EuroGard V
Botanic gardens in the age of climate change
Supplementary proceedings
The Botanic Garden – Live Science

The Botanic Garden of the University of Helsinki is part of the Finnish Museum of Natural History. Our vision is a world where humans know the life forms with which they share this planet, are informed of their evolution, and have the understanding to appreciate all the diversity of nature.

We implement this vision by reinforcing our status as an internationally significant research institution of biodiversity and as a centre of species information. Together with the other botanic gardens and museums of natural history in Finland, we maintain and further compile the Finnish national collections of natural history.

The Botanic Garden, founded in Turku in 1678, is the oldest institution in Finland maintaining collections of natural history. In 1829, the Garden, together with the University, moved to Helsinki and was re-established in its present location in Kaisaniemi. Nowadays, the Garden also maintains premises in Kumpula.

_Ulasmus_ is an occasional series published by the Botanic Garden of the University of Helsinki. It features guide books, teaching material, and other thematic issues. The series was named after one of Finland’s tallest specimens of fluttery elm (Ulmus laevis Pallas), which grew in Kaisaniemi Botanic Garden until 1988. The Ulmus logo was designed by Marja Koistinen.
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Botanic gardens have knowledge and skills and run activities that help in our understanding of nature, in conserving species and in informing the public on issues related to climate change. In order to review the work and expertises gained by botanic gardens, the Fifth European Botanic Gardens Congress ‘EuroGardV’ was charged to bring to light current important scientific, policy, and educational topics. One of the key aims of the congress was to bring climate change to the fore and further develop the activities of botanic gardens to counteract risks concerning loss of plant diversity.

EuroGardV – Botanic Gardens in the Age of Climate Change, was organised by the European Consortium of Botanic Gardens (ECBG), Botanic Gardens Conservation International (BGCI), and the Helsinki University Botanic Garden in Helsinki in June 2009. In all, 127 papers, including nine keynote lectures, were presented at the congress and seven workshops were arranged (Lehvävirta et al. 2009).

The first part of the proceedings of EuroGardV was published as a Special Issue of Biodiversity and Conservation (Vol. 20, no. 2, 2011). A selection of 16 papers appeared together with a summarising introduction by Schulman and Lehvävirta (2011). This peer-reviewed volume of Ulmus represents a supplementary proceedings of the congress. Here we have the privilege of complementing the previous selection with nine additional papers by 24 authors. This collection further emphasises the diversity of activities run by botanic gardens throughout Europe and beyond. Furthermore, it is clear that all the core functions of botanic gardens – curation of scientific plant collections, research, conservation, education and display – may, by enhancing our knowledge and disseminating information to society, have a direct bearing on climate change adaptation.

Bavcon (p. 8) reviews the history of seed exchange between the University Botanic Gardens Ljubljana and other botanic gardens in Europe. He notes that this traditional activity is important to strengthen the more recently commenced conservation work of the collection institutions when seeds are collected in the wild and data on origin are carefully recorded. Carefully recorded collecting can produce valuable seed material for ex situ conservation and projects carrying out ecological restoration or assisted migration trials. Stefaniak and Bomanovska (p. 15) demonstrate how even small and relatively recently established gardens can make important contributions to local public education and to conservation work; for instance, as in the case of the Teaching and Experimental Botanical Garden of the University of Lodz, by participating in monitoring of endangered plants. Guseva and colleagues (p. 23), with their example of apple tree collections in Moscow State University’s Botanical Garden, elucidate how building up a collection combining wild species and cultivars provides benefits for the conservation of the widest possible intra-generic genetic diversity and, very importantly, for the sustainable utilisation of biodiversity.

For botanic gardens that are custodians of large tracts of land it is also possible to make contributions to in situ conservation within their own boundaries. Cultural biotopes may be especially relevant in this context, as in the case of the National Botanic Garden of Latvia taking part in grassland conservation, as reported by Strode and Roze (p. 33).

Ex situ conservation of plants is not just a matter of straightforward collecting but research on germination methods is also needed. Zilinskaite and colleagues (p. 39) describe this kind of work done at the Botanical Garden of Vilnius University. They also show how the garden can make a direct link between research, conservation, and the utilisation of plants, in their case e.g. for amenity horticulture. But this link can in botanic gardens also be made for edible wild plants, as Menale and Muoio (p. 51) demonstrate in their report from Naples Botanical Garden in Italy. They also show how
traditional knowledge on plant use has been gathered and utilised for building educative displays. Such combined efforts to study and save both biological and cultural diversity are invaluable and should be further encouraged.

Volchanskaya and Firsov (p. 56) describe how large and continuously replenished collections of botanic gardens, when carefully documented and regularly monitored, can be particularly valuable for identifying plant responses to climate change. Firsov (p. 70) continues by explaining how such monitoring in the St. Petersburg region tells us not only that previously tender plants now survive winters but also that previously hardy species have started to show frost damage due to early spring growth. Very similar trends have been observed in the two botanic gardens of the Finnish Museum of Natural History in Helsinki (L. Schulman, pers. obs.).

The volume is concluded by Prokhorov and colleagues (p. 80) who demonstrate the value of comprehensive collection databases and integrated information systems. In addition to various analyses on collection diversity in relation to climatic parameters, such systems provide opportunities to develop nation-wide collection policies so as to create the most representative national collections. For climate change adaptation and the rescue of plant biodiversity, however, such approaches should not be limited by national borders but should preferably be applied to whole bioclimatic regions, both old and predicted new ones.

We hope that the proceedings of the EuroGardV congress help to make it clear to a wide audience that botanic gardens have a considerable value as assets in our work to better understand the consequences of and adapt to climate change. Furthermore, we hope that these fine examples provided by sister institutions will inspire still further innovative and collaborative projects at and among botanic gardens. With these words we turn our eyes to the next meeting in the EBGC’s EuroGard series. EuroGard VI is due in late May of 2012 on the Greek island of Chios (www.eurogardvi.gr/). We are confident that this congress will reveal another exciting array of activities taking the work of botanic gardens further into the era of climate change. Our wish is that the collective voices of botanic gardens around the world will be better heard and their expertise efficiently used to mitigate climate change impacts.

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References


SEED EXCHANGE ON THE BASIS OF INDEX SEMINUM

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Abstract

The year 2009 marks the 120th anniversary of the first publication of the seed index, Index seminum in horto botanico c.r. Labacensi anno 1888 collectorum, by the University Botanic Gardens Ljubljana, Slovenia. The jubilee edition was published in January 2009. The first seed index comprised 909 species collected from the Botanic Garden. The 1888 Index seminum was sent to 30 botanic gardens. After 120 years, the index continues to be published once a year or once every second year. Since 1997, it has also been available in electronic format. Compared to 1888, the present-day index includes fewer species collected from the Garden and a lower number is available for exchange; but in addition to the seeds harvested from the Garden it now includes seeds from nature, accompanied by information on localities and harvesters. For the Index seminum of 2008, 690 species were collected from the Botanic Garden and 509 of these were actually put on the Index seminum. In the same year, more than 600 units were collected from the wild of which 524 were available for exchange. During the last decade the Index seminum has been sent to 300 addresses per year, while about 160 botanic gardens ordered seeds from the Ljubljana Garden during this time. Seed exchange is important for ex situ and in situ conservation. Sending seeds of endangered plant species to other botanic gardens can help save the species and allow them to survive under various climatic conditions.

Keywords: Index seminum, Verzeichnis, Samen-Verzeichniss, University Botanic Gardens Ljubljana, Index plantarum Horti botanici, Botanični vrt Univerze v Ljubljani

Introduction

Seed exchange is an important ex situ and in situ conservation strategy. Sending seeds of endangered plant species to other botanic gardens can help protect the species and allow them to survive under various climatic conditions.

In the past, botanic gardens functioned as institutions through which important plant species were brought into wider use. Subject to research, new species acquired greater importance. This is why the development of botanic gardens exerted a strong influence upon the progress of civilization in general (Don and King 1996; Musgrave et al. 1998; Campbell-Culwer 2001). While numerous botanic gardens continue to issue seed indexes in printed and increasingly so in electronic form, the opinions on the importance of seed exchange on the basis of seed indexes are divided (Heywood 1964 a, b). Some even believe that the Index seminum has more or less outlived its importance (Aplin et al. 2007, Aplin and Heywood 2008).

Botanic gardens came into existence primarily due to the needs of medical and later also botanical studies (Don and King 1996; Monem 2007). The first botanic gardens were founded in the 16th and 17th centuries as an integral part of European universities: in Italy in Pisa in 1543 and in Padua in 1545, in Leipzig, Germany, in 1580, in Leyden, the Netherlands, in 1587, in Montpellier, France, and Heidelberg, Germany, in 1593, in Copenhagen, Denmark, in 1600, in Oxford, Great Britain, in 1621, in Uppsala, Sweden, in 1655, and in Vienna, Austria, in 1752 (Monem 2007). Additionally, royal botanic gardens were created (Edinburgh in 1670, Kew in 1759) while gardens sometimes existed also within museums (in Paris in 1640) (Monem 2007). Botanic gardens were founded also by different societies, for instance
the Chelsea Physic Garden in 1673 as the Apothecaries’ Garden (Monem 2007).

The purpose of botanic gardens was to create systematic collections, allowing the identification and study of plants. The gardens also served as recipients of newly discovered plants, which were later distributed all over the world and put to use in a variety of ways (Bown 1992; Minter 2000; Monem 2007).

A more systematic collection of plants began with the development of modern botanic gardens. When Linné (1753) introduced the system of binomial nomenclature, which followed his division of nature into three kingdoms, this provided a basis for a more systematic management of collections. Many botanic garden sent explorers all over the world. They participated in expeditions to unknown or little known parts of the Earth. These so-called plant hunters explored the world, collecting plants from remote parts of the globe (Musgrave et al. 1998). While some of these plants never left botanic gardens, others became important cultivated plants contributing to sustenance of the European population (Don and King 1996; Monem 2007). Many plants that have become popular in horticulture were also originally introduced by botanic gardens. A true revolution in the transportation of plants was brought about by the so-called Wardian case, which was a miniature hothouse allowing the shipment of plants during long sea voyages to botanic gardens (Young 1987). Plants and their seeds did not remain restricted to their parent gardens. They were initially exchanged between garden heads as a matter of polite gestures, however, over the years such exchange developed into a formalized and well established collaboration between botanic gardens (Young 1987).

Early Days of Printing Index seminum in Present-day Slovenia

Alfonz Paulin, who became director of the University Botanic Gardens Ljubljana in 1886, embarked upon a more intensive field collection (Paulin 1912). Although the exchange of seeds with other botanic gardens had by then been well established, it was in 1888 that he edited the first list of seeds collected in that year, and he published it in January 1889 (Paulin 1889).

As such, 2008 marked the 120th anniversary of harvesting and the determination of plant seeds for the Index seminum in Slovenia. These indexes have been preserved in the Garden archives. The Index seminum is printed and sent off in the year following the year of seed harvesting, so the January 2009 issue of the Index seminum honoured the 120th anniversary of the first publication of the seed index. The Index seminum in horto botanico c. r. Labacensi anno 1888 collectorum included species arranged alphabetically by scientific name. It was printed on four pages of a larger 23 x 29.4 cm format so that, in fact, there was just a single sheet of paper which, when folded, measured 23 cm in width.

This first Index included 909 plants, 149 on the front page, 284 on the second, 279 on the third and 197 on the last page. Although the title indicated that this was a list of seeds, the Index also included some live plants or plant parts. Of these 909 species, 12 were live plants, 23 bulbs, 3 tubers and 15 rhizomes. According to the available data, that Index seminum was distributed to 30 botanic gardens all over Europe (Paulin 1928). Based on the historical data presented in Fig. 1, orders started to arrive from different European botanic gardens already during the first decade of publishing the seed index, which was later published every second year.

A considerable number of the original seed indexes are still kept in the archives of the Ljubljana Botanic Garden, indicating 1889 as the harvesting year. The Garden is also in possession of book-bound seed indexes received from

![Figure 1. Number of orders received from European botanic gardens during the first decade since the publication of Index seminum in Slovenia. Note that not all years are presented.](image-url)
various European botanic gardens between 1884 and 1897. The Garden archives include seven such books referring to different years or a couple of years together.

The appearance of the *Index seminum* has changed over the years. Paulin's major work was doubtlessly a dry herbarium collection (*Flora exsiccata Carniolica*), which began to be published in 1901 and continued until 1936, when comprising 2000 taxa. Paulin's rich written legacy, stored in the Library of the Slovenian Academy of Sciences and Arts, was researched by Wraber (2008). This work lists all issues of the *Index seminum* by Paulin that are stored in the Ljubljana Botanic Garden.

*Index seminum in Europe*

Seed exchange based on a seed index presumably started in 1648 when Jacob Bobart compiled the first index of seeds collected in the Oxford Botanic Garden. According to Aplin et al. (2007) this is considered to be the first printed seed index (Table 1), even though a 1614 manuscript of the "Semina Horti Medici" from the Botanic Garden Padova (Orto botanico di Padova) exists (Cappelleti and Ongaro 2008). As reported by some authors, the first known exchange of seeds between botanic gardens is the one between Chelsea Physic Gardens and Hortus Botanicus, Leiden University. When John Watts, director of the Chelsea Physic Gardens, visited Hortus Botanicus, Leiden University in 1683, he also brought seeds with him. Even so, the first printed index of the Chelsea Physic Gardens was only created in 1901 (Monem 2007).

Even though the Ljubljana Botanic Garden published no printed seed index prior to 1888, some older seed lists dating back to 1884, 1885, 1886 and 1887 exist (Table 2).

**Comparison Between the First and Present Index of the Ljubljana Botanic Garden**

The Ljubljana Botanic Garden nowadays sends its seed index to 300 botanic gardens. As shown in Fig. 2, covering the period of the last ten years, the number of institutions ordering seeds ranges between ca. 140 and 170, with 1 700 to 2 400 seed packages dispatched per year.

### Table 1. First printed *Index seminum* in Europe.

<table>
<thead>
<tr>
<th>Year</th>
<th>Botanic Garden</th>
</tr>
</thead>
<tbody>
<tr>
<td>1614</td>
<td>Orto botanico di Padova</td>
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<td>1648</td>
<td>Oxford Botanic Garden</td>
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<tr>
<td>1797</td>
<td>Horto Acad. Rheno Trajectino, now Utrecht University Botanic Gardens</td>
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<tr>
<td>1802</td>
<td>Vilnius University Botanic Garden</td>
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<td>1822</td>
<td>The University Botanic Garden of Köbenhavn</td>
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<tr>
<td>1836</td>
<td>The University Botanic Garden of Bonn</td>
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<tr>
<td>1839</td>
<td>The University Botanic Garden of Oslo</td>
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<td>1841</td>
<td>The University Botanic Garden of Basle</td>
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<td>1843</td>
<td>Helsinki</td>
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<tr>
<td>1853</td>
<td>Uppsala</td>
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<tr>
<td>1880</td>
<td>Ireland by the Glasnevin Botanic Gardens</td>
</tr>
<tr>
<td>1889</td>
<td>Index seminum in horto botanico c. r. Labacensi anno 1888 collectorum (Today University Botanic Garden Ljubljana)</td>
</tr>
<tr>
<td>1901</td>
<td>Chelsea Physic Garden</td>
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<tr>
<td>1925</td>
<td>The Botanic Garden of the University of Latvia</td>
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</tbody>
</table>

**Discussion**

The archives of the Botanic Garden of the University of Ljubljana include indexes received from different botanic gardens from 1884 to the present. Some indexes referring to single years are missing. The indexes from different botanic gardens for the period between 1884 and 1892 are listed in Table 2 in the order in which they are bound into a large format book. Despite the binding, some of the indexes are folded and their edges are not properly cut. Many indexes are check-marked in red or certain lines are crossed out in blue. The fact that the indexes are full of such annotations indicates that the ordering of plants must have been quite intense. Every index bears a hand-written date, most probably the date on which it was received. Even today we still observe such practices and always put a date on each newly arrived index. In addition to the initial years (1884–1892) there are also indexes of different European botanic gardens of the years 1892–1895 and 1897 that are not included in Table 2. Table 2 covers only the contents of the first two books featuring the indexes for the period between 1884 and 1890 comprised in the first book, while the second book includes the indexes of 1891 and just some indexes of
Table 2. *Index seminum* from different European gardens in the archives of the University Botanic Garden Ljubljana (Slovenia).

<table>
<thead>
<tr>
<th>Description</th>
<th>Year</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auswahl von Früchten und Saamen gesammelt 1884 in dem botanischen Garten der Univeristat zu Leipzig</td>
<td>1884</td>
<td>Leipzig</td>
</tr>
<tr>
<td>Auswahl von Früchten und Saamen gesammelt 1885 in dem botanischen Garten der Univeristat zu Leipzig</td>
<td>1885</td>
<td>Leipzig</td>
</tr>
<tr>
<td>Verzeichniss gerantirt keimfähiger Samen von G. Treffer in Luttach Sand Tirol</td>
<td>1887</td>
<td>Luttach Sand Tirol</td>
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<tr>
<td>Verzeichniss für Lebende Tiroler-Pflanzen v G. Treffer</td>
<td>1887</td>
<td>Luttach Sand Tirol</td>
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<tr>
<td>Delectus seminum e collectione anni 1886, quae in horto caesareo-regio botanico Universitatis Pragensis pro mutua communicatione offeruntur</td>
<td>1886</td>
<td>Prag</td>
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<td>Semina selecta e messe anni 1886 ab Horto Upsaliensis oblata</td>
<td>1886</td>
<td>Upsal</td>
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<tr>
<td>Index seminum Horto Botanico Reg. Berolinensi anno 1886 collectorum</td>
<td>1886</td>
<td>Berlin</td>
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<tr>
<td>Delectus seminum botanico Universitatis Budapestinensis anno 1886 collectorum</td>
<td>1886</td>
<td>Budapest</td>
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<tr>
<td>Index Königlichen botanischen Garten zu Dresden, collection 1886</td>
<td>1886</td>
<td>Dresden</td>
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<td>Liste des Plantes de Montagnes élevées au Jardin Alpin D’acclimation de Genève 1887-1888</td>
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<td>Genève</td>
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<td>Auswahl – Liste über Alpenpflanzen, seltene Staudengewächse Freilandfärne, Sträucher für Heide- und Moorerde Erdorchideen von H. Gusmus Rosenheim (Bayern) in katalog F. Sündermann Lindau am Bodensee (Bayern)</td>
<td>1887-1888</td>
<td>Rosenheim (Bayern)</td>
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<td>Verzeichniz von Alpenpflanzen, subalpinen Stauden, Freilandfärnen, Erdorchideen und Wasserpflanzen von April 1886</td>
<td>1886</td>
<td>München</td>
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<td>Index seminum in Horto Botanico Universitatis Amstelodamensis, 1891</td>
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<td>Berlin</td>
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<tr>
<td>Sämereien zum Tausch aus dem Königlichen botanischen Garten der Universität, 1891</td>
<td>1891</td>
<td>Breslau</td>
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<td>Graz</td>
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<td>Umbelliferarum Collectio C. F. Seidellii Dresdensis ad Weinböhla, 1891</td>
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<td>Freiburg</td>
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<td>Genève</td>
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<td>Greifswald</td>
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<td>Halle</td>
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<td>Verzeichnis Samen und Pflanzen welche die Verwaltung des Botanischen Gardens zu Innsbruck zum Tausche anbietet, 1891</td>
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<td>Jenensis</td>
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<td>Hauenau</td>
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<td>Auszug aus dem Hauptverzeichnis nebst Nachtrag für 1892 F. Sündermann</td>
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<td>Delectus seminum in horto botanico Loveniensis anno 1890 collectorum</td>
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<td>Delectus sporarum seminum fructum quae Hortus Bergianus Stockholmiensis, 1891</td>
<td>1891</td>
<td>Stockholm</td>
</tr>
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<td>Delectus seminum quae Hortus Botanicus Tergestinus, 1891</td>
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<td>Tergestis</td>
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<td>Auswahl der Sämereien in botanischen Garten der Universität Tübingen, 1891</td>
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<td>Tübingen</td>
</tr>
<tr>
<td>Semina selecta e messe anni 1891 ab Horto Upsaliensi oblata</td>
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<td>Upsal</td>
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<td>Auswahl von Sämereien des botanischen Gardens der Universität Würzburg, 1891</td>
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<td>Verzeichniss der von der Eidgenössischen Samen – Control – Station in Zürich im Tausch angebotenen Samen, 1892</td>
<td>1892</td>
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</table>
Book-bound indexes exist also for the remaining years, all until 1897, however, they are not presented Table 2 as this would make the list too broad. The Ljubljana Botanic Garden also has indexes from other years up to the present. Initial indexes were bound into books, but this is no longer the case. The indexes of some years are either missing or may not have been printed for these particular years.

