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Powdery Mildews (Helotiales, Erysiphaceae) of Anthropogenic and Natural Communities of Taimyr (Arctic Siberia)

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Abstract—Economic development of the Arctic contributes to distribution of new alien fungal species to the north. In the Taimyr region, 38 species of powdery mildew fungi have been identified, 25 of which are new for the region. Alien and cryptogenic species account for 52.6% of powdery mildew fungi. Fungi were found on 53 host plant species, 28 of which are new for the Russian Arctic. Among the host plants, the share of alien and cryptogenic species is 45.3%. In contrast to the data for alien flora, the proportion of alien species in the mycobiota decreases from north to south, although this result requires further verification.

Keywords: alien species, Arctic, climate change, microfungi

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INTRODUCTION

The development of the economic potential of the Russian Arctic is one of the state's priority tasks (*Strategiya razvitiya Arkticheskoi zony*..., 2020). Owing to increased economic activity, there is a potential for an increase in the number of cases of alien species being introduced into Arctic regions, whose negative impact on natural and transformed ecosystems could cause serious economic losses (Kirichenko et al., 2021; Schertler et al., 2024).

The emergence and naturalization of alien species in high-latitude regions is currently an actively studied problem. Studies of alien plants in the global Arctic revealed the presence of 341 species (8.6% of all Arctic flora), of which 188 (i.e., more than 50%) were able to naturalize in at least one of the areas studied where they were not native (Wasowicz et al., 2020). For the Russian Arctic, 333 alien species have been identified; their share in the total species richness varies from 1.4 to 27.8% in different regions (Morozova and Tishkov, 2021).

Along with the introduction of plants, there is an unintentional import of associated phytopathogenic fungi and oomycetes, which pose a threat to economically important plants (Gorlenko, 1975; Liebhold et al., 2012). One of the groups of micromycetes for which the processes of accidental introduction and subsequent spontaneous spread have been well studied is powdery mildew fungi (phylum Ascomycota, order Helotiales, family Erysiphaceae), widely represented in the lists of alien mycobiota of different countries (Bulgakov and Shiryaev, 2021; Voglmayr et al., 2023). Several representatives of the group were included in the list of the 100 most dangerous fungal pathogens on the planet (Schertler et al., 2024).

Powdery mildew fungi in high latitudes have been understudied, as demonstrated in the work *Fungi of the Russian Arctic* (Karatygin et al., 1999). Given the extent and diversity of the natural zones of this territory, as well as the low level of its study, it is likely that more species will become known as the amount of collected material increases. The aim of this work is to study the species richness of powdery mildew fungi in the Taimyr region of Krasnoyarsk krai.

MATERIALS AND METHODS

The Taimyr Dolgano-Nenets district of Krasnoyarsk krai (hereinafter referred to as the Taimyr district) is located in the Asian part of Russia and has an area of about 880000 km^2. Most of the region's territory lies in the permafrost zone, in the subarctic belt, characterized by a sharply continental climate with long cold winters and a short summer season; the average annual temperature is -7.9 ± 2°C; the average temperatures in January and July are -25.8 ± 6.1°C and 14.9 ± 2.6°C, respectively (average temperatures are calculated over the past 30 years). The average annual precipitation is about 300 mm.

The Putorana Plateau is located in the southwestern part of the region. The average height of the mountains is 900–1200 m, as a result of which altitudinal zonation is expressed. The study of the vegetation of this floristically rich territory has been going on for quite a long time; reviews of it are given in a number of publications (Pospelova and Pospelov, 2007). In this study, material was collected on the western slope of the Dry Mountains of the Lama Range, on the southern shore of Lake Lama.

In the southern part of Taimyr, there is one of the largest polar cities in the world—Norilsk, where more than 170 000 people permanently reside. The city is the center of the Norilsk industrial region, where intensive mining takes place. In view of the lack of road and rail links, goods are imported into Norilsk primarily through the Dudinka seaport. About 20 000 people permanently reside in the city of Dudinka. In both cities, work is underway to green public spaces, and residents themselves are also actively organizing flower beds, greenhouses, and hotbeds.

In July–September 2024, 91 plant samples with traces of powdery mildew fungi were collected in all the main biotopes found in the study area (the city of Norilsk and neighboring settlements, on the Putorana Plateau—the shore of Lake Lama, Omon-Yur'akh river valley, forests of the lower belt and rocky mountain slopes, mountain forest tundra). The collected plants were herbarized and then identified using reference materials (Pospelova and Pospelov, 2007). The relevance of species names was checked using the taxonomic portal Plants of the World Online (POWO, 2025).

