia and the Far East. One of the founders of the Siberian branch of the Russian Geographical Society was Yu.I. Stubendorf (1811-1878). In 1844-1848 he collected plants at Munku-Sardyk; in 1848-1862 as a naturalist and physician, he accompanied N. Muravyov-Amursky, the Governor-General of Eastern Siberia N, on a trip to Siberia (Irkutsk - Yakutsk - Okhotsk - Petropavlovsk port - Ayan - Yakutsk - Irkutsk) and conducted ethnographic, archival and botanical research. Yu.I. Stubendorf gave his collections to St. Petersburg Botanical Garden, where K.A. Meyer dealt with them. Our database contains information on 13 alien species collected by him.

In 1853-1854, expedition by R. Maak (1825-1886) explored the vast territory of the Vilyuy basin and part of the basin of the Olenek River. A year later, R. Maak headed the Amur expedition and explored the Amur region (1855-1856) and the valley of the Ussuri River (1859-1860). On these territories, he found four alien species.

The study of the flora of the Far East by Russian botanists was initiated by Academician K.I. Maximovich (1827-1891). In 1854 the frigate "Diana" made a round-the-world voyage, entered the De-Kastri bay and remained in the Amur region until 1857 because of the war. With great difficulties, Maksimovich investigated the vegetation of this unknown land and collected a rich herbarium collection. In 1859, Maksimovich undertook a new journey through Siberia to Irkutsk, Transbaikalia, along the Sungari and Ussuri Rivers to Nikolaevsk and then to Japan. The 24 oldest herbarium collections of alien species bear the signature "Maxim."

In the spring and summer of 1855, L.I. Shrenk (1826-1894) set off from Nikolaevsk up the Amur river, reached the mouth of the Ussuri river and ascended to the mouth of the Khor river. In the winter of 1855-1856, he made several trips along the western coast of Sakhalin and to the valley of the Tym River.

On Steven's recommendation, G.I. Radde (1831-1903) was chosen as a collector. His travels lasted five years. In 1855, Radde traveled around Lake Baikal on a fishing boat, visited the mouth of the Upper Angara, the Barguzin Bay, and reached Lake Goose in the Selenga district by dry route. 1856 was devoted to the study of the Dauria steppes and the Chokondo mountains in the Trans-Baikal
Territory along the route Verkhneudinsk - Chita - Nerchinsk plant - Argun – the Sokhondo peak. In 1857 and 1858, Radde walked from Chita to the mouth of the Ussuri river, and in 1859 he explored the eastern part of the Sayan Range, Tunka, Nilova Pustyn and Munku-Sardyk.

In 1867-1869, the Ussuri region was studied by N.M. Przhevalsky (1839-1888). He was the first to emphasize the unique combination of northern and southern flora elements in the Ussuri taiga. The BIN herbarium contains samples of three alien species collected from the vicinity of Lake Khanka and the Ussuri basin: *Thlaspi arvense*, *Capsella bursa-pastoris*, and *Brassica juncea*.

A.L. Chekanovsky, I. D. Chersky and F.M. Avgustinovich, exiled to Siberia after the Polish uprising of 1863 contributed to the study of alien species. Many herbarium collections (16 alien species) belong to F.M. Avgustinovich (1809-1891). In 1871 as a member of the commission Avgustinovich went to Sakhalin to study the conditions of hard labor, and in 1872-1873 he traveled to Primorye, Irkutsk and Tobolsk provinces. In 1874, as a member of the medical commission Avgustinovich traveled through the Vilyui District of Yakutia and in 1875-1876 - from VerkhneKolymsk to the mouth. In 1879 and 1880, he visited Sakhalin, accompanying exiles.

In 1889-1893, F.K. Karo (1845-1927) herbarized plants from the vicinity of Nerchinsk, and in 1897-1902 and 1910-1913 he worked in Blagoveschensk and Zeiskaya Pristan (the Amur Region). During his stay in Russia, he collected 80 thousand plant samples.

Many first collections of alien species belonged to N.A. Palchovsky (1862-1909). He worked as a forester in Suchan, and in 1899-1907, he was a military forester of the South Ussuri region. He was a friend and mentor of V.K. Arsenyev; as a botanist he participated in his 1906 Sikhote-Alin expedition and in some earlier campaigns.