Comparing the index of seeds harvested in 1888 with the index of 2008, the first main difference is that the number of species whose seeds were collected in the Garden is now lower than in the past. Nowadays the seeds of more than 1200 species are collected in the Garden. Depending on quantity of seeds in each lot, about 600 from the Garden and 400 from nature are put on the Index seminum, so that the sum total ranges between 900 and 1000 species. Concerning the harvest of 1888, it is not clear whether the seeds were only from the Garden or also from nature but the number of seed list entries in that year was 909, which is as many as we manage to harvest nowadays from the Garden and from nature. Fieldwork is more time-consuming. Irrespective of the fact that the index includes only about 600 species harvested from the Garden, we collect many more but only include those to the index that have been reliably determined and of sufficient quantity of seeds for exchange.

Seed exchange remains an important activity of botanic gardens (Howard et al. 1964; Heywood 1976; Thompson 1964; Yeo and King 1965). Increasing importance is attributed to seeds harvested from nature (Heywood 1964b). Numerous researchers require seeds for research projects and doctoral dissertations. Internet-facilitated requests of this kind arrive almost on a weekly basis. While it may seem as if the exchange of seeds is rather outdated and actually no longer needed, the Internet and on-line access to the Index seminum resulted in a more active exchange in comparison with classical approaches (Jury and Ibbett 1985). This is why the Index seminum remains established as one of the functions of botanic gardens (Heywood 1964a), now accessible to all Internet users through the general European index of available species. Nowadays, the use of the Index seminum is no longer restricted to botanic gardens but has much wider applicability since numerous researchers studying single species and genera, or dealing with population genetics, apply to botanic gardens for live parts of plants or their seeds.

Seeds collected from nature are particularly important, and has increased in number from year to year, even though some authors report that the number of seeds collected from the wild is declining (Aplin et al. 2007; Aplin and Heywood 2008). This does not apply to the

Figure 2. Number of institutions ordering seeds from the Ljubljana Botanic Garden.
Ljubljana Garden, which is evident from the number of seeds collected from nature. We also observe that the orders for seeds from nature are more frequent so that we regularly run out of seeds from nature sooner than seeds from the Garden. As is evident from Fig. 2, these requests are relatively numerous every year. Variation in the number of requests results mostly from the fact that we do not always manage to issue the Index seminum by December or at least in early January. This is associated with a large numbers of species whose determination needs to be re-checked and which have to be cleansed to evaluate which of them are available in sufficient numbers for exchange.

Numerous seeds from nature are ordered for the purposes of population or genetic studies. Many customers ask for additional information from our database, as detailed data are available but not published due to the shortage of space. Such exchange among botanic gardens is extremely important also from the point of view of education and demonstration. It often happens that a species already well adapted to the Garden ceases to develop seeds or some plants die of old age and need to be replaced. If botanic gardens wish to conserve and demonstrate the wealth of biodiversity and also function as keepers of study collections, then the exchange of seeds is a very important source of acquiring seeds of plants intended for this purpose. While it is true that botanic gardens harbour many plants of unknown origin, these still play an important role in the education of new botanists. If a live plant has been observed at least once before, it is much more likely to be identified in the wild. Although it may seem that picture galleries of plants available on the Internet can replace actual experience, practical work repeatedly shows that plants need to be seen in vivo. This is where the role of botanic gardens is most important. If they manage to conserve their collections at this level, they will be making immense contributions to the conservation of plants in nature - in situ conservation, which is the task of botanic gardens laid down in the Convention on Biodiversity (Wyse Jackson 1997).

Equally important is also the educational role of botanic gardens (Willison 1994). Protection of certain rare species is essential due to the possibility of maintaining a larger number of specimens in different environments where botanic gardens are located. As for extremely endangered species it is important to make sure that the number of specimens is not too small (Oostermeijer 1999). The training of new botanists lays the groundwork for their future work in nature. Inventorying and conservation in nature can be effective only through their work (Akeroyd 1996, 1997). This is why ex situ and in situ conservation of plants are so closely interrelated. In the era of information technology we are losing knowledge about the environment in which we live. As a consequence, conservation of live collections for educational and demonstrational purposes is now even more important than in the past when people lived in a much closer relationship with nature.

Acknowledgements


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PLANT COLLECTIONS IN THE TEACHING AND EXPERIMENTAL BOTANICAL GARDEN OF THE UNIVERSITY OF LODZ (POLAND)

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Abstract

The Teaching and Experimental Botanical Garden of the University of Lodz was established in 1985 and covers an area of 1.02 ha. Teaching constitutes the main function of the Garden, while the plant collection is also used for scientific purposes. The garden also plays an important social role, being a major green area in the centre of a large city. The collection of plants includes native species and plants of foreign origin, and is divided into two parts: a collection of trees and bushes and a collection of herbaceous plants. The garden contains 295 species and varieties of trees and bushes. Broadleaf species predominate with 276 taxa. Among coniferous species, the world's most long-lived tree species - Pinus aristata – is worth mentioning. The collection of herbaceous plants includes 498 species and varieties, mostly representing native flora (358 taxa). Herbaceous plants represent various kinds of habitats: sandy grasslands, peat bogs, coniferous forests and deciduous forests. The garden takes part in ecological monitoring of species placed under legal protection in Poland, threatened species and species from Natura 2000 habitats. A species of priority concern is Galium cracoviense, a Polish endemic which features on the European list of endangered species, protected by regulations of the Bern Convention.

Key words: endangered species, endemic species, plant collections, vascular plants, university botanical garden

Abbreviations

CR - critically endangered
E, EN - endangered
EW - extinct in wild
N2000 - Natura 2000
PP - partly protected

PRB - Polish Red Data Book of Plants
PRL - Polish Red List of Vascular Plants
R - rare
SP - strictly protected species
V, VU - vulnerable

Introduction

In the face of species extinctions and the destruction of their habitats, botanical gardens have become centres of nature conservation (Wyse Jackson and Sutherland 2000; Maunder et al. 2001a; Niba and Samways 2006; Khurun 2008). Currently, botanical gardens across the world contain over 10 000 rare and endangered species (Botanic Gardens Conservation International. www.bgci.org/resources/1528/. Cited 20 Jul 2009). For several dozen species, botanical gardens are their only and final refuge (Maunder et al. 2001b). Botanical garden play an important role in the reproduction of rare and endangered species, through storage of their seeds in seed banks and in cultivation, to cooperation with governments and other groups whose goal is to reintroduce species into the wild and to reconstruct their natural habitats. Among various types of botanical gardens, those affiliated with universities have a special place (Wyse Jackson and Sutherland 2000). On the one hand they fulfil the function of sui generis nature reserves, while on the other hand the collections they contain serve teaching purposes and are the
location and object of scientific research.

As opposed to other university-affiliated botanical gardens in Poland, the botanical garden of the University of Lodz does not constitute a separate legal entity, being internally managed by the Faculty of Biology and Environmental Protection (Stefaniak 2008). In its current shape and location, the Teaching and Experimental Botanical Garden has existed since 1985, although activities connected with its foundation started in 1979 (Kurzac 2007; Stefaniak 2008).

Conflict in the history of the garden occurred when a new seat for the Faculty of Law and Administration of the University of Lodz (Collegium Iuridicum) was constructed in 2007, which occupied 0.88 ha (about 47 percent) of the primary usable area of the garden. It became necessary to transplant a number of specimens of trees and shrubs to new localities, not only within the garden, but also in green areas around buildings of the Faculty of Biology and Environmental Protection. The construction process caused a transformation in the shape and size of the garden and created a need to inventory the flora in the garden. Detailed floristic studies were carried out in 2007–2008 (Stefaniak 2008). The aim of this inventory was to examine the garden collections (trees, shrubs and herbaceous plants), to examine the herbaceous plants that spread spontaneously throughout the Garden and to create a graphical representation of the location of all tree specimens on the garden map, as well as to estimate the losses in the collections incurred as a result of Collegium Iuridicum construction.

The present paper features only selected results of the inventory concerning the present collection of the Garden, with special emphasis on species that are rare, absent and protected in the Polish flora.

Materials and methods

The Teaching and Experimental Botanical Garden of the Faculty of Biology and Environmental Protection (University of Lodz) is situated in the centre of Lodz, the 3rd largest city of Poland (Fig. 1). The total surface area of the garden is 1.02 ha.

The garden is located at 19°29’ 05” E and 51°46’ 40” N, in the northern part of the physical

and geographical mesoregion of the Lodz Heights. The climate of the area is characterized by an average annual rainfall of 600–625 mm, with an average annual temperature of 7.5 °C; the warmest month is July (17.5–18 °C), and the coldest month is January (-3 °C). The length of the vegetative period is 215 days with a threshold value of 5 °C, or 237 days with a threshold value of 3 °C (Diehl 1997). The garden is situated on sandy and clay soils (Witosławski 2006).

The garden is a teaching and experimental garden, i.e. the collections are mainly used for teaching purposes and for scientific research. Furthermore, during the spring and autumn seasons the garden is open to the public. The head of the Department of Geobotany and Plant Ecology is the curator of the garden. Management duties include the selection of plant material, creating necessary collections to be used for the education of biology and environmental protection students, and taking care of aesthetic qualities and the external image of the garden.

The garden features herbaceous and ligneous plants, represented by species of both
native and foreign origin. The herbaceous collection represents 189 small plots (3.75 m² per plot) surrounded by a cement curb. Plants are planted in family plots according to the Takhtajan systematic order (Takhtajan 1980), in order to make students aware of the morphological diversity within and between families, such as the structures of various types of flowers, inflorescences and fruits.

During 2007–2008, floristic studies were carried out in the garden. Observations were made from the plots and the pathways that separate them, as well as from the whole garden. Floristic data were gathered as lists that included all vascular plants, both herbaceous and woody. Furthermore, all specimens from the collection of trees and shrubs were counted, their heights and diameters at breast level measured and their locations marked on a map of the garden. Based on the collected data, the cultivated flora (collection) and spontaneous flora of the garden were analysed with regards to their taxonomical, ecological and geographical diversity (Stefaniak 2008). The present study includes only selected elements of this analysis, i.e., general characteristics of the vascular floral collection with special emphasis on valuable species (endangered and protected) from Poland’s native flora that grows in the garden.

The red list of vascular plants in Poland (Zarzycki and Szelań 2006) was used to identify the threat status of the plants listed, supplemented with information from the Polish Red Data Book of Plants (Kaźmierczakowa and Zarzycki 2001). The European threatened plant list (Sharrock and Jones 2009) was also used. Legally protected species were chosen according to current Regulation of the Minister of Environment on 9 July 2004 with reference to the species of natural plants covered by protection. The threat status was then used as a decisive factor when preparing a list of the most valuable plants of the collections. Threat categories for species were according to Kaźmierczakowa and Zarzycki (2001) and Zarzycki and Szelań (2006). The nomenclature of herbaceous vascular plants follows Mirek et al. (2002) whereas names of woody species are from Seneta and Dolutowski (2000).

Results

The dendrological collection (arboretum) currently includes 295 species and varieties of trees and shrubs. They belong to 58 families and 302 genera. The most numerous genera are the following: Acer (10 taxa), Pinus (9), Prunus (7) and Salix (6). The most valuable parts of the collection are species of Eurasian provenance, including those native to Poland, represented by about 39 taxa (Figs. 2, 3). These include common trees and shrubs occurring in forests of Poland, such as Abies alba, Pinus sylvestris, Carpinus betulus, Fagus sylvatica, Sorbus aucuparia and Frangula alnus. For educational purposes, the garden also features a rich collection of species typical of Polish parks, such as Acer saccharinum and Physocarpus opulifolius.

Taxonomic diversity of the dendroflora is increased by taxa originating from different

Figure 2. Number of woody and herbaceous species in the garden collection. Explanations: 1 – total number of species, 2 – alien species, 3 – native species.
parts of the world. Many North American species are present (52 taxa), such as *Calycanthus floridus* and *Gymnocladus dioicus*. Furthermore, many trees and shrubs from East Asia grow in the garden, e.g. *Cryptomeria japonica* and *Chamaecyparis obtuse*. The Mediterranean region is represented by *Buxus sempervirens* and *Fraxinus ornus*.

Many tree and shrub species present are aesthetically pleasing. These include taxa that are impressive in bloom (*Amygdalus triloba*, *Forsythia intermedia*) or in fruit (*Cotoneaster sp.*, *Pyracantha sp.*), or are characterized by their peculiar habit (e.g. *Salix matsudana ‘Tortuosa’*). The arboretum section also features fruit trees, such as *Malus* spp., *Pyrus* spp., *Prunus* spp., *Cerasus* spp., *Cornus mas* and *Hippophae rhamnoides*.

The collection of herbaceous plants includes about 498 species, of which most are native (358 taxa). The herbaceous plants collected in the garden belong to 58 families, with the following rich in species: Asteraceae (76 species), Lamiaceae (42), Ranunculaceae (34) and Liliaceae (31).

The collected herbaceous plants are representative of various habitats (Fig. 4). The majority of species are forest plants (116), including *Melittis melissophyllum*, *Hacquetia epipactis*, *Leucojum vernum* and *Laserpitium latifolium*. The xerothermic grassland group includes 78 species, e.g. *Primula veris*, *Dorycnium germanicum*, *Linum flavum* and *Stipa capillata*. There are also 55 species of meadow plants, e.g. *Valeriana officinalis*, *Trollius europaeus* and *Iris graminea*. Among aquatic, moor and marshland species (36), the most interesting are *Salvinia natans*, *Marsilea quadrifolia*, *Butomus umbellatus* and *Iris sibirica*. The group of rock species (8) includes *Crocus vernus* and *Chrysanthemum alpinum*. The group of synanthropic plants consists of 65 species. Those worth mentioning include *Reseda lutea*, *Papaver rhoeas* and *Chelidonium majus*.

Many of the cultivated herbaceous plants serve practical purposes, for example plants with medicinal properties (*Solidago virgaurea*, *Vaccinium vitis-idaea*, *Helichrysum arenarium*, *Hypericum perforatum*, *Carum carvi*, *Artemisia absinthium*) and plants used for seasoning (*Levisticum officinale*, *Artemisia dracunculus*).

The most valuable part of the collection in the garden includes rare, endangered and protected species. The collection of “special care” plants includes 72 taxa (Table 1). The most numerous group are species protected by Polish law, including 51 species strictly protected and 17 partially protected (according to the Decree of the Minister of the Environment of 9 July, 2004), for example: *Adonis vernalis*, *Angelica archangelica*, *Dianthus plumarius* and *Fritillaria meleagris*. Moreover, the collection features 16 species listed in the Polish Red Data Book of Plants (Kaźmierczakowa and Zarzycki 2001), e.g. *Chamaedaphne calyculata*, *Dorycnium germanicum* and *Galium cracoviense*, as well as 18 species included in the red list of vascular plants of Poland (Zarzycki and Szeląg 2006), such as *Dictamnus albus*, *Dracocephalum ruyschiana* and *Linosyris vulgaris*. Species of particular value are those characterized by a high risk of extinction: endangered and vulnerable species. Moreover,
<table>
<thead>
<tr>
<th>No.</th>
<th>Species</th>
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<td>PP</td>
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<td>2</td>
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<td>3</td>
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<td>Aruncus sylvestris</td>
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<td>Iris sibirica</td>
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**Herbal plants**
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**Woody plants**

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<tr>
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<th>Species</th>
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<tbody>
<tr>
<td>1.</td>
<td><em>Betula humilis</em></td>
<td>+</td>
<td>EN</td>
</tr>
<tr>
<td>2.</td>
<td><em>Betula nana</em></td>
<td>+</td>
<td>EN</td>
</tr>
<tr>
<td>3.</td>
<td><em>Frangula alnus</em></td>
<td>+</td>
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<tr>
<td>4.</td>
<td><em>Pinus cembra</em></td>
<td>+</td>
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<tr>
<td>5.</td>
<td><em>Pinus mugo</em></td>
<td>+</td>
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<tr>
<td>6.</td>
<td><em>Ribes nigrum</em></td>
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</tr>
<tr>
<td>7.</td>
<td><em>Sorbus intermedia</em></td>
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</tr>
<tr>
<td>8.</td>
<td><em>Sorbus torminalis</em></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td><em>Staphylea pinnata</em></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td><em>Taxus baccata</em></td>
<td>+</td>
<td>VU</td>
</tr>
<tr>
<td>11.</td>
<td><em>Viburnum opulus</em></td>
<td>+</td>
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</table>
the valuable species also include three taxa from habitats of the Natura 2000 European network of protected areas (Stefaniak 2008): *Marsilea quadrifolia*, *Galium cracoviense* and *Carlina onopordifolia*.

Most (90) species from the valuable group of plants belong to the collection of herbaceous plants. One of the most interesting species in the garden is *Galium cracoviense*, with the highest protection status in Poland. It is a Polish endemic, whose exclusive location is in Olsztyn near Częstochowa (Kaźmierczakowa and Zarzycki 2001). It is also a species included in the European list of protected plant species, protected by regulations of the Bern Convention and listed in Appendix II and IV of the Habitat Directive (Sharrock and Jones 2009). Another important species under *ex situ* protection is *Potentilla micrantha*. This species is typical of oak-hornbeam forests. In Poland, it occurs only in two locations, and its status in the Polish Red Data Book of Plants is vulnerable (VU) (Kaźmierczakowa and Zarzycki 2001). Also worth mentioning are *Betula nana* (EN) and *B. humilis* (EN), glacial relicts that occur in Poland in a few locations (Zając and Zając 2001).

Among legally protected species, most precious are the following woody species: *Pinus cembra, P. mugo, Staphylea pinnata, Sorbus torminalis, S. intermedia* and *Taxus baccata*.

**Discussion**

Conservation is one of the major tasks of botanical gardens in order to preserve the world’s floral diversity, both regionally and globally (Wyse Jackson and Sutherland 2000; Chin 2008; Khurun 2008; Sharrock and Jones 2009). The Teaching and Experimental Botanical Garden of the Faculty of Biology and Environmental Protection, being an internal unit of the University of Lodz, fulfils this function. However, due to climatic and habitat conditions, as well as its relatively small area, the aims are mainly pursued with respect to the Polish vascular flora. The small garden consists of as many as 793 taxa, which constitutes 22.3 percent of the entire vascular flora of Poland (Mirek et al. 2002).

The collection reflects the taxonomical and ecological variety of our flora (Stefaniak 2008). The garden includes species of the most important families (such as Asteraceae, Poaceae, Liliaceae), representatives of most of the growth forms of vascular plants (trees, shrubs, dwarf shrubs, herbaceous plants), and species typical of the majority of Poland’s habitat types (meadows, forests, xerothermic grasslands).

The plants are cultivated from seeds or from specimens obtained from documented natural habitats. Therefore, the collection may be the basis for prospective reintroductions of endangered taxa into substitute localities (Stefaniak 2008). Protection makes it possible to research the biology and ecology of endangered plants, which increases the level of knowledge and their protection status (Sharrock and Jones 2009).

The collections are continuously augmented with new species, which is the reason for the close cooperation between the University Garden in Lodz and other Polish botanical gardens, e.g. the Arboreta in Rogów and Kórnik (Stefaniak 2008). However, it is important to realise that the main purpose of this garden is to educate students from the Faculty of Biology and Environmental Protection. The collected plant material is the basis for lectures in many subjects and in all fields of biological studies. The possibility for students to come into contact with living plants, often in their natural environment, develops a sense of observation, and skills in noticing differences and similarities (Kurzac 2007; Stefaniak 2008).

**Acknowledgements**

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and flowering plants. W. Szafer Institute of Botany, Institute of Nature Conservation, Polish Academy of Sciences, Cracow


COLLECTION OF APPLE TREES IN MOSCOW UNIVERSITY’S BOTANICAL GARDEN

Potential of Moscow State University’s Botanical Garden collection of decorative and fruit apple trees in the context of climate change

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Abstract

Founded in 1951, the collection of apple trees (Malus Mill.) is one of the most valuable collections in the Botanical Garden of Moscow’s State University. The Garden’s work with Malus focuses on three main issues: (1) conserving cultivars of Malus domestica, (2) conserving wild species of Malus, and (3) breeding. The main purpose of these activities is to conserve the gene pool and study the behaviour of different species and cultivars under Moscow’s climatic conditions in order to expand breeding programmes and make wider practical use of the hardiest and most valuable cultivars and species. In recent years Moscow has often experienced unusual temperature conditions during winter (long autumns, prolonged winter thaws), enabling us to take a fresh look at the collection to identify hardy cultivars and species, as well as those that fare badly under such conditions. Multi-year field monitoring is therefore especially important in times of climate change, when species and cultivars that appeared to be resistant can fare badly under these new temperature conditions, while others can be used more widely.