Powdery mildew fungi were identified using light microscopy. The names of the fungi were checked against the Mycobank taxonomic database (2025).

To date, the powdery mildew fungi of the Taimyr region have been most fully described by Karis and Põldmaa (1974). In the 1960s and 1970s, they discovered 13 species of fungi (taking into account the updated taxonomy of the group) on 22 species of host plants. When working with previously published materials and herbarium specimens, the names of plants and micromycetes were checked against the current taxonomy of the aforementioned databases. When calculating the species richness of powdery mildew fungi in the polar regions, all finds north of the Arctic Circle with an indication of the host plant were taken into account.

Alien species include powdery mildew fungi for which the region of origin has been established and/or whose specific host plants are not found in Taimyr. Species whose specific hosts have a range boundary that runs through a region or part of a region were not considered as alien. Plant and fungal species that are likely alien to Taimyr, were considered cryptogenic.

RESULTS

In 2024, 30 species of powdery mildew fungi were collected in the cities of Norilsk (including Snezhnogorsk) and Dudinka, as well as on the Putorana Plateau. Taking into account previously published data for the Taimyr region (Karis and Põldmaa, 1974), the complete list consists of 38 species of fungi (Table 1).

The list of host plants for powdery mildew fungi in Taimyr includes 53 species from 23 families. According to the results of this work, the list of host plants of the fungi family Erysiphaceae in the Taimyr region increased by 32 species. For the first time in the Russian Arctic, 28 plant species are listed as hosts of powdery mildew fungi, 21 (75%) of which are alien (*Acer negundo*, *Cucurbita pepo*, *Syringa josikaea*, and others). Additionally on four species of plants (*Dasiphora fruticosa*, *Sanguisorba officinalis*, etc.), powdery mildew fungi were previously recorded on the polar territories of Russia outside of Taimyr; are given for the region as powdery mildew host plants for the first time.

DISCUSSION

Powdery Mildew Fungi and Host Plants in Taimyr

The list of powdery mildew fungi compiled during this study is the largest for all regions of the Arctic sector of Russia and one of the largest for Arctic regions in the world. New to the Russian Arctic, including Taimyr, are 22 species of powdery mildew fungi (*Erysiphe adunca*, *E.* aff. *alnicola*, *E. baeumleri*, *E. convolvuli*, *E. ehrenbergii*, *E. macleayae*, *E. polygoni*, *E. russellii*, *E. syringae-japonicae*, *E. urticae*, *Golovinomyces asterum* var. *asterum* and var. *solidaginis*, *G. bolayi*, *G. latisporus*, *G. sonchicola*, *G. sordidus*, *Phyllactinia* cf. *betulae*, *Podosphaera fuliginea*, *P.* aff. *pannosa*, *P.* aff. *polemonii*, *P. tridactyla*, *P. xanthii*, *Sawadaea negundinis*). Previously known from the Arctic, but for the first time, three more species were found in Taimyr (*Erysiphe trifoliorum*, *Golovinomyces macrocarpus*, *Podosphaera ferruginea*). The presence of the genus *Phyllactinia* Lév in the Russian Arctic has been demonstrated for the first time, represented by the species *P. betulae*. On the distribution map of "*Phyllactinia guttata*" in North Asia, one of the points is located on the territory of the Taimyr Peninsula; however, no references to the original source are given (Karis and Elliku, 1997). The largest genera in terms of the number of species are *Podosphaera* (14 species, 36.8%), *Erysiphe* (12 species, 31.6%), and *Golovinomyces* (9 species, 23.7%). Genera *Blumeria*, *Sawadaea* and *Phyllactinia* are each represented by one species.

18 species of fungi (47.4%) are considered native. Cryptogenic and alien species comprise 6 and 14 species, respectively (together 52.6%). Among the alien species, 7 are widespread throughout Eurasia (*Erysiphe adunca, E. convolvuli, E. trifoliorum, Golovinomyces sonchicola, G. sordidus, Podosphaera xanthii, P. tridactyla*), 3 species have a primary range in East Asia (*Erysiphe ehrenbergii, E. macleayae, E. syringae-japonicae*), and 4 are in North America (*Erysiphe russellii, Golovinomyces asterum, G. latisporus, Sawadaea negundinis*) (Voglmayr et al., 2023).