In total, this stage includes the collection of 47 alien species: *Amaranthus retroflexus* (Amaranthaceae), *Carum carvi*, *Pimpinella saxifraga* (Apiaceae), *Achillea millefolium*, *Arctium lappa*, *Artemisia annua*, *A. sieversiana*, *A. vulgaris*, *Crepis tectorum*, *Helianthus tuberosus*, *Lepidotecca suaveolens*, *Senecio vulgaris*, *Sonchus oleraceus*, *Tripleurospermum inodorum*, *Tussilago farfara*, *Xanthium strumarium* (Asteraceae), *Brassica juncea*, *Capsella bursa-pastoris*, *Descurainia sophia*, *Lepidium densiflorum*, *Thlaspi arvense*, *Turrritis glabra*, *Velarum officinale* (Brassicaceae), *Cannabis sativa*, *Humulus lupulus* (Cannabaceae), *Cerastium holosteoides* (Caryophyllaceae), *Convolvulus arvensis* (Convolvulaceae), *Cuscuta europaea* (Cuscutaceae), *Hippophae rhamnoides* (Elaeagnaceae), *Euphorbia virga* (Euphorbiaceae), *Medicago lupulina*, *Melilotus albus*, *Trifolium pratense*, *T. repens* (Fabaceae), *Glechoma hederacea* (Lamiaceae), *Linaria vulgaris*, *Plantago major*, *Veronica peregrina* (Plantaginaceae), *Festuca pratensis*, *Hordeum jubatum*, *Phleum pratense*, *Poa annua*, *P. compressa* (Poaceae), *Potentilla multifida*, *P. norvegica*, *Rubus idaeus* (Rosaceae), *Galium aparine* (Rubiaceae).

With rare exceptions, these are ruderal species common for European Russia, introduced into the region unintentionally, mainly as weeds of crops. These plants are widespread in the Far Eastern Federal District (on average, in 9-10 subjects out of 11). However, they are weakly competitive; for such a long time they populated all possible ecological niches and are no longer perceived as alien. It does not make sense to take any special measures to control their numbers beyond the usual weed control measures.

3.2. Stage 2. Expeditions of the first half of the 20th century, from the commissioning of the Transsib to World War II

The construction of the Trans-Siberian Railway has significantly increased the volume of alien plant species. The Great Siberian Route was put into operation in 1903, but for two more years trains were transported across Baikal Lake on a special ferry. V.L. Komarov studied the nature of the Far East in 1895 and showed interest in this region until the end of his life. V.L. Komarov substantiated the identification of a special “Manchurian” floristic region and wrote two works: “Flora of the Kamchatka Peninsula” and “Keys to Plants of the Far Eastern Territory.”

One of the founders of the Trans-Baikal branch of the Geographical Society was G.A. Stukov (1845-1912). He made the first botanical collections in the vicinity of Nerchinsk. In 1908, he took part
in an expedition aimed to explore the Aginsk steppe and collected an extensive herbarium of plants. He collected 28 alien species out of 38 registered in the Trans-Baikal Territory.

During this period, there was an increase in the agricultural colonization of the region, which was an incentive for the study of the flora of Eastern Siberia and the Far East. The scientific substantiation of colonization was presented by the Soil-Botanical Expeditions of the Resettlement Administration of the Department of Agriculture. The search groups consisted of a soil scientist and a botanist. For 8 years (1908-1914) at least 50 (!) expeditions to Siberia and the Far East were organized. They collected about 200 thousand herbarium sheets, which made it possible to compile the summary "Flora of Asiatic Russia" [6].

In the Siberian regions of the Far Eastern Federal District (Yakutia, Buryatia, Trans-Baikal Territory), collections of alien species made by P. Mikhno, A. Zhukova, M. Korotkiy and P. Nikolaev, K.F. Trofimova and V.E. Rudnitsky, N. Shipchinsky, Y. Tsinzerling, M.P. Tomin, V. Sukachev and G. Poplavskaya, V. Drobov and A. Tarabukin prevail. In Primorye, the main collections of alien species were made by V.L. Komarov and E. Alisova, L. Bulavkina, I.K. Shishkin, M.F. Grishko, N.A. Desulavi, I.V. Popov, I.V. Zhirov, V. Petrov.

This stage includes the collection of 30 alien species: Arctium tomentosum, Bidens frondosa, Cirsium setosum, Conyza canadensis, Cyclachaena xanthiifolia, Galinsoga parviflora, Leontodon autumnalis, Taraxacum officinale (Asteraceae), Impatiens glandulifera (Balsaminaceae), Echiurn vulgare (Boraginaceae), Armoracia rusticana, Berteroa incana (Brassicaceae), Scleranthus annuus, Spergula arvensis (Caryophyllaceae), Echinocystis lobata (Cucurbitaceae), Cuscuta campestris (Cuscutaceae), Lotus corniculatus, Trifolium arvense, T. campestre, T. hybridum (Fabaceae), Juncus tenuis (Juncaceae), Galeopsis ladanum (Lamiaceae), Oenothera biennis (Onagraceae), Xanthoxalis corniculata (Oxalidaceae), Odontites vulgaris, Verbascum thapsus, Veronica chamaedrys, V. scutellata (Plantaginaceae), Elymus novae-angliae (Poaceae), Alchemilla subcrenata (Rosaceae). These plants are not as widespread in the Far Eastern Federal District as the first group (on average, in 6-7 regions out of 11), they are mostly ruderal and synanthropic weeds.