Keywords: breeding, food safety, orchard, Russia, scab, cultivars of Malus, wild apple tree.

Abbreviations

MSU – Moscow State University

Introduction

Wild apple trees – the ancestors of cultivars – first appeared around 65 million years ago (Langenfeld 1991). In ancient times, there were so many wild apple trees in the forests of central Russia that the region was known as the “apple kingdom”. By the early 16th century, the towns and countryside of the Moscow Principality were simply drowning in orchards. Until the middle of the 20th century, the main types were of the so-called “popular selection”. But with the development of biology, and especially genetics, work began on breeding new cultivars, and the apple tree became widely used not only for its fruit, but also for decoration (Volf 1915). In 1950 Moscow State University began breeding apple trees as its Botanical Garden expanded to occupy new grounds. Initially, those grounds were on the outskirts of Moscow, but are nowadays virtually in the city centre. Alongside the traditional botanic garden sections, 4.5 ha were set aside in 1951 for planting with fruit trees (Anonymous 2006).

The orchard currently comprises three sections. In the first of these, to study the genetic potential of the apple tree, the orchard’s founder, S. I. Isayev and his staff created an impressive collection of apple trees of the “popular selection” and contemporary (for the 1950s) Soviet and foreign cultivars, together with pear trees and berry plants. The apple orchard currently boasts 200 cultivars (5 trees of each cultivar, thus around 1 000 trees), some of which have little practical value, but have useful properties that can be used in breeding, such as resistance to scab and frost. The second section is planted with species and decorative forms of Malus. In 1974, under
the supervision of V. Vartapetyan, a collection of wild-growing species of apple tree of different classifications and from various geographical regions was founded. This collection currently comprises 24 species and 16 hybrids from the 5 main centres of Malus diversity: Europe, Central Asia, East Asia, Siberia and the Far East, and America (Table 1) (Vartapetian 2004). The third section is used for apple tree breeding, which the Garden has been working on for almost 60 years.

In 60 years of field observations, a large volume of data has been compiled on the status of the apple tree species and cultivars under Moscow’s climatic conditions. In recent years, due to temperature fluctuations during the resting period (November–March), new data have been obtained on winter resistance, yield, and resistance to disease in a number of cultivars and species (Vanina 2009). The main focus of our work is the introduction and preservation of the gene pool of fruiting apple tree cultivars and species, while assessing their tolerance to climate change for use in breeding and further propagation.

**Materials and methods**

All data used in this paper were obtained through lengthy (from 10 to 55 years for different cultivars) field observations and laboratory studies of the trees growing in MSU’s Botanical Garden. Parameters such as tree dimensions, resistance to scab, frost-resistance, fructification time and yield were recorded for five trees per cultivar. Other parameters (levels of vitamins and biologically active substances in the fruit) were measured in the laboratory. Data collecting was based on standard Russian methodologies as published in the Programme and Methodology for Studying Fruit, Berry and Nut Plant Cultivars, 1973 (in Russian).

**Tree height:** determined by *in situ* measurements of 15-year-old apple trees.

**Frost-resistance:** determined by multi-year monitoring of the tree’s condition. The most valuable results were obtained following extreme winter conditions (severe frosts, lengthy periods of frost, low and very high snow cover) such as the winters of 1978–79, 2002–03 and 2006–07. The effects of abrupt changes in winter temperatures and the starting date of permanent winter-time snow cover were also assessed by recording the following parameters: extent of injury to the previous year’s shoots; bark on trunk; timber. Appendix 1 summarises frost-resistance data using a 5-point scale: 0 – no signs of frostbite; 1 – very slight frostbite: yellowish timber, small areas of burned bark; 2 – slight frostbite: yellowish timber, light-brown timber, slight superficial damage or small areas of deep

<table>
<thead>
<tr>
<th>Species and hybrids of Siberia and Far East</th>
</tr>
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<tbody>
<tr>
<td><em>M. baccata</em> (L.) Borkh</td>
</tr>
<tr>
<td><em>M. manschurica</em> (Maxim.) Kom.</td>
</tr>
<tr>
<td><em>M. hamardabanica</em> Vart.et Sol</td>
</tr>
<tr>
<td><em>M. sachalinensis</em> (Kom.) Yuz.</td>
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</tbody>
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</thead>
<tbody>
<tr>
<td><em>M. sylvestris</em> (L.) Mill.</td>
</tr>
<tr>
<td><em>M. x pumila</em> Mill.</td>
</tr>
<tr>
<td><em>M. x pumila</em> v. <em>pendula</em> Mill.</td>
</tr>
<tr>
<td><em>M. orientalis</em> Uglitzk.</td>
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<tr>
<td><em>M. praecox</em> (Pall.) Borch.</td>
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<tbody>
<tr>
<td><em>M. sieversii</em> (Ldb.) Roem</td>
</tr>
<tr>
<td><em>M. niedzwetzkyana</em> Dieck.</td>
</tr>
<tr>
<td><em>M. x purpureae</em> (Barbier) Rehd.</td>
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<tbody>
<tr>
<td><em>M. coronaria</em> (L.) Mill.</td>
</tr>
<tr>
<td><em>M. ioensis</em> (Wood) Britt.</td>
</tr>
<tr>
<td><em>M. x platycarpa</em> Rehd.</td>
</tr>
<tr>
<td><em>M. soulardia</em> (Bailey.) Britt. Crab Cola, Hansen</td>
</tr>
<tr>
<td><em>M. fusca</em> (Raf.) Schneid.</td>
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<tr>
<th>Species and hybrids of East Asia</th>
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<tbody>
<tr>
<td><em>M. sieboldii</em> (Regel) Rehd.</td>
</tr>
<tr>
<td><em>M. x robusta</em> (Carr.) Rehd.</td>
</tr>
<tr>
<td><em>M. x coerulescens</em></td>
</tr>
<tr>
<td><em>M. x kaido</em> Mak.</td>
</tr>
<tr>
<td><em>M. halliana</em> Koehne.</td>
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<tr>
<td><em>M. x adstringens</em> Zabel.</td>
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<tr>
<td><em>M. x scheideckeri</em> (Spach.) Zabel.</td>
</tr>
<tr>
<td><em>M. cerasifera</em> Spach.</td>
</tr>
<tr>
<td><em>M. sikkimensis</em> (Wenzig.) Koehne.</td>
</tr>
<tr>
<td><em>M. x prunifolia</em> (Willd.) Borkh.</td>
</tr>
<tr>
<td><em>M. pratii</em> (HemsI.) Schneid.</td>
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<tr>
<td><em>M. x floribunda</em> Sieb.</td>
</tr>
<tr>
<td><em>M. sargentii</em> Rehd.</td>
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<tr>
<td><em>M. zumi</em> (Mats.) Rehd.</td>
</tr>
<tr>
<td><em>M. x Nan-Schan</em></td>
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<tr>
<td><em>M. x ringo</em> Rehd.</td>
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<tr>
<td><em>M. hupehensis</em> (Pamp.) Rehd.</td>
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<tr>
<td><em>M. kansuensis</em> Schneid.</td>
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<tr>
<td><em>M. x spectabilis</em> (Ait.) Borkh.</td>
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<tr>
<td><em>M. x denticulata</em> Lavalle</td>
</tr>
<tr>
<td><em>M. transitoria</em> (Batal.) Schneid.</td>
</tr>
<tr>
<td><em>M. yunnanensis</em> (Franch.) Schneid.</td>
</tr>
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</table>
damage to bark, shrinkage of some annual shoots; 3 – substantial frostbite: brown timber, medium-intensity burns, damage of up to 50 percent of the trunk's circumference, dropping of 2–3 year old branches; 4 – very severe frostbite: dark-brown timber, severe burns covering over 50 percent of the trunk's circumference, most of the crown frozen; 5 – tree freezes entirely or to the level of snow cover.

**Time when fructification started:** monitored in young trees since time of planting. The time at which a cultivar begins to fructify is taken as the year after planting in the Garden when at least 50 percent of the trees began to fructify and produced a crop of no less than 3 kg.

**Fruit crop and weight:** the whole fruit harvest of each tree separately was weighed after harvesting each year. Twenty individual fruit were then weighed, followed by that of the largest and the smallest specimens. These data were used to calculate the average weight of an apple as well as average productivity of each cultivar.

**Time of ripening:** this was determined by multi-year monitoring of a range of attributes - typical skin colouring and fruit aroma, size and density of fruit, ease of picking, appearance of characteristic taste and browning of seeds.

**Taste:** determined by at least 5 years of annual tasting upon optimal maturity. Tasting was performed by a panel of experts using a 5-category scale: excellent, very good, good, satisfactory, mediocre.

**Storability:** determined by statistical monitoring of fruit stored in different types of packaging (wooden box or plastic package) at a temperature of +2–+4 °C and relative humidity of 85–90 percent. The storage period ended when fruit losses reached 10 percent of initial quantity.

**Resistance to scab:** determined by multi-year monitoring (at least 10 years) and comparative analysis with other cultivars (to eliminate weather effects). Five trees of each cultivar were monitored under field conditions and leaf damage was assessed. The leaves were examined on four sides of the tree and evaluated on a 5-point scale: 0 – no damage; 1 – slight damage, up to 10 percent of leaves affected; 2 – average damage, up to 25 percent of leaves affected; 3 – severe damage, up to 50 percent of leaves; 4 – very severe damage, over 50 percent of leaves.

**Breeding work:** Cultivars selected on the basis of one or several promising breeding properties were included in the crossbreeding programme. Cultivars lacking functional stamens were artificially pollinated. A total of 15 crossbred combinations were included, with pollination of up to 200 flowers for each combination. 1 500 hybrid seedlings were produced.

**Research on the Collection**

The breeding programme is based on an extensive collection of geographically distant cultivars from Russia, former Soviet Union countries, USA and Canada. The main focus has been on breeding for resistance to frost, harsh conditions and disease, and on enhancing levels of biologically active substances in the fruit (Vitamin C, P-active substances) and β-carotene. The programme has involved extensive crossbreeding of geographically distant cultivars, such as frost-resistant trees from central Russia with American trees resistant to scab (agent – fungus *Ventura inaequalis*) – the most destructive disease in Russia's central belt (Ischenko 1990). This crossbred species has proved very interesting for breeding purposes. The new cultivars (Medunitsa, Desertnoe Isaeya, Osennyay radost', Yuniy Naturalist) are highly resistant to frost (surviving temperatures of -45 °C and suffering no damage from spring frosts), while remaining immune to scab (Vartapetyan 2004). The new cultivars are either early-summer or late-winter plants. Over the past 15 years, 25 fruit and 7 decorative cultivars of wild apple trees have passed government testing programmes and have been included in the State Register of Breeding Achievements permitted for use. Patents have been taken out on 10 new cultivars and 4 decorative wild hybrids. Breeding and production of new cultivars resistant to scab will produce savings on chemicals and energy and, most importantly, will help maintain full, high-quality crops and improve the environment. Appendix 1 summarises key data: tree height, time of start of fructification, resistance to frost and scab, taste, size and fruit ripening period for the 110 most valuable cultivars from the collection of Moscow State University’s Botanical Garden.

Most research on the collection of wild species and hybrids of apple trees consists of
monitoring the behaviour of the genotypes under Moscow's climatic conditions in order to identify the hardiest cultivars for use in future large-fruit breeding programmes and urban landscaping. The species selected, as a result of 35 years of research, originate from different geographical areas with wide variation in phenophase timing. The wild species are highly decorative not only when in blossom, but even when budding. Many species can be spectacular during this period, with buds of different shapes and colours. The trees gradually pass from this phase into the blossoming period, with the two phases together lasting up to 3–4 weeks. By exploiting the differences in phenophase timing in different species it is possible to set out arrangements that blossom continuously for a whole month, from early May to early June. One example of this is an arrangement consisting of *M. baccata* (L.) Borkh, *M. kaido* Mak., *M. sieboldii* (Regel) Rehd, *M. sikkimensis* (Wenzig.) Koehne., *M. sachalinensis* (Kom.) Yuz., *M. zumi* (Mats.) Rehd., *M. hupehensis* (Pamp.) Rehd. and *M. transitoria* (Batal.) Schneid. Wild species are also very decorative during fruiting, displaying fruits of different colours, shapes and sizes. This period begins when apples begin to colour (August) and continues until snow cover forms (November). Of all the species that have been studied, 14 have potential as decorative plants for urban landscaping in Russia's central European belt. These species have a wide range of decorative attributes: height from 2 to 8 m, crown ranging from broad spreading to pyramidal, leaf cover from dappled to solid, leaf shape from integral to lobed, size of fruit from 8 to 30 mm, fruit colour from yellow-green via red to burgundy, autumn colouring of leaves from pale-green via shades of yellow to brown-anthocyanin. Plans are now being made for mass propagation of these species for use in Moscow's urban spaces.

Thanks to this substantial body of genetic material it has been possible to evaluate the behaviour of different cultivars in a changing climate – a process which is most evident in cities. According to Moscow State University's weather station, located 300 m from the Botanical Garden's fruit section, temperatures are rising at a rate of 1.2 °C per 30 years, with most of that increase occurring during the winter months. Winters in the 1990s were on average 2.2 °C warmer than in 1961–1990, and snow cover comes later. In the winter of 2007–08, it was only in the last few days of January that the snow settled. The weather station reports an overall increase in precipitation (mainly during the winter period) and cloud cover, with a slight reduction in penetration of solar energy (due to increased cloud cover) (Isaev 2005). There is also an increase in the number of thaw days during winter. Recent years have often seen prolonged thaws causing all the snow to melt in the middle of winter, with some cultivars and species of apple tree beginning to vegetate. It is these prolonged thaws in February and March, followed by abrupt drops in temperature (of up to 15–18 °C in a single day), that cause most damage to the plants' condition and productivity.

These changes have not affected the composition of our apple tree collection, with the exception of the extremely cold winter of 1978–79 when many of the trees died. We attribute the stability of the collection to the great ecological diversity of the cultivars, hybrids and species it contains. At the same time, unfavourable weather conditions can often have a direct or indirect impact (by spreading diseases and pests) on the state of the plants. For example, the long autumn of 2007 caused *M. mandschurica* (Maxim.) Kom. and *M. baccata* (L.) Borkh to start vegetating, and the subsequent frosts of up to -15 °C destroyed the flower buds and weakened the plants during the 2007, 2008 and 2009 vegetative seasons (Vanina 2009). This provides us with information on the strong and weak points of each cultivar, hybrid and species in our collection.

**Conclusions and Future Prospects**

Climatologists predict that current climatic trends will continue for at least the medium term (2030–2050) (http://climate2008.igce.ru), which means they could seriously affect the structure of the local flora – both natural and cultivated.

One of the effects that climate change will have – which is already becoming apparent – is a threat to food security in various regions of the world. Using the hardiest local species (which are often not the most productive) and adapting agriculture to local environmental conditions will greatly reduce the dependence of local communities on global food production.
We believe that botanical gardens should play an active role in addressing the issue of food security. The collection of apple trees in Moscow State University's Botanical Garden is one of the most valuable not only in Russia, but in the whole of Eastern Europe. No less important is the fact that this collection has been monitored continuously for several decades, allowing assessments to be made on plant resistance to local conditions and climate change. This database forms an excellent foundation for future breeding programmes.

Preserving and rejuvenating the collection is an important task for the coming years. Many of the trees in our Garden are already approaching a critical age. In order to continue monitoring the genotypes in a changing climate and extend the experiment for a further 30–50 years, the collection needs to be rejuvenated. We also plan to introduce modern microclone propagation techniques to: (1) preserve plant genotypes in vitro; (2) grow own-root plants with preserved genotype; and (3) facilitate plant exchanges with other botanical gardens to assess their viability under different climatic conditions.

We hope that the results of this work will be of practical value both in Russia and other European countries with similar environmental conditions, particularly in northern Europe.

Acknowledgements

This paper is the result of hard work by the staff of the fruit garden section of Moscow State University’s Botanical Garden over a period of almost 60 years. Thanks to all of you.

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<tr>
<th>Cultivar</th>
<th>Author, city, country</th>
<th>Tree height [i]</th>
<th>Frost resistance</th>
<th>Time of start of fructification (years)</th>
<th>Max. crop from one tree (kg)</th>
<th>Time of ripening [ii]</th>
<th>Max weight of the fruit (g)</th>
<th>Taste</th>
<th>Storability</th>
<th>Resistance to scab</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altaiskii Golubok</td>
<td>N.Lisavenco, Altai, Russia</td>
<td>Tall</td>
<td>0</td>
<td>3–4</td>
<td>200</td>
<td>Summer</td>
<td>30</td>
<td>Satisfactory</td>
<td>December</td>
<td>1</td>
</tr>
<tr>
<td>Anis Alyi</td>
<td>Popular selection (Ps.)</td>
<td>Tall</td>
<td>0</td>
<td>7–8</td>
<td>250</td>
<td>Autumn</td>
<td>100</td>
<td>Good</td>
<td>February</td>
<td>2</td>
</tr>
<tr>
<td>Anis Polosatyi</td>
<td>Ps.</td>
<td>Tall</td>
<td>0</td>
<td>7–8</td>
<td>330</td>
<td>Late autumn</td>
<td>100</td>
<td>Good</td>
<td>March</td>
<td>2</td>
</tr>
<tr>
<td>Anisovka</td>
<td>I.Michurin, Michurinsk, Russia</td>
<td>Tall</td>
<td>0</td>
<td>7–8</td>
<td>200</td>
<td>Late autumn</td>
<td>Near 60</td>
<td>Good</td>
<td>March</td>
<td>1</td>
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<tr>
<td>Antei</td>
<td>Belorussia</td>
<td>Medium</td>
<td>0</td>
<td>3–4</td>
<td>200</td>
<td>Winter</td>
<td>250</td>
<td>Very good</td>
<td>February</td>
<td>2</td>
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<tr>
<td>Antonovka Desertnaya</td>
<td>S.Isaev, Michurinsk, Russia</td>
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<td>0</td>
<td>4–5</td>
<td>140</td>
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<td>200</td>
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<td>March</td>
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<td>2–3</td>
<td>5–6</td>
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<td>Winter</td>
<td>130</td>
<td>Very Good</td>
<td>February</td>
<td>2</td>
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<td>Pamyat' Michurina</td>
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<td>Tall</td>
<td>2–3</td>
<td>4–5</td>
<td>200</td>
<td>Late winter</td>
<td>150</td>
<td>Excellent</td>
<td>May</td>
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<td>2–3</td>
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<td>250</td>
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<td>Summer</td>
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<td>Height</td>
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<td>Flowers or Leaves</td>
<td>Fruits or Stems</td>
<td>Harvest</td>
<td>Quality</td>
<td>Harvest Time</td>
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<td>120</td>
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<td>April</td>
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<td>6–7</td>
<td>250</td>
<td>Winter</td>
<td>250</td>
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<td>April</td>
<td>1</td>
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<td>S.Isaev, Russia</td>
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<td>5–6</td>
<td>250</td>
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<td>200</td>
<td>Excellent</td>
<td>April</td>
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<td>Podmoskovnoye</td>
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<td>0</td>
<td>4–5</td>
<td>Medium Autumn</td>
<td>280</td>
<td>Good</td>
<td>November</td>
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<tr>
<td>Polivitaminnoye</td>
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<td>0</td>
<td>4–5</td>
<td>Medium Winter</td>
<td>160</td>
<td>Good</td>
<td>January</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Pomon-Kitayka</td>
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<td>Medium</td>
<td>1</td>
<td>4–5</td>
<td>250</td>
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<td>180</td>
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<td>5</td>
<td>250</td>
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<td>Good</td>
<td>January</td>
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<td>V.Velichkin, Moscow region, Russia</td>
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<td>0</td>
<td>5</td>
<td>250</td>
<td>Late winter</td>
<td>120</td>
<td>Excellent</td>
<td>April</td>
<td>3</td>
</tr>
<tr>
<td>Rekord Michurina</td>
<td>A.Tikhonova, Russia</td>
<td>Medium</td>
<td>2–3</td>
<td>5</td>
<td>250</td>
<td>Late summer</td>
<td>120</td>
<td>Excellent</td>
<td>3–4 weeks</td>
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<tr>
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<td>I.Michurin, Michurinsk Russia</td>
<td>Medium</td>
<td>1</td>
<td>6–8</td>
<td>210</td>
<td>Late winter</td>
<td>200</td>
<td>Satisfactory</td>
<td>April</td>
<td>3</td>
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<td>2–3</td>
<td>6–7</td>
<td>250</td>
<td>Winter</td>
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<td>5–6</td>
<td>200</td>
<td>Late winter</td>
<td>140</td>
<td>Good</td>
<td>April</td>
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</tr>
<tr>
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<td>1</td>
<td>5–6</td>
<td>250</td>
<td>Late winter</td>
<td>350</td>
<td>Excellent</td>
<td>April</td>
<td>3</td>
</tr>
<tr>
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<td>2–3</td>
<td>5</td>
<td>High</td>
<td>Late summer</td>
<td>160</td>
<td>Excellent</td>
<td>November</td>
<td>1</td>
</tr>
<tr>
<td>Sinap Orlovskiy</td>
<td>Orel, Russia</td>
<td>Medium</td>
<td>2–3</td>
<td>5</td>
<td>Medium Winter</td>
<td>160</td>
<td>Good</td>
<td>May</td>
<td>2</td>
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<tr>
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<td>1</td>
<td>4–5</td>
<td>170</td>
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<td>150</td>
<td>Good</td>
<td>Up to June</td>
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<tr>
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<td>0</td>
<td>5–6</td>
<td>150</td>
<td>Late winter</td>
<td>200</td>
<td>Good</td>
<td>April</td>
<td>3</td>
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<td>1</td>
<td>5–6</td>
<td>250</td>
<td>Winter</td>
<td>200</td>
<td>Good</td>
<td>February</td>
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<td>4–5</td>
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<td>Autumn</td>
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<td>Excellent</td>
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<td>200</td>
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<td>150</td>
<td>Good</td>
<td>Up to December</td>
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</tr>
<tr>
<td>Spartan</td>
<td>Canada</td>
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<td>2–3</td>
<td>3–4</td>
<td>60</td>
<td>Winter</td>
<td>120</td>
<td>Excellent</td>
<td>April</td>
<td>1</td>
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<tr>
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<td>120</td>
<td>Excellent</td>
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<td>Studencheskoye</td>
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<td>2–3</td>
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<td>Good</td>
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<tr>
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<td>6–8</td>
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<td>150</td>
<td>Excellent</td>
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<td>I. Tellisaare, Estonia</td>
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<td>3</td>
<td>4–5</td>
<td>200</td>
<td>Winter</td>
<td>150</td>
<td>Good</td>
<td>April</td>
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<td>Uralskoye Nalivnoye</td>
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<td>3–4</td>
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<td>Autumn</td>
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<td>Good</td>
<td>3 weeks</td>
<td>2</td>
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<td>Origin</td>
<td>Size</td>
<td>Harvest Time</td>
<td>Failure</td>
<td>Quality</td>
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<td>Price</td>
<td>Trees</td>
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<td>0</td>
<td>5</td>
<td>250</td>
<td>Early autumn</td>
<td>170</td>
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<tr>
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<td>USA</td>
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<td>3</td>
<td>3-4</td>
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<td>Winter</td>
<td>150</td>
<td>1</td>
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<td>140</td>
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<td>Saratov, Russia</td>
<td>Tall</td>
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<td>4-5</td>
<td>120</td>
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<td>200</td>
<td>2</td>
<td></td>
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<td>Shafrannoye</td>
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<td>Shreyfling</td>
<td>P.s.</td>
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<td>0-1</td>
<td>5-6</td>
<td>400</td>
<td>Late autumn</td>
<td>210</td>
<td>2</td>
<td></td>
<td></td>
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<tr>
<td>Yubilyar</td>
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<td>2-3</td>
<td>4-5</td>
<td>200</td>
<td>Autumn</td>
<td>150</td>
<td>1</td>
<td></td>
<td></td>
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<tr>
<td>Yunyy Naturalist</td>
<td>S. Isaev, Michurinsk, Russia</td>
<td>Medium</td>
<td>0-1</td>
<td>3-5</td>
<td>250</td>
<td>Autumn</td>
<td>150</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