Cryptogenic species of fungi are associated with synantropic plant species common in Eurasia, but

Table 1. List of powdery mildew species collected on native and introduced plants of Taimyr

Fungus	Substrate	Biotope
Blumeria graminicola M. Liu et Hambl (=*Erysiphe graminis* (DC.) Merát)	*Poa alpigena* Lindm., *P. arctica* R. Br., *Poa* sp., *Puccinellia* sp.; +**Festuca* sp.	A, N
+**Erysiphe adunca* (Wallr.) Link	+*Populus tremula* L.	A
+*Erysiphe* aff. *alnicola* M. Bradshaw	+*Alnus alnobetula* subsp. *fruticosa* (Rupr.) Raus	N
E. aquilegiae DC. var. *ranunculi* (Grev.) R.Y. Zheng et C.Q. Chen (=*E. ranunculi* Grev.)	*Delphinium middendorffii* Trautv.	A
+°*E. baeumleri* (Magnus) U. Braun et S. Takam.	+**Vicia sepium* L.	A
+**E. convolvuli* DC.	+**Convolvulus arvensis* L.	A
+**E. ehrenbergii* (Lév.) U. Braun, M. Bradshaw et S. Takam.	+**Lonicera xylosteum* L.	A
+**E. macleayae* R.Y. Zheng et G.Q. Chen	+**Chelidonium majus* L.	A
+°*E. polygonum* DC. s.str.	+**Polygonum aviculare* L., +**Persicaria lapathifolia* (L.) Delarbre	A
+**E. russellii* (Clinton) U. Braun et S. Takam.	+**Oxalis stricta* L.	A
+**E. syringae-japonicae* (U. Braun) U. Braun et S. Takam.	+**Syringa josikaea* J. Jacq. ex Rchb.	A
#**E. trifoliorum* (Wallr.) U. Braun	+**Lupinus polyphyllus* Lindl.	A
+°*E. urticae* (Wallr.) S. Blumer	+**Urtica dioica* L.	A
°*Golovinomyces artemisiae* (Grev.) V.P. Heluta (=*Erysiphe artemisiae* Grev.)	**Artemisia vulgaris* L.	A
+**G. asterum* var. *asterum* (Schwein.) U. Braun, in Braun and Cook	+**Symphyotrichum novi-belgii* (L.) G.L. Nesom	A
+**G. asterum* var. *solidaginis* U. Braun	+**Solidago canadensis* L.	A
+°*G. bolayi* S. Takam., Lebeda et M. Götz	+**Petunia* × *atkinsiana* (Sweet) D. Don ex W.H. Baxter	A
+**G. latisporus* (U. Braun) P.-L. Qiu et S.Y. Liu	+**Helianthus tuberosus* L.	A
#°*G. macrocarpus* (Speer) U. Braun	#°*Tanacetum vulgare* L.	A
G. magnicellulatus (U. Braun) V.P. Heluta s. lat. (=*Erysiphe cichoracearum* f. *polemonii*)	*Polemonium villosum* Rudolph ex George	A, N
G. orontii (Castagne) V.P. Heluta (=*Erysiphe valerianae* (Jacz.) S. Blumer)	*Valeriana capitata* Pall. ex Link	A, N
+**G. sonchicola* U. Braun and R.T.A. Cook	+**Sonchus arvensis* L.	A
+**G. sordidus* (L. Junell) V.P. Heluta	+**Plantago major* L.	A
+*Phyllactinia* cf. *betulae* (DC.) Fuss	Presumably +*Betula* sp. (see Discussion)	A
Podosphaera alpina (S. Blumer) U. Braun et S. Takam. (=*Sphaerotheca alpina* S. Blumer)	*Micranthes punctata* (L.) Losinsk. (=*Saxifraga punctata* L.)	A
P. aphanis (Wallr.) U. Braun et S. Takam. (=*S. alchemillae* (Grev.) L. Junell)	*Comarum palustre* L., *Potentilla stipularis* L.; #*Dasiphora fruticosa* (L.) Rydb., +*Rubus sachalinensis* Levl.	A, N
P. astragali (L. Junell) U. Braun et S. Takam. (=*S. astragali* L. Junell)	*Astragalus umbellatus* Bunge, *Oxytropis arctica* R. Br.	N
P. drabae (Juel) U. Braun et S. Takam. (=*S. drabae* Juel)	*Draba* sp.	A
P. erigerontis canadensis (Lév.) U. Braun et T.Z. Liu (=*S. erigerontis canadensis* (Lév.) L. Junell)	*Taraxacum officinale* coll.; *Taraxacum* sp.	A, N
#*P. ferruginea* (Schltdl.) U. Braun et S. Takam.	#*Sanguisorba officinalis* L.	N
P. fugax (Penz. et Sacc.) U. Braun et S. Takam. (=*S. fugax* Penz. et Sacc.)	*Geranium* sp.	A

Table 1. (Contd.)