3.3. Stage 3. Study of the flora of Eastern Siberia and the Far East after the Second World War and until 1980 - the "boom" in the study of adventive species.

In the post-war period, the anthropogenic disturbance of the territory increased, which contributed to the emergence of many new alien species. In this period, herbarium collections were made by M.N. Karavaev, who since 1938 studied the vegetation cover of Yakutia and in 1951-1954 was a member of the Yakutsk expedition of the Council for the Study of Productive Forces. It is necessary to mention the numerous botanical expeditions to the Far East by V.N. Voroshilov, D.P. Vorobiev, P.G. Gorovoy and A.I. Schreter. The alien plants collected by them are stored in the leading herbarium storages, and the data of colonization was presented by the Soil-Botanical Expeditions of the Resettlement Administration of the Department of Agriculture. The search groups consisted of a soil scientist and a botanist. For 8 years (1908-1914) at least 50 (!) expeditions to Siberia and the Far East were organized. They collected about 200 thousand herbarium sheets, which made it possible to compile the summary "Flora of Asiatic Russia" [6].

In the Siberian regions of the Far Eastern Federal District (Yakutia, Buryatia, Trans-Baikal Territory), collections of alien species made by P. Mikhno, A. Zhukova, M. Korotkiy and P. Nikolaev, K.F. Trofimova and V.E. Rudnitsky, N. Shipchinsky, Y. Tsinzerling, M.P. Tomin, V. Sukachev and G. Poplavskaya, V. Drobov and A. Tarabukin prevail. In Primorye, the main collections of alien species were made by V.L. Komarov and E. Alisova, L. Bulavkina, I.K. Shishkin, M.F. Grishko, N.A. Desulavi, I.V. Popov, I.V. Zhirov, V. Petrov.

This stage includes the collection of 30 alien species: Arctium tomentosum, Bidens frondosa, Cirsium setosum, Conyza canadensis, Cyclachaena xanthiifolia, Galinsoga parviflora, Leontodon autumnalis, Taraxacum officinale (Asteraceae), Impatiens glandulifera (Balsaminaceae), Echiurn vulgare (Boraginaceae), Armoracia rusticana, Berteroa incana (Brassicaceae), Scleranthus annuus, Spergula arvensis (Caryophyllaceae), Echinocystis lobata (Cucurbitaceae), Cuscuta campestris (Cuscutaceae), Lotus corniculatus, Trifolium arvense, T. campestre, T. hybridum (Fabaceae), Juncus tenuis (Juncaceae), Galeopsis ladanum (Lamiaceae), Oenothera biennis (Onagraceae), Xanthoxalis corniculata (Oxalidaceae), Odontites vulgaris, Verbascum thapsus, Veronica chamaedrys, V. scutellata (Plantaginaceae), Elymus novae-angliae (Poaceae), Alchemilla subcrenata (Rosaceae). These plants are not as widespread in the Far Eastern Federal District as the first group (on average, in 6-7 regions out of 11), they are mostly ruderal and synanthropic weeds.

This stage includes the collection of 29 alien species: Pastinaca sylvestris (Apiaceae), Ambrosia artemisiifolia, Aster novi-belgi, Carduus acanthoides, Galinsoga quadriradiata, Lactuca serriola, Phalacroloma annuum, Pilosella aurantiaca, Rudbeckia hirta, Senecio viscosus, Solidago canadensis, S. gigantea (Asteraceae), Impatiens parviflora (Balsaminaceae), Nonea rossica (Boraginaceae), Bunias orientalis, Hesperis matronalis (Brassicaceae), Campanula rapunculoides (Campanulaceae), Saponaria officinalis (Caryophyllaceae), Lupinus polyphyllus, Robinia pseudoacacia, Vicia tetrasperma (Fabaceae), Centaurium pulchellum (Gentianaceae), Hypericum perforatum (Hypericaceae), Siyринчium septentrionale (Iridaceae), Rhinanthus minor (Orobanchaceae), Dactylis glomerata (Poaceae), Microcerasus tomentosa, Physocarpus opulifolia (Rosaceae), Solanum nigrum (Solanaceae). These plants are distributed quite locally in the Far Eastern
Federal District (on average, in 4-5 subjects out of 11), however, among them there are truly aggressive invasive species, in particular, *Ambrosia artemisiifolia*.