[i] Tall – height of the tree is more than 6 m (usually 6-8 m), Medium – height is 4-6 m.

INVENTORY OF GRASSLAND BIOTOPES OF THE NATIONAL BOTANIC GARDEN OF LATVIA – PRELIMINARY RESULTS

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Abstract

Conservation, renovation and the maintenance of grassland biotopes are substantial contributions to the conservation of Latvian biodiversity, as more than 520 flowering plants and pteridophytes grow in semi-natural grasslands in the country. In the National Botanic Garden (NBG) of Latvia (total area 129 ha), semi-natural, non-fertilized grasslands are represented. The NBG provides a good opportunity to reconstruct, maintain and monitor semi-natural grassland biotopes and to provide public education. In 2008, an inventory of biotopes in the NBG was initiated. The aim of this activity was to locate botanically valuable biotopes in the NBG in order to provide management options to increase grassland biodiversity. In this paper, preliminary results of this inventory are presented. We show that due to regular mowing in the NBG, mesophile grassland biotopes have developed. After the inventory, monitoring started as well as a program for the conservation and increasing of biological diversity. The evaluation of NBG biotopes, their proper management and layout will increase the value of the NBG as a specially protected nature territory and will contribute substantially to the conservation of grassland biotopes.

Key words: biodiversity, conservation, grassland biotopes, management, National Botanic Garden of Latvia

Introduction

In agreement with global and European plant conservation strategies, the *ex situ* conservation of native plant species biodiversity is one of the main tasks of botanic gardens (Wyse Jackson and Sutherland 2000). The National Botanic Garden (NBG) of Latvia is characterized by a number of different biotopes: dendrological plantings, grasslands with various soil fertility and moisture conditions, ponds, and ditches partly or completely dry in summer. In 2008 an inventory of biotopes, inter alia grasslands of the NBG was initiated. The aim of this activity was to assess the biodiversity of native plant communities at the NBG and to determine possibilities for its conservation and increase.

Forest is the final stage of succession in many areas in Latvia. As such, the existence of grasslands depends on the impact of economic activities of people, e.g. grazing and mowing. Grasslands where mowing or grazing has been the main management activity for at least 15 years (no fertilizers, no additional seed sowing) are considered to be semi-natural grasslands. In recent years, terms such as “meadow” and “pasture” have been replaced with “grassland” (Anonymous 2000a; Kabucis 2001).

In Latvia, semi-natural grassland biotopes are particularly important for the conservation of plant species biodiversity, since more than 520 flowering plant and pteridophyte species occur in these biotopes, i.e. a third of the native flora as well as 40 percent of Latvia’s Red Data Book plant species (ca. 128 species). Nowadays the diversity of grasslands in Latvia is under threat. Semi-natural grassland cover is less than 0.3–0.5 percent of the total area of the country, and these grasslands are highly fragmented (Auniņš 2010; Rūsiņa 2008a).

Grasslands are highly dynamic plant communities. The cessation of mowing and grazing causes a dramatic decrease of species diversity (Anonymous 2000b). The accumulation
of grass biomass decreases light penetration to the soil layer, thus changing moisture conditions. This prevents the regeneration of many plant species, culminating in the decrease of species richness and a depletion of the seed bank (Gazenbeek 2008).

The restoration of grasslands is of particular importance in specially protected nature territories (SPNT), which increases the value of these areas (Račinska 2002). Since the NBG has a SPNT status, there is an opportunity to promote conservation and to perform long term management in all biotopes to maintain and increase floral biodiversity. As a result of these activities, plant species richness of the NBG is expected to increase. Education is also an important aspect of the NBG because the native flora can be presented in semi-natural biotopes to the public.

In Latvia, little practical experience exists in performing grassland management. Studies on the impacts of different grassland management approaches on the vegetation have only started in recent years (Jermacāne et al. 2002; Straupe and Adamovičs 2003; Rūsiņa 2008a, b). Grassland management projects usually last for 5–6 years, which is too short a period to observe specific trends (Gazenbeek 2008). This is because plant communities adapt to new management relatively slowly and become stable very gradually (Bakker et al. 1996).

In 2008, a long-term vegetation research project was started at the NBG. The aim of the first stage of this project is to locate botanically valuable grassland biotopes in the NBG to promote their conservation. The long-term objective of this project is to assess the value of all NBG grassland biotopes in the context of conservation and in the protection of grassland biotopes in Latvia. Furthermore, data and experiences obtained on vegetation changes in grasslands continuously managed will provide useful insight for the management of grassland biotopes in other botanic gardens and SPNT.

Materials and methods

Research site

The NBG (founded in 1956, total area 129 ha) is located 18 km to the southeast of Riga, the capital of Latvia (56°58’ N, 24°04’ E). The territory is plain – 14–26 m above sea level (Zvirgzds 1986). The botanic garden consists of both closed and opened drainage systems. In ditches, completely dry in summer, there are calcareous springs of underground waters. Riga’s Hydroelectric Power Station (HEPS) has a considerable impact on the hydrological conditions of the NBG. The NBG experiences early and late spring frosts and severe winters. The territory of the dendrarium is influenced by cold airflows originating from bogs located northwards (Cinovskis 1999).

NBG is situated in the Middle Latvian geobotanic region, where mesophile grasslands with Medicago falcata L., Ononis arvensis L., Galium verum L., Fragaria viridis Duchesne, Origanum vulgare L., Filipendula vulgaris Moench, and Trifolium montanum L. are typical biotopes (Tabaka et al. 1987). However, the garden is characterized by more grassland biotopes compared to the region because water level fluctuations provide for a diversity of plant communities.

In order to maintain grassland biotopes, the key management method is mowing, with occasional grazing in a few localities. All NBG grassland biotopes are mowed at least once a year. The first mowing is carried out from the 10th of May to the 23rd of June. Only in certain biotopes, where rare and protected plant species occur, is late mowing carried out (i.e. in August) to ensure the successful maturation and dissemination of seeds. Soil fertilization, additional seed sowing and old grass burning is not practiced.

Research methods

The territory was studied using the track method. The field form used in the Latvian (Latvian Fund for Nature) – Dutch (Royal Netherlands Nature Conservation Society) collaborative project “Meadow inventory in Latvia” was modified and adapted to NBG conditions (Anonymous 2000b). Data on historical and current management, threats to the biotope, list of all flowering plant species including indicators, characteristic and dominant species, and the percentage cover or the number of individuals were included in this form.

The manual “Habitats of Latvia. Classifier” was used to classify the biotopes (Kabucis 2001).
The classification is based on ecological, floristic and phytosociological studies. Grassland biotopes were defined after the description of biotopes and the identification of characteristic species.

Plant nomenclature followed “Flora of vascular plants of Latvia. List of taxa” (Gavrilova and Šulcs 1999). The locations of grassland biotopes were marked on a map of the NBG.

**Results and Discussion**

The inventory identified mesophile grassland biotopes in the NBG. According to the manual “Habitats of Latvia. Classifier” this group of biotopes is called lowland meadows (E.2. Mēreni mitras pļavas) with corresponding category in the manual “A classification of Palearctic habitats” – “38. Mesophile grasslands”. The types and subtypes of biotopes with corresponding categories in some other classifiers are summarized in Table 1.

The inspected biotopes are grasslands of intermediate botanical value. This means that they are well developed with a natural spatial structure including 3–5 indicator species of semi-natural grasslands. In addition, Dactylorhiza baltica (Klinge) N.I. Orlova – an indicator of semi-natural grasslands and a protected species – was found. More than 30 flowering plant species in all biotopes, excluding Nardus grasslands, were identified (Table 2). Nardus grasslands occur in acidic, nutrient-poor sandy soils. Although plant species diversity is relatively low, these grasslands have a unique species composition. In Latvia, as well as in Europe, Nardus grasslands is a rapidly vanishing habitat type (Auniņš 2010).

The management policy of the NBG is the continuance and natural restoration of key grassland biotopes. We suggest that the current management regime, i.e. mowing once (for E.2.2. Mesophile pastures and areas with rare and protected species) or twice (for E.2.3. Hay meadows, those with no protected species) a year, should be continued. In 2009, the first mowing of these biotopes was delayed until July to promote seed maturation and dissemination. To maintain the low vegetation in Nardus grasslands, mowing should be performed bi-annually, along with

### Table 1. Mesophile grassland biotopes found in the National Botanic Garden of Latvia and corresponding categories in some other classifiers.

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Type: E.2.3. Īstās pļavas (E.2.3. Hay meadows) Subtype: E.2.3.1. Festuca pratensis pļavas (E.2.3.1. Festuca pratensis grasslands) Subtype: E.2.3.2. Helictotrihon pubescens pļavas (E.2.3.2. Helictotrihon pubescens grasslands)</td>
<td>Lowland hay meadows</td>
<td>6510 Lowland hay meadows</td>
</tr>
</tbody>
</table>

*– priority European Union Habitats.
**Table 2.** Flowering plant species of the inspected mesophile grassland biotopes in the NBG.

<table>
<thead>
<tr>
<th>Grassland biotope*</th>
<th>Characteristic species</th>
<th>Constant species</th>
<th>Dominant species</th>
<th>Indicator species of semi-natural grasslands</th>
</tr>
</thead>
<tbody>
<tr>
<td>E.2.1. Nardus grasslands</td>
<td><em>Calluna vulgaris, Dianthus deltoides, Hypericum maculatum, Luzula multiflora, Nardus stricta, Potentilla erecta, Polygala vulgaris, Sieglingia decumbens, Viola canina</em></td>
<td><em>Agrostis tenuis, Anthoxanthum odoratum, Briza media, Deschampsia caespitosa, Potentilla erecta, Solidago virgaurea</em></td>
<td><em>Nardus stricta, Calluna vulgaris</em></td>
<td><em>Briza media, Dianthus deltoides, Sieglingia decumbens</em></td>
</tr>
<tr>
<td>E.2.2. Mesophile pastures</td>
<td><em>Agrostis tenuis, Anthoxanthum odoratum, Briza media, Festuca rubra, Leontodon autumnalis, Luzula campestris, Plantago lanceolata, Prunella vulgaris, Trifolium repens</em></td>
<td><em>Achillea millefolium, Briza media, Cerastium holosteoides, Galium album, Leontodon hispidus, Phleum pratense, Polygala vulgaris, Primula veris, Ranunculus acris, Veronica chamaedrys</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E.2.2.1. Anthoxanthum odoratum - Agrostis tenuis grasslands</td>
<td></td>
<td><em>Anthoxanthum odoratum, Agrostis tenuis</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E.2.2.2. Anthoxanthum odoratum – Briza media grasslands</td>
<td></td>
<td><em>Leontodon hispidus, Linum catharticum, Phleum pratense, Plantago lanceolata, Polygala vulgaris, Primula veris, Trifolium repens, Trifolium pratense</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E.2.3. Hay meadows</td>
<td><em>Carum carvi, Crepis biennis, Knautia arvensis, Leucanthemum vulgare, Tragopodon pratensis</em></td>
<td><em>Anthriscus sylvestris, Campanula patula, Centaurea jacea, Galium album, Lathyrus pratensis, Medicago lupulina, Poa pratensis, Trifolium pratense, Vicia cracca</em></td>
<td><em>Helictotrichon pubescens</em></td>
<td></td>
</tr>
<tr>
<td>E.2.3.1. Festuca pratensis grasslands</td>
<td></td>
<td><em>Anthriscus sylvestris, Carum carvi, Centaurea jacea, Galium album, Helicotrichon pubescens, Lathyrus pratensis, Leucanthemum vulgare, Medicago lupulina, Poa pratensis, Trifolium pratense</em></td>
<td><em>Festuca pratensis, Phleum pratense, codominant - Dactylis glomerata</em></td>
<td><em>Plantago media, Primula veris, Briza media, Galium boreale</em></td>
</tr>
<tr>
<td>E.2.3.2. Helicotrichon pubescens grasslands</td>
<td></td>
<td><em>Anthraxanthum odoratum, Briza media, Centaurea jacea, Deschampsia caespitosa, Festuca pratensis, Galium boreale, Lathyrus pratensis, Geum rivale, Ranunculus acris</em></td>
<td><em>Helicotrichon pubescens</em></td>
<td><em>Dactylorhiza baltica, Galium boreale, Plantago media, Briza media.</em></td>
</tr>
</tbody>
</table>

increasing cutting height.

Unimproved (without sowing seeds of Phleum pratense, Dactylis glomerata and without fertilizer) grassland biotopes are of little value for agricultural purposes and in many cases they are abandoned. For this reason, maintaining these biotopes in the NBG is very important. In general, there are two typical ways to transform these biotopes: without management they become overgrown, or due to soil fertilization plant mass productivity increases, as observed in grasslands in NBG, while biodiversity decreases.

Inventories of grassland biotopes and the realization of management programs for different biotopes in the NBG will be done in the future. Management is based on Latvian and European grassland management experiences and recommendations from experts, as well as on biotope management experience obtained during the last 4 years at the NBG. Results obtained from other European countries must be evaluated cautiously because of climatic, edaphic and orographic differences as well as differences in vegetation (Londo 1990; Berendse et al. 1992; Willems 2001; Wahlman and Milberg 2002).

As Gazenbeek pointed out (2008, p. 19), a dominant approach to long-term grassland management is grazing. This may be because semi-natural or natural grasslands are not economically attractive due to low nutrient content in the grass compared to other types of forage. Both in Latvia and Estonia, late mowing is the usual practice in grassland management, to allow for seed and bird maturation (Gazenbeek 2008, p. 21). In the NBG, late mowing is only practiced in biotopes where rare and protected plant species occur – in order to provide conditions for seed maturation and dissemination.

Future activities of the NBG include the construction and maintenance of semi-natural grassland biotope models. This is the first stage of creating “The trail of biotopes” for the purposes of scientific research and public education about biodiversity. This activity is important at both Latvian and European scales.

References


EX SITU CONSERVATION AND INVESTIGATION OF RARE AND ENDANGERED PLANTS OF LITHUANIA

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Abstract

The preservation of rare species in Lithuania was first discussed in 1959 with the adoption of the Law on the Protection of the Environment. Currently, there is a system of nature reserves in Lithuania to preserve plants in situ. Research on rare and endangered plants is conducted within the programme of Scientific Research of Plant Genetic Resources of Lithuania, which started in 1993. Three institutions are involved in these activities, one of which is the Botanical Garden of Vilnius University. The Coordinating Centre of Ornamental Plant Genetic Resources set up in the Botanical Garden of Vilnius University coordinates the research on the ex situ conservation of rare and endangered plants. Ex situ conservation includes plants growing in collections from various studies. This study presents the data from three ex situ collections of rare and endangered plants. Our results revealed that the seeds of Agrostemma githago L. and Agrimonia procera Wallr. germinated successfully in all media, while Trifolium rubens L. seeds did not germinate well. Dianthus superbus L. and Arnica montana L. germinated well on a filter paper substrate, while Iris sibirica L. and Gratiola officinalis L. seeds did not germinate well on filter paper. Plants of all 21 species preserved in culture were successfully cultivated and adapted to ex situ conditions and propagated. Most of these plants were decorative. Our findings are important for the popularization of Lithuanian preserved plants and for their horticultural use. The collections of preserved plants will serve as a rich source of endangered plants to be used in reintroductions into the wild.

Keywords: ex situ collections, plant growth, seed germination

Introduction

In Lithuania occur 1 344 indigenous and 548 exotic plant species, with 16 indigenous plant species already having gone extinct in the country. Eleven vascular plant species and three moss species (Table 1), preserved by the European Union directive of habitats, occur in Lithuania. As such, it is necessary to establish special territories to protect these species (Raudonikis 2006).

The latest Red Data Book of Lithuania (RDBL; Rasomavicius 2007) contains descriptions of 339 plants: 1 Equisetophyta (Horsetail), 1 Phaeophyta (Brown algae), 1 Pinophyta (Conifer), 1 Rhodophyta (Red algae), 3 Lycopodiophyta (Club mosses), 8 Polypodiophyta (Ferns), 10 Charophyta (Charophytes), 93 Bryophyta (Mosses) and 221 Magnoliophyta (Flowering plants) (Rasomavicius 2007). Species in the RDBL are divided into five categories that follow the same classification as is used in the International Union for Conservation of Nature (IUCN) Red List of 1976 (IUCN 1976): (Ex) – Extinct or possibly extinct species; 1 (E) – Endangered species on the verge of extinction yet can be saved only with the implementation of special conservation measures; 2 (V) – Vulnerable species whose population figures and abundances are rapidly decreasing; 3 (R) – Rare
species with a small number of populations due to their biological characteristics; 4 (I) – Indeterminate species, which cannot be included in the other categories due to lack of data; and 5 (Rs) – Restored species once included in the Red List whose abundance has since been restored.