Fungus	Substrate	Biotope
+*P. fuliginea* (Schltdl.) U. Braun et S. Takam.	*Lagotis glauca* subsp. *minor* (Willd.) Hultén (=*Lagotis minor* (Willd.) Standl.), +*Veronica longifolia* L.	N
P. fusca (Fr.) U. Braun and Shishkoff (=*S. fusca* (Fr.) S. Blumer)	*Endocellion sibiricum* (J.F. Gmel.) Toman (=*Nordosmia gmelinii* (DC.)), *Lagotis glauca* subsp. *minor* (=*L. minor*); +*Arnica angustifolia* subsp. *iljinii* (Maguire) I.K. Ferguson (=*A. iljinii* (Maguire) Iljin)	N
+*Podosphaera* aff. *pannosa* (Wallr.) de Bary	+*Rosa acicularis* Lindl.	N
P. phtheirospermi (Henn. et Shirai) U. Braun et T.Z. Liu (=*S. melampyri* Junell)	*Castilleja rubra* (Drobow) Rebrist. (=*C. pallida* var. *rubra* Drobow), *Pedicularis amoena* Adams ex Steven, *P. capitata* Adams, *P. oederi* Vahl, *P. verticillata* L.	A, N
+*Podosphaera* aff. *polemonii* (L. Junell) U. Braun et S. Takam.	+*Polemonium boreale* Adams	N
+**P. tridactyla* (Wallr.) de Bary s.str.	+**Prunus padus* L.	A
+**P. xanthii* (Castagne) U. Braun et Shishkoff	+**Calendula officinalis* L., +**Cucurbita pepo* L.	A
+**Sawadaea negundinis* Homma	+**Acer negundo* L.	A

+—new species of fungi and host plants for the Russian Arctic, including Taimyr; #—species previously known from the Arctic, but described for the first time from Taimyr. If the species was collected previously (Karis and Põldmaa, 1974) and again during the present work, the host plants are separated by a semicolon. An asterisk marks an alien species, and the symbol "°" marks a cryptogenic species. Biotopes: A—anthropogenic, N—natural.

alien to Taimyr. However, the presence in the native flora of Taimyr of closely related plants known as hosts of the corresponding fungi does not allow us to confidently speak about the alien nature of these species. *Golovinomyces bolayi* during this study was found on an alien petunia; however, this fungus is a polyphagous species and is capable of affecting plants that naturally grow in Taimyr. The lack of trophic specialization makes its supposed natural range and status in the region uncertain.

In the natural habitats of Taimyr, the dominant genus is *Podosphaera* (69.2% of species). In the case of anthropogenic habitats of the genus *Podosphaera*, *Golovinomyces*, and Erysiphe, they occupy approximately equal shares of 30 ± 5%. In our preliminary lists of powdery mildew fungi in the European Arctic territories, species of *Podosphaera* also constituted a significant proportion of the total species richness of the group (40% in Iceland, 37.5% in the Faroe Islands, 40% in Arctic Norway). For comparison, in Sverdlovsk oblast, this figure is 19%; in the Southern Urals,