### 3.4. Active and purposeful search for alien species and study of biological invasions (1980-present)

Since the 1980s, special publications on alien species and floristic summaries began to appear [8-10]. All data on the alien flora of the Russian Far East known by the end of the 20th century were summarized by V.N. Voroshilov [11] and the authors of "Vascular Plants ..." (1985–1996) and "Flora of the Russian Far East ....". A great contribution to the identification of the alien flora fraction was made by A.K. Skvortsov, N.N. Tsvelev, S.G. Kudrin, and M.S. Ignatov.

The modern generalization of information on alien species, on the basis of the computer database "Flora of the Russian Far East", was carried out by A.Ye. and Z.V. Kozhevnikovs [12].

In the last decade, data on the invasive species of the Far Eastern Federal District began to be published. These include the Black Book of Siberia [13], summaries on regional floras [14-15], as well as articles on some of the most aggressive, including quarantine, species: coltsfoot, ragweed, ash-leaved maple, amorph, robinia, sea buckthorn, cyclachene, dodder, etc. [16-17].

This stage includes the first collection of 11 alien species: *Acer negundo* (Aceraceae), *Aegopodium podagraria*, *Heracleum sosnowskyi* (Apiaceae), *Aster novae-angliae*, *Xanthium albinum* (Asteraceae), *Symphytum caucasicum* (Boraginaceae), *Cakile edentula* (Brassicaceae), *Knautia arvensis* (Dipsacaceae), *Amorpha fruticosa* (Fabaceae), *Elodea canadensis* (Hydrocharitaceae), *Parthenocissus inserta* (Vitaceae). These plants are distributed rather locally in the Far Eastern Federal District (on average, in 3-4 regions out of 11). However, they are the most aggressive invasive species and require special control measures. It is necessary to monitor their dispersal and annually destroy the invasive populations.

Thus, of the 117 invasive species of the Far Eastern Federal District, 40% were found at the first stage of studies of the flora, 26% - at the second stage, 25% - at the third stage, and 9% - at the fourth stage. Seven species are found only in two regions of 11, seven species - in three regions 12 species - in four regions. The largest number of species (19) was found in five out of 11 regions. 10 species were found in six regions, 12 species - in seven regions, 7 species - in eight regions, 15 species - in nine regions, 17 species - in ten regions. In all 11 regions, 11 alien species are represented (Fig. 1).

**Figure 1.** The relationship between the number of regions where the alien species was found and the number of species recorded at each stage of distribution. Horizontally - the number of regions of the Far Eastern Federal District, vertically - the number of species in this number of regions.

Representation of species in the regions positively correlates with the time of their introduction. In all 11 regions of the Far Eastern Federal District, there are only those species that were registered...
before 1900; in 10 regions, species were registered before 1900 and one species was registered at the second stage of the study. Conversely, among the species growing in only two regions, there are no “old” species, but the dominant species are those found in recent decades. At the same time, locally distributed and only recently discovered alien plants are the most aggressive invasive species that require special control measures.

Seven species are only beginning to invade natural plant communities, 88 species are actively invading natural plant communities. Twenty-two species belong to the “transformers”, which actively invade natural and seminatural plant communities, change the physiognomy of ecosystems, disrupt succession links, form single-species dense stands significant in area and force out and (or) obstruct the reproduction of aborigine species: Acer negundo, Heracleum sosnowskyi, Pastinaca sylvestris, Ambrosia artemisiifolia, Bidens frondosa, Cirsium setosum, Galinsoga parviflora, Phalacrocorax anuun, Solidago canadensis, S. gigantean, Sonchus oleraceus, Impatiens glandulifera, Symphytum caucasicum, Humulus lupulus, Echinocystis lobata, Cuscuta campestris, Hippophae rhamnoides, Lupinus polyphyllus, Elodea canadensis, Glechoma hederacea, Xanthoxalis corniculata, Hordeum jubatum.

4. Conclusion
Of the 117 invasive species of the Far Eastern Federal District, 47 ones were registered for the first time before the construction of the Transsib, i.e. at the turn of the 1900s, 30 - from 1900 to World War II, 29 - from 1940 to 1980, i.e. before the start of the study of the alien faction of the flora, and 11 species - from 1980 to the present. There is a positive correlation between the duration of growth of an alien species and its representation in 11 regions of the Far Eastern Federal District and a negative correlation between the duration of growth and invasive activity of the species.

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