There are three legitimate collections of rare and endangered plants in Lithuania, which are run by educational institutions. These areas are earmarked for educational and environmental protection training activities. The first collection is situated at the Agrobiological Station (Tamosava) and at the Centre of Agriculture in Buivydis (nowadays Department of Agrotechnology of Vilnius College (DAVC), Fig. 1). The richest collection of preserved plants can be found in the botanical garden of the secondary school in Traupis (Anyksciai) where approximately 150 plant species included in the Red Data Book of Lithuania grow and flourish (Fig. 2). Plant species endangered throughout Europe can be found in this botanical garden: *Thesium ebracteatum* Hayne, *Pulsatilla patens* (L.) Mill, *Dianthus arenarius* L., *Linaria loeselii* Schweigg. *Agrimonia pilosa* Ledeb.

Material and Methods

Seed germination study


The aim of this study was to investigate the ex situ collections of rare and endangered plants to elucidate seed germination and plant features of these plants. Data from three rare and preserved ex situ plant collections in Lithuania, such as seed germination under laboratory and field conditions, biology, morphology, phenology, decorativeness and possibilities for the reproduction of 21 plant species included in the Red Data Book of Lithuania are presented.

<table>
<thead>
<tr>
<th>Vascular plants</th>
<th>Mosses</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Aldrovanda vesiculosa</em> L.</td>
<td><em>Dicranum viride</em> (Sull. Et Lesq.) Lindb.</td>
</tr>
<tr>
<td><em>Botrychium simplex</em> E. Hitchc.</td>
<td><em>Hamatocaulis vernicosus</em> (Mitt.) Hedenäs</td>
</tr>
<tr>
<td><em>Cypripedium calceolus</em> L.</td>
<td><em>Buxbaumia viridis</em> (Moug. Ex Lam. Et DC) Brid. Ex Moug. Et Nestl</td>
</tr>
<tr>
<td><em>Liparis loeselii</em> (L.) Rich.</td>
<td></td>
</tr>
<tr>
<td><em>Najas flexilis</em> (Wild.) et W. L.E. Schmidt</td>
<td></td>
</tr>
<tr>
<td><em>Pulsatilla patens</em> (L.) Mill.</td>
<td></td>
</tr>
<tr>
<td><em>Saxifraga hirculus</em> L.</td>
<td></td>
</tr>
<tr>
<td><em>Thesium ebracteatum</em> Hayne</td>
<td></td>
</tr>
<tr>
<td><em>Dianthus arenarius</em> L.</td>
<td></td>
</tr>
<tr>
<td><em>Linaria loeselii</em> Schweigg.</td>
<td></td>
</tr>
<tr>
<td><em>Agrimonia pilosa</em> Ledeb.</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Plant species in Lithuania listed in the European Union directive of habitats
school in Traupis, Fig. 2; Botanical Garden of Vilnius University, Fig. 3). Seed germination was tested at the Vilnius Pedagogical University and the Botanical Garden of Vilnius University using methods confirmed by the order of the Minister of Agriculture of Lithuania (Nr 3D-436, 17 October 2003) and prepared according to the rules of the International Seed Testing Association (Chapter 5 “Investigation of seed germination”) (Valstybes 2003). All seeds collected from plants cultivated in ex situ collections were kept at room temperature (20 ±2 °C) in paper bags and seeds late were stratified. The germination of 100 mature seeds per species was carried out on filter paper in Petri dishes and in potting soil (50 percent peat bog, 50 percent peat moor) at a temperature of 25 ±2 °C under light conditions in the laboratory. Seedling growth was observed under laboratory conditions in vivo, and in field collections ex situ. The initiation of seed germination, mean germinating power and seedling vitality were observed. Seed germination is expressed as the percentage of seeds that germinated, while germination power represents the percentage of seeds germinated during a certain period of time. Seed germination was evaluated after 3, 7, and 10 days, and later. Seeds that germinated with difficulty were observed for three months (some seeds germinated late and germination is plant specific).

### Plant features

Twenty-one plant species (Agrostemma githago L., Agrimonia procera Wallr., Allium angulosum L., Allium vineale L., Allium ursinum L., Arnica montana L., Astrancia major L., Beckmania eruciformis (L.) Host., Campanula bononiensis L., Gratiola officinalis L., Hedera helix L., Iris sibirica L., Lithospermum officinale L., Lunaria rediviva L., Mentha longifolia L., Polemonium caeruleum L., Prunella grandiflora L.(Scholler), Salvia pratensis L., Scabiosa columbaria L., Stachys recta L. and Trifolium rubens L.) growing in ex situ collections were used to investigate certain features. For example, height, plant reproduction (seeds or vegetatively), flowering intensity, adaptation, state of the plant, damage by diseases and pests, and the evaluation of decorative characteristics were carried out in an ex situ collection, set up in Buivydiskes near Vilnius. These plants are grown in an exposition established in an open grassy area (Fig. 1). Plants of each species cultivated occupied an area of 1 m². The upper layer of the soil of these 1 m² areas contained 2.93–3.19 percent of humus, 324–400 mg kg⁻¹ of available phosphorus (P₂O₅), 86–130 mg kg⁻¹ of available potassium (K₂O), 2 520–20 500 mg kg⁻¹ of calcium (Ca), 400–1 688 mg kg⁻¹ of magnesium (Mg) and 0.088–0.146 percent of total nitrogen (N). Soil pH was 6.7–7.6. Chemical analyses of the soil samples were performed using the following methods: the method of Turin (ISO 10694, 1995) for humus, available P₂O₅ and K₂O using the method Egner-Riem-Domingo (Å-L) (GOST 262008-91, 1993), atomic absorption spectrometry method for calcium and magnesium (SVP D-06), the Kjeldahl method (ISO 11261, 1995) for total nitrogen and the potentiometer method for pH_KCl (ISO 10390, 1994) at the Agrochemical research centre of the Lithuanian Institute of Agriculture.

Seed germination and germination power were expressed as percentages ±SE. Data analysis was carried out using the statistical analysis tools of MS EXCEL 2002.

### Results

#### Seed germination

Because of a lack of seeds we were not able
to investigate the germination power of the following species on the seedling substrate: Allium angulosum L., Arnica montana L., Beckmania eruciformis (L.) Host, Dianthus superbus L., Gratiola officinalis L, Iris sibirica L. and Scabiosa columbaria L. Plant cultivation from seeds is significant for the enrichment of plant collections, and is particularly relevant for endangered species. Plants cultivated from seeds adapt to new environmental conditions more easily.

Effects of the substrate

Seeds from all 17 plant species studied (Table 2) germinated, ranging from 8–100 percent success rate. Seeds placed on filter paper (Fig. 4) germinated earlier than seeds placed on
### Table 2. Seed germinating power and seedling vitality of some Red Data Book plant species in Lithuania, germinated on filter paper and in potting soil

<table>
<thead>
<tr>
<th>Species/Treat category in Lithuania</th>
<th>Seed collection location</th>
<th>Substrate</th>
<th>Seed germination starts (in days)</th>
<th>Average germinating power (%)</th>
<th>Seedling vitality (points*)</th>
<th>Seeds were collected in year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agrostemma githago L./ 2 (V)</td>
<td>DAVC</td>
<td>filter paper</td>
<td>1</td>
<td>100 ± 0</td>
<td>4</td>
<td>2008</td>
</tr>
<tr>
<td></td>
<td></td>
<td>potting soil</td>
<td>2</td>
<td>100 ± 0</td>
<td>5</td>
<td>2008</td>
</tr>
<tr>
<td></td>
<td></td>
<td>filter paper</td>
<td>1</td>
<td>100 ± 0</td>
<td>4</td>
<td>1970</td>
</tr>
<tr>
<td></td>
<td></td>
<td>potting soil</td>
<td>2</td>
<td>100 ± 0</td>
<td>5</td>
<td>1970</td>
</tr>
<tr>
<td>Agrimonia procera Wallr./ 3 (R)</td>
<td>Traupis</td>
<td>filter paper</td>
<td>18</td>
<td>78 ± 5</td>
<td>1</td>
<td>2008</td>
</tr>
<tr>
<td></td>
<td></td>
<td>potting soil</td>
<td>19</td>
<td>80 ± 8</td>
<td>2</td>
<td>2007</td>
</tr>
<tr>
<td><strong>Allium angulosum</strong> L./ 3 (R)</td>
<td>Traupis</td>
<td>filter paper</td>
<td>4-5</td>
<td>26 ± 2</td>
<td>5</td>
<td>2008</td>
</tr>
<tr>
<td><strong>Arnica montana</strong> L./ 2 (V)</td>
<td>Traupis</td>
<td>filter paper</td>
<td>5</td>
<td>83 ± 2</td>
<td>4</td>
<td>1981; 2005</td>
</tr>
<tr>
<td>Astrantia major L.</td>
<td>Traupis</td>
<td>filter paper</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2008</td>
</tr>
<tr>
<td><strong>Beckmania eruciformis</strong> (L.)</td>
<td>Traupis</td>
<td>filter paper</td>
<td>2 - 3 - 9</td>
<td>75 ± 5</td>
<td>3</td>
<td>2007</td>
</tr>
<tr>
<td>Campanula bononiensis L./2 (V)</td>
<td>Traupis</td>
<td>filter paper</td>
<td>6</td>
<td>44 ± 2</td>
<td>1</td>
<td>2008</td>
</tr>
<tr>
<td></td>
<td></td>
<td>potting soil</td>
<td>20</td>
<td>25 ± 3</td>
<td>3</td>
<td>2008</td>
</tr>
<tr>
<td><strong>Dianthus superbus</strong> L./1 (E)</td>
<td>BGVU</td>
<td>filter paper</td>
<td>8</td>
<td>86 ± 4</td>
<td>4</td>
<td>2006</td>
</tr>
<tr>
<td>Erica tetralix L./ 1 (E) BGVU</td>
<td>filter paper</td>
<td>3</td>
<td>50 ± 3</td>
<td>4</td>
<td>2006</td>
<td></td>
</tr>
<tr>
<td><strong>Gratiola officinalis</strong> L./ 1 (E)</td>
<td>DAVC</td>
<td>filter paper</td>
<td>4</td>
<td>16 ± 2</td>
<td>2</td>
<td>2008</td>
</tr>
<tr>
<td><strong>Iris sibirica</strong> L./ 2 (V)</td>
<td>BGVU</td>
<td>filter paper</td>
<td>15 - 18</td>
<td>12 ± 2</td>
<td>4</td>
<td>2008</td>
</tr>
<tr>
<td>Lithospermum officinale L./ 3 (R)</td>
<td>BGVU</td>
<td>filter paper</td>
<td>8</td>
<td>35 ± 5</td>
<td>4</td>
<td>2008</td>
</tr>
<tr>
<td></td>
<td></td>
<td>potting soil</td>
<td>11</td>
<td>24 ± 2</td>
<td>5</td>
<td>2008</td>
</tr>
<tr>
<td><strong>Lunaria rediviva</strong> L/5 (Rs)</td>
<td>DAVC</td>
<td>filter paper</td>
<td>11</td>
<td>25 ± 6</td>
<td>3</td>
<td>2006¹</td>
</tr>
<tr>
<td>Polemonium m caeruleum L./ 2 (V)</td>
<td>BGVU</td>
<td>filter paper</td>
<td>4</td>
<td>78 ± 4</td>
<td>4</td>
<td>2007</td>
</tr>
<tr>
<td></td>
<td></td>
<td>potting soil</td>
<td>5 - 6</td>
<td>84 ± 3</td>
<td>5</td>
<td>2007</td>
</tr>
<tr>
<td>Prunella grandiflora L.(Scholler) /2(V)</td>
<td>DAVC</td>
<td>filter paper</td>
<td>3 - 4</td>
<td>30 ± 10</td>
<td>4</td>
<td>2008</td>
</tr>
<tr>
<td></td>
<td></td>
<td>potting soil</td>
<td>8</td>
<td>12 ± 2</td>
<td>4</td>
<td>2008</td>
</tr>
<tr>
<td>Salvia pratensis L./ 3 (R)</td>
<td>DAVC</td>
<td>filter paper</td>
<td>5 - 9</td>
<td>42 ± 8</td>
<td>4</td>
<td>2008</td>
</tr>
<tr>
<td></td>
<td></td>
<td>potting soil</td>
<td>14 - 35</td>
<td>28 ± 4</td>
<td>4</td>
<td>2008</td>
</tr>
<tr>
<td><strong>Scabiosa columbaria</strong> L./ 3 (R)</td>
<td>Traupis</td>
<td>filter paper</td>
<td>9 - 15</td>
<td>30 ± 3</td>
<td>3</td>
<td>2006</td>
</tr>
<tr>
<td>Trifolium rubens L./ 3 (R)</td>
<td>BGVU</td>
<td>filter paper</td>
<td>10 - 20</td>
<td>15 ± 7</td>
<td>4</td>
<td>2008</td>
</tr>
<tr>
<td></td>
<td></td>
<td>potting soil</td>
<td>10</td>
<td>8 ± 0.5</td>
<td>4</td>
<td>2008</td>
</tr>
</tbody>
</table>

*Seedling vitality, points: 5 – seedlings are healthy, of high vitality, grow rapidly; 4 – seedlings are healthy, developed normally; 3 – seedlings with medium vitality, grow slowly, leaves slightly damaged and faded; 2 – seedlings with weak vitality, grow very slowly, leaves are faded and yellowed; 1 – seedlings are damaged, diseased, distorted, leaves are severely damaged; 0 – seedlings died

** Ongoing studies (on the seedling substrate)

¹ seeds stratificated

**Figure 4. Agrostemma githago L. seed germination and seedlings growing on filter paper (days since sowing day): a - 1 day; b, c - 2 days; d, e - 3 days and f - 10 days**
Seedling vitality was greater and they grew more rapidly than seeds that had been sown in potting soil or directly to the soil in the autumn. Seeds of *Agrostemma githago* L., in particular, germinated rapidly, and remained viable for several decades. For example, all seeds of this species, collected in 1970, germinated. Seeds of *Lithospermum officinalis* L. started to germinate in 8–11 days, but some seeds took up to three months to germinate. Haghbeen et al. (2006) tried to germinate healthy seeds of *Lithospermum officinale* in a different way and obtained negative results. Hence, it is recommended to scratch the hard crusts of the seeds to enhance germination. Seeds sown in soil germinated slowly, but seedlings were stronger, of great vitality, and all seedlings produced leaves. However, seeds on filter paper germinated faster but seedlings showed lower vitality, with some dying after planting into pots. The seeds of *Astrantia major* L. placed on filter paper did not germinate under laboratory conditions. These plants propagate from seeds in the wild, and can be viable for several years. The germinating power of the seeds of *Lunaria rediviva* L. was 93 percent for one-year-old seeds; 85 percent for two-year-old seeds, and only 52 percent for three-year-old seeds under field conditions.

**The effects of stratification**

Unstratified seeds of *Lunaria rediviva* L. did not germinate under laboratory conditions while stratified seeds (2 months at 4 °C) germinated; with a germination power of 25 percent (Table 2). The germination power of *Salvia pratensis* L. seeds varied from 25 to 60 percent, depending on year. Seeds of *Trifolium rubens* L. have strong husks and soaked slowly, thus germinated with difficulty. Germination power increased when seeds were treated with sulphuric acid before germination, but this depended on immersion time. After immersion for 5 min, germinating power was 10%, 10 min – 20%, 20 min – 60%, 30 min – 100%, 45 min – 95%, and 60 min – 80%.

**The evaluation of ex situ collections of rare and endangered plants in Lithuania**

Features of plants in *ex situ* collections (Table 3) are discussed below, taking into consideration results from investigations of these plants in situ, published in the Lithuanian SSR Flora (Aleksandraviciute et al. 1961; Bagdonaite et al. 1963; Aleksandraviciute et al. 1971; Butkus et al. 1976; Galinis et al. 1980) and the Red Data Book of Lithuania (Rasomavicius 2007).

*Agrostemma githago* L. (Caryophyllaceae) During the first half of the 20th century this species was a frequent annual weed of corn crops and grew in *Stellarietea-Mediae* communities. Later, *A. githago* vanished due to the use of plant protection chemicals and the treatment of crop seeds with mordants. At the beginning of the 21st century the use of chemicals decreased, and this plant can again be found in fields. This decorative species is easily cultivated and propagated (from seeds). *Agrostemma githago* L. adapts well to the conditions of cultivation in culture, and is morphologically similar under *ex situ* and *in situ* conditions; however, sometimes under *ex situ* conditions the plants are even more exuberant.
Table 3. The evaluation of growth of some plants preserved ex situ in Lithuania

<table>
<thead>
<tr>
<th>Species/ Treat category in Lithuania</th>
<th>Propagation from seeds</th>
<th>Vegetative propagation</th>
<th>Adaptation to ex situ conditions compared to plants in natural habitats</th>
<th>Flowering intensity</th>
<th>Damage by diseases and pests</th>
<th>State of the plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Points</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td><strong>Agrostemma githago</strong> L./ 2(V)</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><strong>Agrimonia procera</strong> Wall./ 3 (R)</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><strong>Allium angulosum</strong> L./ 3(R)</td>
<td>+</td>
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1. Propagation from seeds: 1 – does not set seed, 2 – set seed not every year, 3 – set seed every year, no self-sowing, 4 – set seed every year, self-sowing is characteristic
3. Adaptation to ex situ conditions compared to plants in natural habitats: 1 – plants grow but are weaker, 2 – plants grow as well as in natural habitats, 3 – plants grow more vigorously
5. Damage by diseases and pests: 1 – severe damage, every year all plants were damaged, 2 – plants were rarely damaged and only at solitary instances, 3 – healthy, undamaged plants
than in the wild. The species almost went extinct in the 1990s. After land reform, which changed the use and ownership of land, populations have recovered and there are still small rye fields with an abundance of *Agrostemma githago* L. in the southern and south-eastern parts of the country (Rasomavicius 2007).

*Agrimonia procera* Wallr. (Rosaceae) occurs in southern Lithuanian *Carpinion* union foliate forests, and in *Trifolio-Geranietae* and *Rhamno-Prunetea* plant class communities. It propagates from seeds and rhizomes in nature and in collections. *Ex situ* plants are smaller (1.20 ± 0.15 m), but some may reach the same height as plants in natural habitats (0.50–1.80 m). Yearlings only reach 0.20 ± 0.05 m in height and do not flower. Two-year-old plants grow vigorously and reach up to 1.30 ± 0.05 m in height. Self-sowing was observed. The vegetative period starts at the end of March; first leaves open at the beginning of April, leaves are abundant in May, flower buds form in June, and flower in July–August. Seeds are ripe at the end of September. The plant has ornamental value. *Agrimonia procera* adapts well under *ex situ* conditions and no noticeable phenological differences in comparison with *in situ* conditions have been determined.

*Allium angulosum* L. (Alliaceae) is a light-demanding plant. It grows in dry habitats and tolerates flooding and drought. *Allium angulosum* adapts well to cultivation in culture and grows to 0.50–0.70 m in height, flowers abundantly and produces seeds. In open sunny areas it grows more exuberantly. The most important threat to its survival is ploughing of meadows and other changes to habitats.

*Allium vineale* L. (Alliaceae) has ornamental and phytoncidic value, and grows in dry habitats, e.g. meadows, forest edges, slopes; it reaches 0.30–0.80 m in height. The species commonly propagates vegetatively by aerial bulblets, but seeds do not always ripen. Propagation by vivipary in the laboratory revealed that 85 ± 3% germinated after 7–9 days. Seedlings were relocated and the growth of plants under *ex situ* conditions was observed. Only some yearlings flowered, but two-year-old plants flowered abundantly. The vegetative period in the collection starts in April when air temperatures reach +8 °C. Bud burst starts in June and flowers in July–August.

*Allium ursinum* L. (Alliaceae) is perceived as an officinal, decorative plant and is suitable for human consumption. It grows in damp habitats, propagates from seeds and vegetatively. According to Karpavičienė (2004), 90 percent of this species’ habitats are near rivers and springs. Seeds ripen on plants but germ completely when seeds fall to the ground. *Ex situ* plants only reach 0.18 ±0.04 m in height (in nature 0.35–0.40 m), and leaves are narrower and shorter than plants in natural habitats. The vegetative period starts at the end of March and continues until the beginning of June, and ends in the second half of June to the beginning of July (coinciding with the vegetative period in natural habitats).