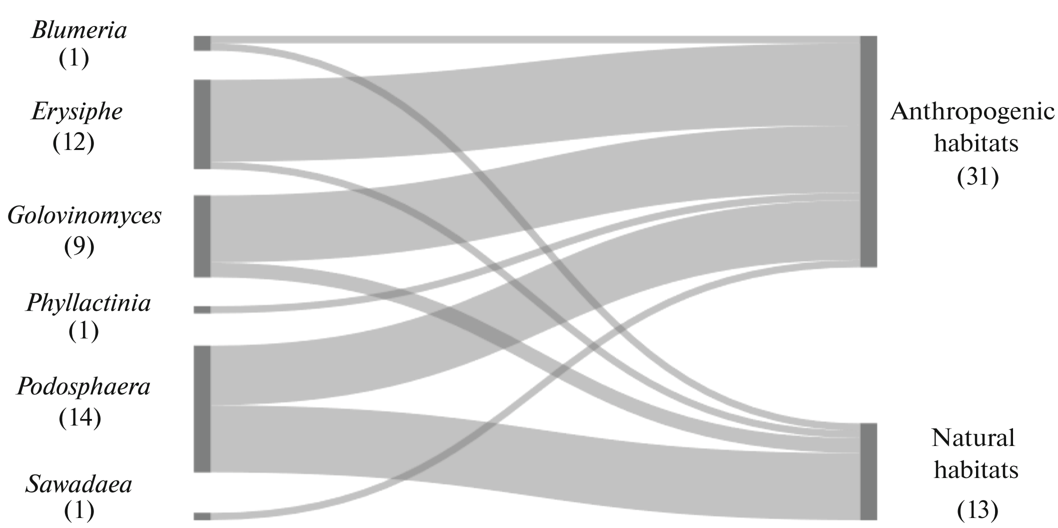

Fig. 1. Number of species in different genera of the family Erysiphaceae in anthropogenic and natural habitats of Taimyr region.

it is 18.6%; and in Moscow oblast, it is 17.5% (personal data of T.S. Bulgakov and A.S. Budimirov). This indicates that genus *Podosphaera* might have adaptatations to high-latitude conditions.

Chasmothecia of the fungus of the genus *Phyllactinia* were found attached to nonhost plant specimens and were apparently carried by air currents from outside. Since all materials were herbarized at the place of collection, these fruiting bodies definitely originate from Norilsk. During the collection of material, we were unable to detect plants affected by fungi of the genus *Phyllactinia*. A study of the morphology of the fungus and a list of potential hosts of this genus in the flora of Taimyr suggest that it belongs to the species *Phyllactinia betulae*. This species is known from other arctic regions, for example from polar region of Scandinavia, where it infects *Betula pubescens* Ehrh. (= *B. tortuosa* Ledeb.)—plant, also widespread in Taimyr.

The largest number of host plant species belong to the families Asteraceae (10 species), Rosaceae (7), and Orobanchaceae (5). Forty-four (83%) species are herbaceous, and nine (17%) species are woody. There are 28 (52.8%) plant species native to Taimyr, including those whose northern border of the range is in the region. Alien and cryptogenic species number 24 (45.3%). Among the alien species, six (25%) originate from North America, and two species each have their primary range in Europe and tropical regions of America (together 16.7% of all alien species). The largest number of introduced plant species—14 (58.3%)—have a wide Eurasian distribution, 6 of which are boreal and 8 are polyzonal species. We have recognized a single cryptogenic plant *Tanacetum vulgare* L., for which isolated finds have been recorded in the Taimyr region, both in anthropogenic and in natural biotopes (Pospelova and Pospelov, 2007). In addition, the species common in Taimyr, *T. boreale* Fisch. ex DC., according to POWO is considered a subspecies *T. vulgare*. This makes the native or alien status of this plant, as well as the fungus associated with it, *Golovinomyces macrocarpus*, undefined.

Polemonium boreale according to our data, for the first time in the world, is cited as a host of powdery mildew fungus of the genus *Podosphaera*. *Arnica angustifolia* is known as a host plant of *P. fusca*; however *A. angustifolia* subsp. *iljinii* (=*A. iljinii*) is registered by us for the first time as a host of this or any other powdery mildew fungus.

Latitudinal Changes in the Proportion of the Alien Fraction of the Erysiphaceae Mycobiota

The vast majority of species of fungi collected in the 20th century are native to the Taimyr region. Only the following species can be classified as cryptogenic: *Golovinomyces artemisiae*, collected near the wall of a greenhouse in Norilsk on *Artemisia vulgaris* (Karis and Põldmaa, 1974), but was not found on local species of wormwood. Although this fungus is known from other parts of the Arctic on other species of arctic wormwood (*A. borealis* Pall., *A. dracunculus* L.), found, including in Taimyr, its aboriginality for the territory under consideration is questioned by us, since here it is associated exclusively with the adventitious common wormwood.