*Arnica montana* L. (Asteraceae) is an officinal, decorative plant that grows in dry pine forests on sandy soils. Vegetative stems are very short (0.01–0.02 m) while generative stems in natural habitats and in collection reach 0.20–0.50m. Plants propagate easily by rhizomes. Seeds ripen in the second half of July and in August. Plants grown from seeds begin to flower in the third year (about 50 percent of the plants), whereas in the fourth year 95–100 percent of the plants produce flowers. According to Penkauskiene (1962), polymorphism is characteristic for plants from different habitats (forest, meadow, moist soil).

*Astrantia major* L. (Apiaceae) grows well in shady and sunny areas and commonly propagates vegetatively. This species has been grown in collections since 1980; it grows vigorously and flowers abundantly. Under *ex situ* conditions, the plant propagates very well vegetatively, i.e. in 3–4 years their branches become stronger, thicker and extend to 50 cm in diameter, and can grow in one place without replanting for up to 10 years. *A. major* is cultivated in parterres and rock-gardens both in Lithuania and in neighbouring countries. This plant has a very long flowering period from the end of June to the start of frost, and the leaves are decorative throughout the season. In Lithuania, the two known sites of *Astrantia major* are outside the main distribution area of the species. The species has probably escaped cultivation. It prefers moist forests of *Alnion-Incanae* in fertile soils rich in carbonate. The largest populations harbour hundreds of individuals. The main threats are forest felling, draining, and the introduction of coniferous
Beckmania eruciformis (L.) Host. (Poaceae). Most of the habitats of this plant are considered to be of artificial origin and only solitary habitats are natural. Plants grown from seeds flower in the first year, and are self-sowing. Plants in the collection grow similarly to plants in the wild. Under ex situ conditions, plants disperse vegetatively and are more exuberant. Some populations are of anthropogenic origin.

Campanula bononiensis L. (Campanulaceae) is characterised by short rhizomes and upright stems. It is a light- and heat-demanding plant, growing in lime soils. Plants grow naturally in Trifolio-Geranietea plant communities, and propagate from seeds and vegetatively. Plants in the collection reach 0.7–1.2 m in height. This decorative plant flowers every year and many seeds are ripe at the end of September.

Gratiola officinalis L. (Scrophulariaceae) grows in moist areas, but can also grow in dry habitats. It grows vigorously in the collection, many plants reach 0.40–0.60 m in height. In natural habitats, plants reach 0.15–0.40 m. Plants propagate rapidly by rhizomes and by rooted stems. This species covered the whole plot (1m²) within three years. The vegetative period begins in March, plants flower in the second half of June and continue until September. Seeds ripen in September and October.

Hedera helix L. (Araliaceae). Lithuania is the north-eastern limit of this species’ home range. Hedera helix L. is heat-loving and is subject to frost damage in severe winters. Plants do not flower in natural habitats and flower rarely in collections. This is an officinal, decorative plant, growing in forests of southern Lithuania. This species has been protected since 1962, RDBL 1(E) threat category. Plants propagate vegetatively. The rooting trailing stems form thick carpets on the ground (Fig. 3). Under Lithuanian climatic conditions, this species suffers from frost. Therefore, the only way to grow it successfully is to have it as a trailing ground cover plant.

Iris sibirica L. (Iridaceae). This rhizomatous plant of moist habitats forms Iridetum-Sibirici communities in Lithuania. Plants propagate from seeds and vegetatively. It is a decorative species and needs to be cultivated near water. Iris sibirica is a long-living plant, with numerous leaf rosettes and flowering shoots, connected by permanent rhizomes with short internodes. Iris sibirica grows in groups of various sizes, though plants growing alone also occur. It seems that this plant can be cultivated in culture. As such, its propagation possibilities in particular are researched, also in other countries. One-year-old plants were planted in the autumn and mulched with composted pine bark and sawdust. Results indicated that Iris sibirica can be cultivated rapidly in an unheated plastic tunnel. Cut flowers were ready for the market 1–3 weeks earlier, and yields and quality were higher than from plants grown outdoors. Mulching plants grown outdoors with bark and sawdust also increased cut flower yields (Pogroszewska 1998). Vegetative reproduction in Iris sibirica consists of the proliferation of individuals followed by their fragmentation. The highest effectiveness of vegetative propagation was observed in the early stages of the plant (Kostrakiewicz 2007).

Lithospermum officinale L. (Boraginaceae) is a perennial herbaceous, decorative and officinal species. Plants grow singly or in groups. An increase in cover of woody species is a threat to this species’ persistence in nature. In collections plants grow vigorously, flower in June and July, and seeds ripen in September. At the end of the vegetative period, ex situ plants can reach up to 0.76–0.79 m in height, while in natural habitats plants reach 0.30–0.60 m in height and very rarely 1 m. Seeds sown directly to the soil in April germinate in May to June, and seedlings develop leaves rapidly. Plants mainly flower in the second year, but sometimes also in the first year. Fruits ripen and seeds from these germinate. Ex situ plants grow vigorously, and propagated and dispersed into the experimental area during the fourth year (The collection of Vilnius College in Buivydiske, Vilnius district). Diseases and pests have not been observed.

Lunaria rediviva L. (Brassicaceae) is under threat due to agriculture and changing habitats. It grows up to 1.20 m in height in moist and shady habitats in nature. L. rediviva has been grown ex situ since 1980. In the first year, plants that germinate from seeds grow up to 0.36 ± 0.02 m in height, but do not flower. Two-year-old plants form 4–6 new stems of 0.96 ± 0.03 m in height, of which only one is generative. Plants stop flowering in June after which fruits
and seeds ripen. Three-year-old and older plants in the collection reach 1 m in height. However, plants growing in open and dry-soil areas are generally shorter (0.90 ± 0.10 m) than plants in natural habitats (moist turf carbonic soils), yet plants grow vigorously and are healthy. *L. rediviva* propagates from seeds and rhizomes and adapts rapidly to changed conditions. Plants are decorative and can be cultivated as ornamentals; its pods have floristic value.

*Mentha longifolia* L. (Lamiaceae) grows in moist habitats on the banks of rivers and lakes as well as in forests. The erect and branchy stems reach up to 0.80–1.00 m in height in natural habitats. *Ex situ* plants adapt rapidly to conditions in the collection, propagate vegetatively and soon cover the whole area. Plants flower and set seeds, but are lower or of the same height (0.70–0.80 m) as in natural habitats. The species is decorative, fragrant, and attractive for bees; it has the potential to be used in horticulture.

*Polemonium caeruleum* L. (Polemoniaceae) grows in moist meadows and on the banks of rivers or lakes, mostly individually. The species is threatened due to draining and overgrowing by woody plants. *Ex situ* plants grow up to 0.80–1.3 m in height, while in situ plants grow to a height of up to 0.50–1.2 m. During moist summers, plants grow to 1.3 m in height, and in dry summers to about 0.80 m. Yearlings flower, but not abundantly. Two-year-old plants begin to flower in the second half of May and continue to flower until mid July; they are self sowing. Propagation by seeds and rhizomes aids in the establishment of individuals in new habitats. The species can, potentially, be successfully reintroduced into its native habitats.

*Prunella grandiflora* L. (Scholler) (Lamiaceae) is a decorative, first-year flowering perennial and attracts bees, and can be widely cultivated. Plants are bushy and compact. They flower in spring and summer and grow well in all soils and is resistant to frost. The plants grow well in sunny and dry places, they propagate by seeds and vegetatively by creeping stems. Natural hybrids with *P. vulgaris* – *P. grandiflora* x *P. vulgaris* were described by Fritsche and Kaltz (2000).

*Salvia pratensis* L. (Lamiaceae) grows in backwaters, beside bushes and in carbonic soils, and reaches 0.30–0.80 m in height. In *ex situ* collections plants grow vigorously, reaching 1.15–1.20 m in height. The species propagates from seeds and vegetatively. Self-sowing was observed.

*Scabiosa columbaria* L. (Dipsacaceae) is light-demanding and grows in dry habitats in nature. The species adapt rapidly *ex situ*, with plants growing taller than in nature. Plant height in nature is 0.10–0.60 m while in the collection some individuals can reach up to 1.20 m in height. Self-sowing was observed. Fruits are wind dispersed and some plants occurred outside the experimental plots.

*Stachys recta* L. (Lamiaceae) occurs in *Trifolio-Geranietea* communities. Plants have erect stems and short rhizomes, and prefer sunny and dry habitats. *S. recta* have been cultivated in *ex situ* collections since 1980. Plant height in natural habitats is 0.10–0.50 m, while 0.50–0.70 m in the collection. The vegetative period starts in mid April, and flowering occurs in June, but single flowers are observed until October. The plant is decorative; it propagates from seeds and by rhizomes.

*Trifolium rubens* L. (Fabaceae) is a decorative plant that grows well *ex situ*. It is frost sensitive and prefers carbonic soils. In spite of good growing conditions (sufficient light, no competition from other plants) *T. rubens* did not multiply in the beds. Plants flower and form pods containing seeds of weak germinating power. *Ex situ* and *in situ* plants reach heights of up to 0.74 ± 0.06 m. The dense purple heads of *T. rubens* can reach 0.14–0.16 m in length (*in situ* 0.04–0.10 m). Individual plants have different numbers of racemes, from 26 to 72.

**Discussion and Conclusions**

In the United Nations Johannesburg Summit in 2002, the relationship between sustainable development of society and the preservation of biological diversity was emphasized. The Global Strategy for Plant Conservation (GSPC), adopted under the Convention on Biological Diversity (CBD) in 2002, calls for 60 percent of threatened plant species to be placed in accessible *ex situ* collections, preferably in the country of origin. The plants cultivated in these Lithuanian collections are a rich resource for reintroduction of endangered plants. The introduction of rare
and endangered plants is carried out in a number of botanical gardens, which is significant for the preservation of the plant gene pool. Cultivating endangered plants and collecting their seeds, the exchange of seed and the development of the collections are important functions of these gardens (Trosteniuk et al. 2009). For example, over 53% of the higher plants species from the Russian Red List are grown in botanical gardens in Russia (Demidov 2005).

Our study shows that most of the species evaluated in the ex situ collections grow vigorously, flower and set viable seeds. Many years of observations revealed that plants reacted differently to habitats changes, but most adapted to new conditions. During the vegetative period, the heights of ex situ plants were often similar but for a few species somewhat different to the heights of plants growing in natural habitats. An important characteristic is plant propagation in the tested area. All the researched plants under ex situ conditions propagated vegetatively, except Agrostemma githago and Trifolium rubens. All the plants flowered intensively except for Hedera helix. Good propagation of plants and intensive flowering are indicators of successful introductions.

The success of introduction depends on plant species and their properties. Rhizomatous plants established in new habitats and propagated rapidly. Astrantia major L. grew vigorously and flowered until frost. Vegetative propagation is also a very important factor. The great majority of tested species are decorative and could be grown as ornamentals.

The preserved plants of Lithuania are grown in three specialized collections (in Buivydiskes, Vilnius and Traupis). The oldest collection is in Buivydiskes, while the richest is in Traupis (150 plant species). The genetic resources of endangered plants are accumulated in collections. This is an active means to preserve endangered plant before reintroducing species to nature from botanic collections, which is becoming an increasingly utilized strategy for plant conservation (Maunder 1992; Kaye 2008). All 21 preserved and endangered plant species investigated under ex situ conditions adapted to new conditions. In fact, the majority of species grew well and propagated successfully. Rhizomatous plants grew most vigorously and propagated into the whole experimental area (e.g. Gratiola officinalis L., Lithospermum officinalis L., Polemonium caeruleum L., Salvia pratensis L., Scabiosa columbaria L.). From all the investigated plant species of the RDBL, only Hedera helix L. did not flower, but this could be explained by the fact that Lithuania is the north-eastern limit of this species’ natural range. However, propagation was ensured due to its ability to propagate vegetatively. The best seed germinating power from all substrates was established for Agrostemma githago L. (100%) and Agrimonia procera Wallr. (78–80%), while the seeds of Trifolium rubens L. (8–15%) did not germinate well. Dianthus superbus L. (86 %) and Arnica montana L. (83%) germinated best in the filter paper substrate, while Iris sibirica L. (12%) and Gratiola officinalis L. (16 %) germinated poorly in this substrate. Plant species of moist habitats, Gratiola officinalis L. and Lunaria rediviva L. grew well, flowered and produced seeds growing in expositions established in sunny and dry area, Allium ursinum L. grew slightly worse, but flowered and produced seeds.

References


Vilnius, p 715


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EX SITU CONSERVATION AND EXHIBITION OF WILD FOOD PLANTS OF THE CAMPANIA REGION AT NAPLES BOTANICAL GARDEN (ITALY)

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Abstract

The use of wild plants as food dates back to ancient times. Food history teaches us that the European diet has changed with the progress of civilization due both to trade and agriculture. In particular, meat consumption has notably increased during the 19th century. The same history teaches us that during food shortages, wild plant consumption was necessary for human survival. Presently, due to climate change it is not always possible to harvest wild food and aromatic and medicinal plants at the right time of the year. Nowadays the use of wild plants as food is still practiced in many tropical areas and in small rural villages. In order to keep background information of useful plants alive, we carried out an ethnobotanical study to identify which species were, or still are in use. We selected a number of plants, including those whose uses are disappearing, to be displayed at the Naples botanical garden. Our aim is to preserve and conserve this popular and historical "green" knowledge ex situ, and to educate the general public on their uses. Currently, Naples botanical garden is an important repository for useful plants and associated information about many important local species.

Keywords: ethnobotanical research, display area, plant exhibition, public education

Introduction

Climate change is become increasingly recognized as one of the greatest challenges to humankind and all life on Earth. Worldwide changes in seasonal patterns, weather events, temperature ranges, and other related phenomena have all been reported and attributed to global climate change. Numerous experts in a wide range of scientific disciplines have warned that the negative impacts of climate change will become more intense and frequent in the future, particularly if environmentally destructive human activities continue unabated (Ahas et al. 2002; Gordo and Sanz 2009). Like all living members of the biosphere, wild food, medicinal and aromatic plants are not immune to the effects of climate change; consequently it is not always possible to harvest them at the right time of year, when their potency is greatest. Some wild plants have begun to flower earlier and shift their ranges in response to changing temperatures and weather patterns (Chmielewsky and Rötzer 2001; Llorens and Peñuelas 2005). Shifting phenologies and ranges may seem of little importance at first glance, but they have the potential to cause great challenges to the survival of species.

The possible effects on local wild plants may be particularly significant due to their value within traditional economies. The future effects of climate change on wild food plants are largely uncertain, and intertwined with changes in human food habits.

The contemporary use of wild plants is still active in many tropical areas and in small rural villages of temperate areas (Shackleton et al. 1998; Ploetz and Orr 2004). Concerning Italy, many studies have been performed on the different ways in which wild plants are used (Galt and Galt 1978; Tumino 1978; Barbagallo et al. 1979; Capasso et al. 1982; Cappelletti 1985; Antonone et al. 1988; Leporatti and Pavesi 1989; Raimondo and Lentini 1990; De Feo et al. 1992; Ballero and Fresu 1993; De Feo and Senatore 1993; Guerrera 1999, 2005; Pieroni 2000; Leporatti and Corradi 2001; Pieroni et al. 2002a, b; Pieroni and Heinrich...
These studies have shown that in small villages, wild plants are still being used for medicinal purposes, as food both for humans and animals, as aromatics, and in producing textiles and to make handworks. Depositories of this information are the older people who, in many cases, represent the majority of the local village population. These people jealously store this knowledge handed down to them throughout generations and they often add personal experiences to the traditional background.

The importance of this kind of study is in the collection of data in order to keep ancient traditions alive, which are destined to disappear otherwise, and to sustain the cultivation of some local plants, whose presence in the wild is often rare due to a changing environment. Moreover, this knowledge could be preserved and diffused to the general public by displaying these species in exhibition areas of botanical gardens.

Displaying Nature: a new exhibition area in Naples botanical garden for educational purposes

Botanical gardens hold documented collections of living plants for the purposes of scientific research, conservation, display and education (Wyse Jackson and Sutherland 2000). With climate change, ex situ conservation is becoming important to store plant biodiversity.

Naples botanical garden was established in 1807 and currently has 25 000 specimens belonging to about 10 000 species in cultivation (De Luca 1992), many of which are rare or endangered. Recently, wild local species of ethnobotanical interest have been introduced for cultivation and new display areas have been organized with wild Mediterranean plants, with the purpose to educate the public and to make people aware of the importance of biodiversity.

One of these display areas has been devoted to the wild food plants of the Campania region (Italy) (Fig. 1), both to increase our ethnobotanical collections and to preserve a precious cultural heritage of traditional use of these plants. The display of species commonly used in everyday life is a useful interpretative strategy to make visitors appreciate nature as a source of scientific knowledge. We have chosen wild food species for our collections because they are interesting to many people. Ethnobotanical studies have showed that in many rural communities the use of wild food plants is still occasionally practised. Nowadays, however, some traditional dishes occur only during certain times of the year, i.e. Christmas, Easter, holy days and local fairs or as occasional preparations.

Recently the consumption of these kinds of aliments has increased thanks to the “slow food” association (Shiva 1993; McGee 2002) that is working to safeguard popular food traditions. For realizing the new display area, we selected 19 species, including those whose use is disappearing. The species to be introduced into cultivation have been identified after having done interviews in small rural villages. The plants for the exhibition have been selected by considering their frequency of utilization and the unusual way of preparation for food.

Each plant in the exhibition area has a label that reports both systematic information and food usage. Below, we report the list of edible wild plants that have been selected for the exhibition area. Used parts and preparation are described.

Exhibition plants

**Althaea officinalis** L. (Malvaceae)

USED PARTS: leaves, roots

Preparation. The young leaves are used in salads or in vegetable soups. In the past, roots were...
ingredients in jams and syrup; they are first boiled and then slightly fried with butter.

_Aspheleia aestivus_ Brot. (Liliaceae)
USED PARTS: tubers
Preparation. Tubers are rich in starch and for this reason they were used during periods of food shortage. Dried and boiled in water they yield a mucilaginous matter that can be mixed with grain to make nutritious bread. Boiling destroys the acridity of the tubers, rendering them quite pleasant to eat.

_Borago officinalis_ L. (Boraginaceae)
USED PARTS: leaves, flowers, flowering tops
Preparation. Raw leaves are used in salads or both raw and cooked leaves are added to soups and pancakes; they are used to fill “ravioli”. _B. officinalis_ is also used as a pot-herb. The leaves are rich in potassium and calcium. Flowers are used raw as a decorative garnish in salads or for producing a “light blue” vinegar. The flowers are nice to look at and have a sweet slightly cucumber-like flavour. Flowering tops were a typical ingredient of a dish made with tomato sauce, sausages, beans and hot chilli pepper.

_Cucurbita maxima_ Duchesne (Cucurbitaceae)
USED PARTS: leaves
Preparation. Leaf shoots raw or boiled in salads. The leaves contain up to 5 percent protein.

_Fagus sylvatica_ L. (Fagaceae)
USED PARTS: fruits
Preparation. Beechnuts or “mast” have a sweet taste and are highly nutritious, about 20 percent protein and 20 percent oil content. The pericarp contains organic substances that are slightly toxic; for this reason fruits are peeled and roasted before eating. These nuts were in common use during times of abundant labour but scarce food sources, such as during the years immediately after World War II. Powder obtained from roasted fruits was used as a substitute for coffee.

_Humulus lupulus_ L. (Cannabaceae)
USED PARTS: shoots
Preparation. Young shoots are boiled and used in salads or in omelettes. The flavour is unique and, to many, tastes delicious.

_Muscari comosum_ (L.) Mill. (Liliaceae)
USED PARTS: Bulbs
Preparation. Bulbs are peeled and cooked, used with potatoes or in omelettes. They have a slightly bitter taste.

_Parietaria officinalis_ L. (Urticaceae)
USED PARTS: young leaves
Preparation. Leaves are used raw or cooked. After boiling, the young leaves are eaten as vegetables or are used in omelettes and soups. Young shoots can be added to mixed salads.

_Papaver rhoeas_ L. (Papaveraceae)
USED PARTS: buds, stalks, flowers
Preparation. Buds are used in salads; dried stalks were used fried with garlic and hot chilli pepper. During periods of food shortages, flowers were used in salads and vegetable soups.

_Portulaca oleracea_ L. (Portulacaceae)
USED PARTS: leaves, stems
Preparation. Young leaves are added to salads or stored in oil. The leaves have a somewhat sour flavour, a spicy and somewhat salty taste, which can be dried and fried with oil, garlic and hot chilli pepper.

_Plantago lanceolata_ L. (Plantaginaceae)
USED PARTS: leaves
Preparation. Young leaves are less fibrous than adult leaves, and are rather bitter and are eaten raw in salads or cooked in soups.