On the basis of the results of this work, the presence of 20 cryptogenic and proven alien species of fungi of the family Erysiphaceae was demonstrated in Taimyr. The increase in the species richness of powdery mildew fungi in the Taimyr region occurred primarily owing to the increase in the number of alien species. It has been established that the proportion of alien flora species decreases from south to north and reaches a minimum in Arctic latitudes (Morozova and Tishkov, 2021). For powdery mildew fungi, according to our primary data, the proportion of alien species, on the contrary, increases in the northern direction. Thus, in Taimyr, alien species of the family Erysiphaceae make up 52.6% of the total species richness; in Sverdlovsk oblast, this figure is 38.4%; in Moscow and Moscow oblast, it is 33.3%; and in St. Petersburg and Leningrad oblast, it is 28.8% (personal data of T.S. Bulgakov and A.S. Budimirov).

A possible explanation is that the diversity of naturally occurring flowering plants, especially cultivated ones, decreases from subtropical to subarctic climate zones. The subtropics are associated with the origin and development of agriculture as such, so it is natural that the majority of agricultural and ornamental cultivars originate from there. By "ornamental plants," we mean not only species that are objects of targeted selection but also native plants used in landscaping. In more southern regions of the temperate zone, the diversity of such native plants is higher. Further north it gradually decreases, until in the subarctic zone the overwhelming majority of these species disappear from natural conditions. For example, in Moscow oblast, ash, European oak, and aspen grow natively and are used in landscaping. In Sverdlovsk oblast, all three species grow in cultivation, but ash is absent from natural communities, oak is on the northeastern border of the range, and aspen is a local species. In the conditions of Taimyr, ash and oak will be alien species, while aspen grows on the northern border of its range and is represented by single individuals (Pospelova and Pospelov, 2007). The decline in the diversity of flowering plants from south to north, with the desire to use a certain set of known species in landscaping, leads to an increase in the proportion of alien plants in anthropogenic communities, since the low diversity of local angiosperms does not compensate for the large number of alien introducers. Since powdery mildew fungi associated with alien plants will also gradually change their status from "native" to "alien," the proportion of alien fungi will increase along with the proportion of introduced hosts.

Features of the Arctic flora, such as the small size of plants and their flowers and the short duration of flowering, limit the range of species applicable in landscaping. This stimulates the import of plant material from nurseries in more southern latitudes. In addition, interest in private garden plots has increased in the region. Gardeners from Norilsk and Dudinka bring or order seeds and seedlings from Krasnoyarsk, Moscow, and St. Petersburg, which sharply increases the species richness of alien flora, which, in turn, leads to increase in the number of associated alien (for Taimyr) fungi.

Thus, the increase in the proportion of alien powdery mildew fungi from south to north is mediated by the increase in the proportion of alien plants. The increase in the proportion of alien plants is a consequence of (1) a decrease in the proportion of native species among the “classic” taxa used in landscaping; (2) the low applicability of native Arctic flora, which is not capable of acting as a replacement for introduced species from the south; and (3) the peculiarities of the organization of subsidiary farms of local residents, who import agricultural crops for personal consumption and ornamental flowering plants for landscaping.

CONCLUSIONS

Fragile Arctic ecosystems, including Taimyr, are currently under unprecedented antropogenic pressure because of large-scale infrastructural projects. Another important factor, that puts pressure on natural ecosystems in the region, is global climate change, which is more pronounced in the Arctic than anywhere else (Rantanen et al., 2022).

The increase in average annual temperatures contributes to the borealization of natural communities in the Arctic and the northward expansion of taiga species, including taiga mycobiota (Shiryaev et al., 2019). In the list of alien plants of the Russian Arctic, boreal species are the dominant group (Morozova and Tishkov, 2021). We observe a similar picture for powdery mildew fungi, where out of 20 alien species, 13 (65%) are boreal or polyzonal. Thus, borealization can be intensified under the influence of both climate change and human economic activity.

The natural and climatic conditions of the Arctic are a restraining factor for the spread of alien plant species. Naturalization is hindered by low temperatures, poor soils, a short growing season, and a specific light regime (Morozova and Tishkov, 2021; Wasowicz et al., 2020). Unlike plants, these factors act only indirectly on parasitic micromycetes, so their spread from the site of introduction may be easier. In addition, powdery mildew fungi, although highly specialized parasites, evolve rapidly and regularly acquire new hosts, which allows them to adapt to changing conditions (Takamatsu et al., 2010). This is why it is necessary to monitor cases of the introduction of alien species of this group into the northern regions. Although in Arctic latitudes alien powdery mildew fungi are confined to introduced plants that are incapable of naturalization, they create a pool of propagules in which a form of micromycete adapted to local species can sooner or later develop.

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ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This work does not contain any studies involving human and animal subjects.

CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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