_Reichardia picroides_ Roth (Asteraceae)
USED PARTS: aerial parts
Preparation. During periods of food shortages, aerial parts were used in salads and vegetable soups. The plant has a pleasant and agreeable flavour with a slight sweetness and very little fibre, which makes for a very acceptable lettuce substitute.

_Sambucus nigra_ L. (Caprifoliaceae)
USED PARTS: flowers
Preparation. The flowers are crisp and somewhat juicy, and have an aromatic smell and flavour. Flowers are used in pancakes.

_Senecio vulgaris_ L. (Asteraceae)
USED PARTS: aerial parts
Preparation. During periods of food shortages,
plants were used raw in salads or stewed in vegetable soups.

*Silene alba* (Mill.) Krause (Caryophyllaceae)
USED PARTS: flowering tops
Preparation. Flowering tops are used in salads.

*Sylibum marianum* (L.) Gaertn. (Asteraceae)
USED PARTS: receptacle
Preparation. Inner parts of the receptacle were boiled and used in salads or soups.

*Taraxacum officinale* Weber (Asteraceae)
USED PARTS: roots, leaves, buds, flowers
Preparation. Roots are boiled and used in salads throughout the year. During spring, leaves, buds and flowers were used raw in salads. Tender young leaves are considerably less bitter than older leaves. The leaves are often blanched (by placing the growing plant in a dark place) before use. This will make them less bitter, but they will also contain less vitamins and minerals (Chevallier 1997).

*Urtica dioica* L. (Urticaceae)
USED PARTS: leaves
Preparation. Leaves are eaten in different ways, are added to soups, as dressing of pastas, and in salads. Young leaves are used in salads, omelettes, pancakes and homemade pasta (gnocchi). Nettles are a very valuable addition to the diet as they are very nutritious and are easily digestible. They are high in minerals, especially iron, and vitamins (especially A and C) (Pfendtner 2004), and can be dried for winter use.

*Vicia faba* L. (Fabaceae)
USED PARTS: hull, tops
Preparation. During periods of food shortages, hulls were peeled, chopped and boiled. Young tender tops are used raw in salads.

**Conclusions**

The exhibition of this particular collection has spurred interest of both the general public and of students. Our aim is to halt the decline of plant resources, and to promote indigenous and local knowledge. We are carrying out many educational and public-awareness programmes in order to support and sustain the local and traditional food use in such a way as to renovate the interest for some species whose uses are now disappearing. We would like to underline the importance of floral diversity by spreading the knowledge of the use of wild species among people whose diet is made up of only cultivated and selected species. During summers we arrange a series of events and invite people to visit the botanical garden to appreciate “slow food” cuisine prepared with local wild and cultivated plants, make seeds available and celebrate indigenous plant conservation. In this way we try to conserve our locally grown economic plant diversity, avoid the loss of plant genetic resources, and make local communities aware of their local treasures.

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WOODY PLANTS OF THE RED DATA BOOK OF RUSSIA IN SAINT-PETERSBURG

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Abstract

The aim of the research project “Biological peculiarities of threatened species of the woody flora of Russia introduced in Saint-Petersburg” (2008–2012) is to introduce Red Data woody species of Russia into botanic garden collections. This implies the careful and detailed study of winter hardiness, reproductive ability and seasonal developmental rhythms for all introduced plants. The botanic garden of the Komarov Botanical Institute of the Russian Academy of Sciences contains the richest collection of threatened woody plants in North-Western Russia (48 species), which has been considerably replenished and enlarged in recent years.

Introduction

Conservation of the floral gene pool, including the plants of Russia, is important in solving current, as well as future ecological problems (Takhtajan 1975). The preservation of species diversity is essential for the continued existence of humans on earth (e.g. Tzvelev 2000). In many botanic gardens in Russia, large collections of rare and threatened plants have been established and maintained. Consequently, considerable experience in the ex situ conservation of the Russian flora has accumulated (Demidov 2005). Up to 2005, 53 percent of the higher plants species from the Russian Red Data List have been cultivated in Russian botanic gardens (Demidov 2005), which is close to the target of 60 percent set by the Global Strategy for Plant Conservation (Secretariat of the CBD 2002). The main method of biodiversity protection is to conserve species in the wild (in situ); the establishment of nature reserves and other protected areas being the most preferable method. However, the ex situ cultivation of threatened species can be an important additional factor of conservation, and many rare plants have survived in botanic gardens and arboreta.

A preliminary estimate of the flora of Russia (without adjacent territories of the former USSR) suggests about 12 000 species of vascular plants (Kamelin 2000). Based on the estimates of experts, between 2000–3000 species are under real threat and in need of conservation measures. It is near impossible to protect such a large number of species, which makes it important to identify the most vulnerable species that may become extinct in the near future. The main limiting factors in the wild are a lack of suitable habitat, the reduction in number and density of populations of many species, the aggressive invasion of weedy species, and global climatic changes (Hanski 2009; Oldfield 2009).

The first edition of the Red Data Book of Russia was published in 1988 (Golovanov et al. 1988). It included 440 species of angiosperms and 11 species of gymnosperms. The 2008 edition of the Red Data Book of Russia (Bardunov and Novikov 2008) listed 514 species of vascular plants (474 angiosperms, 14 gymnosperms and 26 pteridophytes), which accounted for ca. 4 percent of the total wild flora. Of these, 102 species of 72 genera and 39 families are ligneous – those with lignified stems at least at the base and whose above-ground parts do not die completely during winter. Their buds survive above the soil during winter.

The supplement to the Red Data Book (Bardunov and Novikov 2008) includes a list of Russian flora, including 13 species of trees and shrubs, which have not been officially included into the Red Data Book, but require special care and monitoring because they may become threatened in the near future: Genista angustifolia Schischk., Genista scythica Pacz., Ribes ussuriiense Jancz., Hydrangea paniculata Siebold, Ficus carica L., Frangula grandiflora (Fisch. et C.A. Mey.) Grub., Cotoneaster scandinavicus Hylmö, Rosa dolichocarpa Galushko, Sibiraea altaiensis (Laxm.) Schneid., Populus balsamifera L., Salix darpirensis Jurtzev et A. Khokhr., Abies gracilis
Kom. and *Pinus x funebris* Kom.

The majority of threatened species included in the Red Data Book occur in the Russian Far East, followed by the Caucasus. Twenty-two species are endemic to Russia, while 40 species are endemic to the former USSR. Seventeen species belong to the highest category 1, endangered according to the Russian system of threatened plants (Bardunov and Novikov 2008).

The research project “Biological peculiarities of threatened species of the woody flora of Russia introduced in Saint-Petersburg” was carried out in the Botanic garden BIN between 2008–2012. This project is connected with one of the main activities of botanic gardens, which is the cultivation of native flora. The *ex situ* cultivation of threatened and vanishing plant taxa is, in fact, one of the most important functions of botanic gardens. There are considerable opportunities for the replenishment of botanical collections with new plants. Furthermore, there are prospects for the distribution of the most promising and suitable plants into city plantings of St. Petersburg. Many species of the Russian flora have never been cultivated, while many others require repeated introductions and additional testing to become established for use in the horticultural trade.

The aim of this study is the *ex situ* cultivation of ligneous plants of all life forms, which can be found within the limits of the administrative boundaries of St. Petersburg, including all botanical collections and city plantings. Specific aims include, (1) to study the history of cultivation of rare plants, (2) to verify, identify and check all taxa cultivated, (3) to examine their representation in city plantings (not only in botanical collections), (4) to determine their phenotype, in particular their size, under cultivation comparing to natural habitats, to identify the best, largest and oldest specimens, to determine how cultivation has changed them comparing to their natural habitat, (5) to evaluate winter hardiness of each species as the main limiting factor of successful cultivation, using meteorological data, (6) to study biological features of flowering and fruiting, to estimate quality of locally produced seeds – this is especially important because many species are represented by only a few or single specimens, (7) to elaborate suitable and successful agro-technical measures because rare plants as a rule are difficult to cultivate, and (8) to pay particular attention to species that are new to this area, or were cultivated in the past but are absent for some reason nowadays; the organizing of specialized seed picking expeditions may help to obtain well-documented and scientifically important samples.

Attention will also be paid to 10 species of the Red Data Book of the Leningrad region (Tzvelev 2000): *Betula humilis* Schrank, *Cotoneaster integerrimus* Medikus, *Cotoneaster melanocarpus* Fisch. ex Blytt, *Cotoneaster scandinavicus* Hylmö, *Empetrum hermaphroditum* (Lange) Hagerup, *Lonicera caerulea* L., *Myrica gale* L., *Rosa mollis* Sm., *Thymus pycnotrichus* (Uechtr.) Ronniger and *Chamaepericlymenum suecicum* (L.) Aschers. et Graebn. From a practical point of view, we expect to replenish living collections of the Botanic garden BIN and to provide recommendations for their wider cultivation. We also aim to replenish city public parks and the general woody flora of St. Petersburg with new rare trees and shrubs, such as *Abies gracilis*, *Juglans ailanthifolia*, *Larix olgensis*, *Lonicera tolmatchevii*, *Pterocarya pterocarpa* and *Viburnum wrightii*.

The structure of the Project may include the following chapters: (1) The history of introductions, (2) Phenotypes and size distribution in collections and in city plantings, (3) Winter hardiness of rare and threatened species in the age of global climate warming, (4) Dynamics of seasonal development, (5) Peculiarities of flowering and fruiting, (6) Peculiarities of vegetative propagation, (7) Some aspects of the maintenance of rare plants, and (8) Prospects for further primary and secondary introductions.

**Rare and threatened woody species of the Komarov Botanical Institute, St. Petersburg**

The introduction of rare woody plants from poorly known areas of the Russian Empire to St. Petersburg started already in the 18th century, when little was known about threatened plants. The first woody plant introduced was *Taxus baccata*, which was included in the first Catalogue of the Botanic Garden of the Komarov Botanical Institute (BIN) (Siegesbeck 1736). Today, woody
Red Data Book plants are cultivated mostly in the botanic gardens BIN and the Forest-Technical Academy (FTA), which are the leading woody plant collections in St. Petersburg. The FTA collection of threatened ligneous plants is smaller, but these are in good condition, and many are older and larger in size than in BIN. The third botanical garden of the city is the Garden of St. Petersburg State University, which has a rather small collection of outdoor plants. The threatened woody plants cultivated in Botanic Garden BIN are listed in App. 1. The list includes taxa of different categories, according to IUCN Red List Categories and Criteria (2001, Version 3.1), which is also followed by the Red Data Book of Russia (2008). The division into life forms of threatened woody plants of the Russian Federation (see App. 2) follows Sokolov and Svjazeva (1965): T – tree (T1: more than 25 m in height under optimal conditions, T2: 15–25 m, T3: 10–15 m, T4: less than 10 m); S – shrub (S1: more than 3 m in height, S2: 2–3 m, S3: 1–2 m, S4: less than 1 m), DS – dwarf shrub (less than 0.5 m in height), SS – subshrub, DSS – dwarf subshrub, L – liana.

Plants of different life forms are represented in botanic collections, from tall trees (of size classes T1 and T2) (*Betula schmidtii*, *Larix olgensis*) to climbers (*Aristolochia manshuriensis*, *Parthenocissus tricuspidata*) and subshrubs (*Genista tanaitica*). Low shrubs dominate (*Euonymus nanus*, *Microbiota decussata*) while dwarf shrubs (low shrubs with completely lignified shoots, less than 0.5 m in height) and dwarf subshrubs (low shrub with shoots that are not completely lignified) are seldom cultivated, despite the fact that they are well represented in the wild. Species cultivated in St. Petersburg originate from different geographical regions. They represent flora of the European part of Russia (*Cotoneaster alaucinus*), the Caucasus (*Staphylea colchica*) and Siberia (*Sorbotoneaster pozdnjakovii*), but the majority of plants come from the Russian Far East (*Kalopanax septemlobus*, *Oplopanax elatus*). Although 15 threatened woody species (of Russia, the former USSR and Leningrad regions) are used in city plantings in St. Petersburg, only 3 of these (*Cotoneaster lucidus*, *Populus balsamifera*, *Syringa josikaeae*) are used widely.

At the end of the 1980s there were 44 rare species in St. Petersburg, mentioned in the Red Data Books of Russia and the former USSR (Buligin and Firsov 1990). Since then (1988–2010) several expeditions have been organized to the Russian Far East (Primorsky krai, Sakhalin and Kurile Islands, Kamchatka), the Caucasus and the Lower Volga and Lower Don areas. As a result of these expeditions, and due to personal contacts with colleagues from other botanic gardens, the collection of rare species in the St. Petersburg arboreta have increased by more than 10 species. For example, *Magnolia hypoleuca* was obtained from seeds, collected in 1989 at the coast of the Kunashir Strait in the Kunashir Island. *Oplopanax elatus* was collected during a Russian-Swedish expedition to the Sikhote-Alin Mountains of Primorsky krai in 1997. *Lonicer a tolmatchevii* was obtained as a result of an expedition to Sakhalin Island in 2004. The collected material brought to St. Petersburg will be helpful in work on the conservation of red-listed plants. A recent expedition was a joint Russian-Finnish (Botanic Gardens of the University of Helsinki) seed-picking expedition in August-September 2010 to the Lower Khoper-river Nature Park in the steppe zone of Russia, rich in herbaceous and woody taxa. As a result of an international expedition to the Caucasus in September 2011, with participation of botanic gardens of Russia (St. Petersburg and Stavropol), Germany (Hamburg), Sweden (Gotenburg) and China (Changhai), *Genista suanica* Schischk. and *Hedera pastuchowii* Woronow were brought to St. Petersburg.

**Cultivation of threatened species**

Many tasks need to be performed in the near future. For example, the cultivation of a number of threatened species has yet to be evaluated in St. Petersburg (*Anthemis trotzkiana* Claus, *Astragalus fissuralis* Alexeenko, *Onosma polyphylla* Ledeb.), while some species need more trials to refine their cultivation (*Amelopopsis japonica* (Thunb.) Makino). Rare and threatened species, as a rule, require more attention and care in cultivation compared to common and widely distributed plants. Suitable agro-technical measures should be developed, and their propagation requirements should be studied. Many of these rare species are very sensitive
and demand specific ecological conditions, such as specific light, soil, drainage, or moisture conditions. For example, many psammophytes and calcium-loving plants require a special substrate containing chalk and sand.

From a taxonomic point of view the low shrubs and subshrubs are most important for further introduction into horticulture. Their cultivation requires careful preliminary treatment of planting localities, the regular cutting of grass, and the mulching of the soil surface around stems. Because of a lack of seeds it is also important to study all possible ways of vegetative propagation to prevent the accidental loss of species from collections. Placing of the tested species into wider cultivation, for example in parks and gardens of North-Western Russia, should be one of the priorities, because at present nearly all shrubs and subshrubs are cultivated as single specimens, and mainly in botanic gardens.

Insufficient winter hardiness is the main limiting factor for cultivation of rare plants in St. Petersburg. When studying biological peculiarities of rare and threatened plants, special attention should be given to limiting frost damage. However, because of the threat of climatic change, it is also important to study the responses of these rare species to abnormally warm winters, such as the winter 2006–07. In St. Petersburg, data on the dynamics of seasonal development of threatened woody species are lacking. However, such information is important in the light of plant adaptions to new environmental conditions. A connection exists between levels of adaptation of different trees and shrubs to local climate, and a degree of synchronization of their seasonal rhythm to the rhythms of nature (Buligin 1979). Therefore, phenological observations for newly introduced species are required, and the continuation of observations for certain species should be uninterrupted.

A preliminary evaluation of the levels of adaptation of the Red Data Book species of the Russian woody flora introduced to the Botanic Garden BIN (1985–2009) shows that three main groups can be identified: (1) stable under different bioclimatic conditions (after both cold and warm winters); (2) having a clear and strong response to periodically repeated cold and abnormally cold winters; (3) having a clear response to climate warming. Under climate warming, especially noticeable during the colder part of the year, there will be many cases in which previously hardy species become damaged by frost because of early spring growth, which is especially evident for Far Eastern trees and shrubs. In the future, resistance to summer heat and fires may also be of importance. From an *ex situ* conservation point of view, the uninterrupted monitoring of cultivated plants is urgently needed because critical bioclimatic conditions may be different for different species. Taking into consideration the continuous warming of the climate, new methods of agro-techniques and cultivation are needed. Phenological networks and long-term observations providing evidence that the impact of climate change is significant, are important. They will provide valuable information on the status of plants and will assist botanic gardens in long-term planning.

**The presence of woody Red Data Book species in Russian botanic gardens**

It is also of considerable interest to see how woody plants of the Red Data Book of Russia are represented in Russian botanic gardens. Only 60 threatened species of the Russian dendroflora were included in the Catalogue of cultivated woody plants of Russia (Aksenova et al. 1999). However, five of these are cultivated in one botanic garden only, and ten species in two or three gardens only (Firsov and Volchanskaya 2008).

A more recent inventory, Russia’s Red Book Plants in Botanic Garden and Arboreta collections (Demidov 2005) shows that 70 threatened species are in collections – 55 institutions sent their data. Not many species considered to be widely cultivated (represented in at least one third of Russian botanic gardens) are included in this list: *Aristolochia manshuriensis* (21 gardens), *Armeniaca mandshurica* (31), *Corylus colurna* (24), *Cotoneaster lucidus* (39), *Juglans ailanthifolia* (19), *Kalopanax septemlobus* (17), *Microbiota decussata* (18), *Parthenocissus tricuspidata* (18), *Prinsepia sinensis* (30), *Rhododendron schlippenbachii* (18), *Taxus baccata* (35) and *Taxus cuspidata* (22). However, species that are represented in a limited number of gardens are common in the
catalogue. Twenty-five species are cultivated in fewer than five gardens. For example, *Lespedeza cyrtobotrya* is only cultivated in the area of its natural habitat – in the Arboretum of the Mountain-Taiga Research Station (town of Ussurijsk of Primorsky krai) and *Schizophragma hydrangeoides* only in St. Petersburg (botanic gardens of BIN and FTA). Species like *Artemisia senjavinensis* Bess., *Astragalus igoschinae* R. Kam. et Jurtzev, *Daphne baksanica* Pobed. and many others are not cultivated at all. Diligent work is needed to involve the rest of the threatened plants in cultivation. Climate warming, which does not always have a positive effect on plants, nevertheless provides better possibilities for successful adaptation of certain species, which are considered not to be hardy (*Amygdalus pedunculata* Pall.).

Since the beginning of the project “Biological peculiarities of threatened species of woody flora of Russia introduced in Saint-Petersburg”, the history of introductions of threatened woody species in St. Petersburg has been investigated (Volchanskaya 2010). Some problems related to the conservation of rare species at St. Petersburg's botanical collections were discussed at an International Conference organized at FTA in October 2010. It was argued that the significance of botanic gardens has increased because of climate change, and that warming of the climate will have considerable effects on the cultivation of rare species (Volchanskaya et al. 2010a).

The assessment of rare and threatened woody species cultivated at Arboretum FTA has shown that 21 species of the Red Data Book of Russia, 9 species of the Red Data Book of the former USSR and three species of the Red Data Book of the Leningrad region are present in current collections. In total, more than 80 threatened species have been evaluated and cultivated here since introductions started in 1833 (Firsov et al. 2010).

Red Data Book woody species of the Otradnoje Research Station of Komarov Botanical Institute were also studied. Nine species of the Red Data Book of Russia and five species of the former USSR have been identified. Arboretum Otradnoje is situated in a region of severe climatic conditions, 110 km north of St. Petersburg, in the mid taiga zone (St. Petersburg is situated in the southern taiga zone). Results of the Otradnoje Arboretum may be more valid for the Republic of Karelia and the surrounding territory of Finland (Firsov et al. 2009).

The arboretum of the Centre of Complex Landscaping in the town of Pushkin (southern environs of St. Petersburg) was established in 1926. In 2009, more than 20 valuable species have been identified, many of which are represented by large and healthy specimens, including *Cotoneaster lucidus* and *Taxus baccata* of the Red Data Book of Russia (Vekshin et al. 2009).

Conclusions

There are still a number of gaps in our understanding of the biological peculiarities of threatened species, possibilities of their reproduction and estimation of levels of adaptation. We hope that careful study and monitoring, both *ex situ* and *in situ*, will promote the conservation of the diverse Russian flora.

The greatest threat to biodiversity worldwide is habitat loss and fragmentation, in association with climate change (Hanski 2009). The Global Strategy for Plant Conservation (GSPC) and its 16 targets focus on actions relevant for conserving plant diversity in the face of climate change (Oldfield 2009). The St. Petersburg Project corresponds with global efforts to conserve plant diversity under the framework of the GSPC and may help to clarify and foresee new targets post-2010. We should direct our actions in accordance with the Global Strategy for Plant Conservation, which is a strategic framework for plant conservation at global, regional, national, and local levels with its 16 outcome-oriented targets to be met by 2020.

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<table>
<thead>
<tr>
<th>Species name</th>
<th>Year introduced</th>
<th>Number of plants</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. <em>Acer japonicum</em> Thunb.</td>
<td>1984</td>
<td>2</td>
<td>Seeds from Arboretum Novi Dvur (Czech Republic) and from Hamburg botanic garden (Germany). Sensitive to frost. Cultivated from local seeds of the Arboretum FTA: ripe in 2007 and germinated in 2009, the first time in the history of introduction since 1898 (Volchanskaya et al. 2010b).</td>
</tr>
<tr>
<td>2. <em>Aristolochia manshuriensis</em> Kom.</td>
<td>1955</td>
<td>6</td>
<td>Second generation (mother plant since 1909, from the wild of the Russian Far East), since 1955. Large climber: reaches 20 m high using a tree of <em>Ulmus laevis</em> for support. Grown from local seeds. Winter hardy, quick grower, long lived. There is also a third generation. Introduced in general cultivation by Botanic garden BIN.</td>
</tr>
<tr>
<td>3. <em>Armeniaca mandshurica</em> (Maxim.) Skvorts.</td>
<td>~1939</td>
<td>5</td>
<td>There are 2 older plants of unknown origin, reproduction from local seeds in 1988, and seeds from the wild: Partizansky district of Primorsky krai, wide valley at Sikhote-Alin Mountains, 1996. Damaged by frost in cold winters, flowers and fruits episodically.</td>
</tr>
<tr>
<td>8. <em>Corylus colurna</em> L.</td>
<td>~1911</td>
<td>6</td>
<td>Origin unknown. Damaged by frost in cold winters. Stayed in vegetative state for years, but flowered in recent years.</td>
</tr>
<tr>
<td>9. <em>Cotoneaster alaunicus</em> Golits.</td>
<td>1986</td>
<td>1</td>
<td>Seeds collected from the wild in 1984 in the Lipetskaya region, Galichja Gora Nature Reserve. Winter hardy, forms fruits. Propagated by green cuttings. In September 2010 plants and seeds from a new provenance were obtained as a result of a Russian-Finnish expedition to the Nekhaevsky district of the Volgograd region.</td>
</tr>
<tr>
<td>10. <em>Cotoneaster lucidus</em> Schlecht.</td>
<td>before 1935</td>
<td>6</td>
<td>Winter hardy, self-sowing and at times naturalized. There are also several decorative hedges. This species is widely used in city plantings of St. Petersburg. Introduced for general cultivation by the botanic garden BIN. The oldest and largest plant reached 3.7 m in height, 3 cm stem diameter and crown 6.7 x 5.8 m.</td>
</tr>
<tr>
<td>11. <em>Daphne cneorum</em> L. (incl. D. julia K.-Pol.)</td>
<td>2009</td>
<td>1</td>
<td>At the Nursery BIN since 2009: obtained from layering of an old plant, from Otradnoje research station of the Komarov Botanical Institute, Priozersky district of the Leningrad region. Under snow cover in vegetative state. Mother plant from the wild, Lipetskaya Region, Galichja Gora Nature Reserve, died during the winter 2009-2010.</td>
</tr>
</tbody>
</table>
12. Euonymus nanus Bieb. 1990 1 Cuttings from the Botanic garden of the Moscow State University. Fruits (seldom), comparatively winter hardy. Propagated by cuttings. Live plants from the wild were collected in during an expedition to the Caucasus in September 2011 (Razvalka Mountain, environs of Zhelezovodsk).

13. Exochorda serratifolia S. Moore 1978 1 North Korea, Pyongyang botanic garden, from seeds. Flowers and fruits frequently, damages in cold winters.

14. Genista tanaitica P. Smirn. 2005 1 Voronezh region, Podgorinsky district, near Dukhovoje village, chalk denudations of Don River, seeds from the wild (G Firsov and S Grishin, August 2004). Flowers and fruits frequently, propagate vegetatively by cuttings. Upper parts of shoot do not lignify. Distinguished by prolonged growth of shoots, prolonged flowering and late green leaves. May have suffered/decayed during warm winters.

15. Hydrangea petiolaris Siebold et Zucc. 1976 1 Vegetative reproduction in BIN from green cuttings. Damages in cold winters, flowers and fruits regularly and profusely, produces vital seeds. May have decayed in warm winters.


17. Juglans ailanthifolia Carr. 1948 3 Origin unknown. Comparatively winter hardy, is self-sowing. The second and third generations from local seeds are obtained. There are several younger plants at the Nursery, obtained in 2004 near Krasnopolje village, Sakhalin Island, extreme northern point of its natural distribution.


19. Juniperus rigida Siebold et Zucc. 1999 2 Seedlings and seeds from the Vladivostok Botanical Garden-Institute, and from Lazovsky Nature Reserve of Primorsky krai (Ludmila Pshennikova and Kirill Tkachenko). Winter hardy. Fruited since 2007. There are several younger plants at the Nursery. There are also two plants of J. rigida subsp. litoralis Urussov at the Nursery (of dwarf and shrubby habit).


22. Larix olgensis A. Henry 1998 4 Primorsky krai, Lazovsky district, coast of Sea of Japan, mouth of Chernaya River, seeds near locus classicus in September 1997. Winter hardy, in infertile state. The best tree is 5.80 m high, 5 cm in trunk diameter and crown 3.0 x 2.8 m in 13 years.

23. Leptopus colchicus (Fisch. et Mey.) Pojark. 2007 1 Krasnodarsky krai, environs of Sotchi, on the way to Krasnaya Poljana, on a rock near village Monastyr, living plant. Fruited in 2009.

24. Lespedeza tomentosa (Thunb.) Maxim. 2009 4 Seeds from the wild, Vladivostok botanic garden. Sensitive to frost but at the nursery under snow cover. Was included in woody flora of the Russian Far East for the first time by Nedoluzhko (1995) as a dwarf sub-shrub (or may even be a sub-shrub). In Russia our site is the northernmost point of its natural distribution.

25. Lonicera tolmachewii Pojark. 1990 1 Cuttings from the Main Botanic Garden, Moscow (4-th seed reproduction, originally from Sakhalin Island). There are younger plants at the Nursery: Russian-Swedish expedition: Central Sakhalin, Tymovsky district, Tym River flood land forest, near village Berezovaya Poljana, young plant in September 2004 (G Firsov, Bo Nilsson, A Taran). Propagated by cuttings, layers and seeds.
<table>
<thead>
<tr>
<th>No.</th>
<th>Scientific Name</th>
<th>Year</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td><em>Myrica gale</em> L.</td>
<td>2004</td>
<td>The only species of the local flora. St. Petersburg, Yuntolovsky Reserve, swampy forest, living plant (female). There are also several younger plants of the same origin. Flowers and fruits regularly, but requires special places of cultivation, specific soil and careful watering in the dry season.</td>
</tr>
<tr>
<td>29</td>
<td><em>Oplopanax elatus</em> (Nakai) Nakai</td>
<td>1997</td>
<td>Primorsky krai, South Sikhote-Alin Mt., Mt. Golets, dark conifer forest (about 1400 m elevation), produced seeds in September 1997 (G Firsov). Quite winter hardy. Produces viable seeds.</td>
</tr>
<tr>
<td>31</td>
<td><em>Parthenocissus tricuspidata</em> (Siebold et Zucc.) Planch.</td>
<td>1994</td>
<td>Vladivostok Botanic Garden-Institute, young plants and seeds (originally from the south of Khasansky district of Primorsky krai). In vegetative state, sensitive to frost, but survives under snow cover. Originally at the Nursery, one specimen was planted at the Arboreum in 2010. Propagated by cuttings. In vegetative state.</td>
</tr>
<tr>
<td>32</td>
<td><em>Picea glehnii</em> (Fr.Schmidt) Mast.</td>
<td>1955</td>
<td>South of Sakhalin Island, Korsakovskiy district, Muravjevskaya Lowland. The oldest tree in St Petersburg: seeds obtained from Sakhalin in 1953: 18.0 m high, 30 cm diameter of trunk, crown 7.0 x 6.1 m in 56 years. Several younger specimen (seedlings in 1989) are also from the wild: Kunashir Island, southern environs of Yuzhnokurilsk, Lechebny Stream, conifer forest with bamboo undergrowth. Propagated by cutting and grafting.</td>
</tr>
<tr>
<td>33</td>
<td><em>Pinus densiflora</em> Siebold et Zucc.</td>
<td>1996</td>
<td>Primorsky krai, Khasansky district, Gamov Peninsula, among rocks along the Sea of Japan, as living plant (V Reinvald). There are also younger plants of the same provenance from seeds in 1997 (G Firsov). Winter hardy. In vegetative state.</td>
</tr>
<tr>
<td>34</td>
<td><em>Pinus pallasiana</em> D. Don</td>
<td>1960</td>
<td>Younger specimen at the nursery since 1998, seeds from forest plantations of the Kumilzhensky district of the Volgograd region, planted into the Arboretum in 2009. Older tree damaged by frost in cold winters (1984-85, 1986-87), quite hardy in normal and warm winters, fruited recently.</td>
</tr>
<tr>
<td>35</td>
<td><em>Prinsepia sinensis</em> (Oliv.) Bean</td>
<td>1972</td>
<td>The oldest specimen: seeds from the town of Svobodny, Amurskaya region. Damages in cold and in abnormally warm winters. Fruits (very seldom). There are younger plants at the Nursery from Vladivostok (in 1989). Propagated by cuttings.</td>
</tr>
<tr>
<td>36</td>
<td><em>Pterocarya pterocarpa</em> (Michx.) Kunth ex Iljinsk.</td>
<td>1947</td>
<td>Origin unknown. Damages regularly in cold winters, fruited in recent years (since 2000) with the warming of the climate. Can be propagated from its numerous offshoots.</td>
</tr>
<tr>
<td>38</td>
<td><em>Rhododendron fauriei</em> Franch.</td>
<td>2005</td>
<td>Seeds from the Arboretum of the Mountain-Taiga Research Station, Primorsky krai, Ussurijsk. Winter hardy, in vegetative state, one plant was replanted from the nursery to the arboretum in 2011.</td>
</tr>
<tr>
<td>No.</td>
<td>Species</td>
<td>Year</td>
<td>Notes</td>
</tr>
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</tr>
<tr>
<td>39</td>
<td>Rhododendron schlippenbachii Maxim.</td>
<td>1978</td>
<td>Seeds from the Arboretum Rogov, Poland (the oldest plant). Several younger plants are from the wild in the Russian Far East: Khasansky district of Primorsky krai, near Khasan settlement, border with North Korea and China; Khasansky district, Gamov Cape. Quite hardy, fruits regularly, grown from local seeds. Sometimes repeated autumnal flowering occurs.</td>
</tr>
<tr>
<td>40</td>
<td>Ruscus colchicus P.F. Yeo</td>
<td>2009</td>
<td>Living plants from the wild in the Caucasus (Abkhazia, environs of Sukhum), in April 2009 (V Melnikov). Not very hardy, but possible to cultivate outdoors.</td>
</tr>
<tr>
<td>41</td>
<td>Schizophragma hydrangeoides Siebold et Zucc.</td>
<td>1989</td>
<td>Living plant from Kunashir Island in October 1989, near the Alekhino settlement (G Firsov, A Kholopova, N Alexeeva). The first test of this species in the history of introduction. Quite hardy under snow cover, but of slow growth, in vegetative state. Shoots root readily in the soil.</td>
</tr>
<tr>
<td>42</td>
<td>Scrophularia cretacea Fisch. ex Spreng.</td>
<td>2009</td>
<td>Living plants from Lower Khoper Nature Park: chalk hills of Buzuluk River, near khutor Shubinsky of the Alexeevsky district of the Volgograd region. Flowers. The same requirements for cultivation as for Hyssopus cretaceus and Artemisia salisoides.</td>
</tr>
<tr>
<td>43</td>
<td>x Sorbocotoneaster pozdnjakovii Pojark.</td>
<td>1974</td>
<td>This natural hybrid (Sorbus sibirica x Cotoneaster melanocarpus) was described in 1953 and apparently was cultivated in an experimental greenhouse of the Botanical Institute (Svjazeva 2005). Two plants were planted in the Arboretum in 1974, from locus classicus provenance. One of them has more features of Sorbus, another of Cotoneaster. Winter hardy, produces viable seeds annually. Propagate by cuttings. Distinguished by early sprouting and early ripening of fruits.</td>
</tr>
<tr>
<td>44</td>
<td>Staphylea colchica Stev.</td>
<td>1986</td>
<td>Belgium, Antwerp, seeds. Distinguished by late cessation of sprouting and prolonged growth of shoots. Tips of shoots are damaged by frost. Propagated by cuttings.</td>
</tr>
<tr>
<td>45</td>
<td>Staphylea pinnata L.</td>
<td>2009</td>
<td>Cuttings from the Main Botanic Garden RAS, Moscow, 3.07.2009.</td>
</tr>
<tr>
<td>46</td>
<td>Taxus baccata L.</td>
<td>~1925</td>
<td>Specimens were obtained from different places: from the wild of the Caucasus, from greenhouses of the Botanic garden BIN and from botanic gardens of the Ukraine, Finland and the UK. Damaged seriously in cold winters, produces viable seeds (not each year). The oldest plant was planted before 1935 (Svjazeva 2005). Propagated by cuttings. Seldom used in city planting.</td>
</tr>
<tr>
<td>47</td>
<td>Taxus cuspidata Siebold et Zucc. ex Endl.</td>
<td>1941</td>
<td>Cuttings from the Arboretum of St. Petersburg Forest-Technical Academy (provenance of oldest plants). Winter hardy, fruits regularly, self-sowing. There are younger plants at the Nursery from the wild in Russian Far East (Primorsky krai and Sakhalin). Propagate from local seeds and from cuttings.</td>
</tr>
</tbody>
</table>


2. *Amelopsis japonica* (Thunb.) Makino (Vitaceae) Category 1. L (up to 2 m high). Russian Far East (Primorsky krai and Evrejskaya region), China, Japan, Korea Peninsula.

3. *Amygdalus pedunculata* Pall. (Rosaceae) Category 3 d. S2 (0.5-1.5 m high). Russia (Buryat Republic, south of Siberia), Mongolia, China.

4. *Anthemis trotzkiana* Claus (Asteraceae) Category 3 c. DSS (10-30 cm high). Endemic to the former USSR: Russia and Ukraine.


7. *Artemisia hololeuca* Bieb. ex Bess. (Asteraceae) Category 2 a, b. S2 (up to 1 m high). Endemic to the former USSR: Russia and Ukraine.


10. *Amphelopsis japonica* (Thunb.) Makino (Vitaceae) Category 1. L (up to 2 m high). Russian Far East (Primorsky krai and Evrejskaya region), China, Japan, Korea Peninsula.

11. *Amygdalus pedunculata* Pall. (Rosaceae) Category 3 d. S2 (0.5-1.5 m high). Russia (Buryat Republic, south of Siberia), Mongolia, China.

12. *Anthemis trotzkiana* Claus (Asteraceae) Category 3 c. DSS (10-30 cm high). Endemic to the former USSR: Russia and Kazakhstan.


18. *Bothrocaryum controversum* (Hemsl. ex Prain) Pojark. (Cornaceae) Category 3 d. T1 (up to 30 m high). Russian Far East (south of Primorsky krai), China, Japan, Korea Peninsula.


20. *Buxus colchica* Pojark. (Buxaceae) Category 2 a. T3 (up to 10-15 m high). Russia, Georgia, Turkey.

21. *Calophaca wolgarica* (L. fil.) Fisch. ex DC. (Fabaceae) Category 2 a. S2 (20-80 cm high). Endemic to the former USSR: Russia, Ukraine and Kazakhstan.

22. *Caryopteris mongolica* Bunge (Verbenaceae) Category 3 d. DSS (up to 50 cm high). Russia (South of Central Siberia, Buryat Republic), Mongolia, China.

23. *Corylus colurna* L. (Betulaceae) Category 2 b. T1 (up to 30 (50) m high). Russia (Caucasus), Georgia, Azerbaijan, Armenia, Iran, Turkey, Balkan Peninsula.

24. *Corylus colurna* L. (Betulaceae) Category 2 b. T1 (up to 30 (50) m high). Russia (Caucasus), Georgia, Azerbaijan, Armenia, Iran, Turkey, Balkan Peninsula.

25. *Corylus colurna* L. (Betulaceae) Category 2 b. T1 (up to 30 (50) m high). Russia (Caucasus), Georgia, Azerbaijan, Armenia, Iran, Turkey, Balkan Peninsula.

26. *Cotoneaster alaunicus* Golits. (Rosaceae) Category 3 a. Low shrub, 1.5-2 m high.
Endemic to the European Part of Russia (from Moscow to the Volgograd region).

27. *Cotoneaster cinnabarinus* Juz. (Rosaceae) Category 3 e. S2 (up to 1 m high). Endemic to the European Part of Russia (Kola Peninsula and Karelian Republic).


30. *Daphne baksanica* Pobed. (Thymelaeaceae) Category 1. Dwarf shrub, up to 50 cm high. Endemic to Russia (Central Caucasus).


32. *Daphniphyllum humile* Maxim. ex Franch. et Savat. (Daphniphyllaceae) Category 2 a. S2 (up to 1–1.5 m high). Russian Far East (Sakhalin region, Kunashir and Iturup Islands), Japan, Korea Peninsula.


34. *Deutzia glabrata* Kom. (Hydrangeaceae) Category 2 a. S2 (up to 2 m high). Russian Far East (Evrejskaya region, Khabarovsky and Primorsky krai), China, Korea Peninsula.

35. *Diospyros lotus* L. (Ebenaceae) Category 3 d. T2 (up to 25 m high). Russia (Krasnodarsky krai and Dagestan Republic), Georgia, Azerbaijan, Armenia, Tajikistan, Uzbekistan, Turkey, Iran, Afghanistan, India, China, Japan.


38. *Euonymus nanus* Bieb. (Celastraceae) Category 1. S2 (up to 1 m high). Russia, Ukraine, Moldova, Romania, Poland.

39. *Exochorda serratifolia* S. Moore (Rosaceae) Category 1. S2 (up to 1.5 m high). Russian Far East (south of Primorsky krai, Khankaiksky district), China, Korea Peninsula.


41. *Galitzkya pathulata* (Steph.) V. Botschantz. (Brassicaceae) Category 2 a. DSS (5–25 cm high). Endemic to the former USSR: Russia (South Ural and Altai Mts.) and Kazakhstan.

42. *Genista albida* Wildl (Fabaceae) Category 3 e. DSS (10–20 cm high). Endemic to the former USSR: Russia (Krasnodarsky and Stavropolsky krai, Dagestan Republic), Ukraine and Georgia.

43. *Genista humifusa* L. (Fabaceae) Category 3 e. DSS (10–20 cm high). Russia (Krasnodarsky krai, Black Sea Coast of Caucasus), Georgia, Turkey.

44. *Genista suanica* Schischk. (Fabaceae) Category 3 c, e. SS. Endemic to the former USSR: Russia and Ukraine.

45. *Genista tanaitica* P. Smirn. (Fabaceae) Category 3 c. e. SS. Endemic to the former USSR: Russia and Ukraine.

46. *Hedera pastuchowii* Woronow (Araliaceae) Category 2 a. L. Russia (Dagestan), Georgia, Azerbaijan, Iran.

47. *Hedysarum minussinense* B. Fedtsch. (Fabaceae) Category 3 a – rare species, endemic to Russia. DSS (10–40 cm high). Khakassia and south of Krasnojarsky krai (Siberia).

48. *Helianthemum arcticum* (Grosser) Janch. (Cistaceae) Category 1. DSS (10–40 cm high). Endemic to the European part of Russia (Kola Peninsula, White Sea Coast).

49. *Hydrangea petiolaris* Siebold et Zucc. (Hydrangeaceae) Category 3 e. L (up to 20–25 m high). Russian Far East (Sakhalin, Kunashir, Iturip, Urup and Shikotan Islands), Japan.

50. *Hyssopus cretaceus* Dubjan. (Lamiaceae) Category 3 c. DSS (20–40 cm high). Endemic to the former USSR: Russia and Ukraine.
51. *Ilex sugeroki* Maxim. (Aquifoliaceae) Category 3 e. S1. Russian Far East (Sakhalin region, Kunashir and Iturup Islands), Japan.
52. *Juglans ailanthifolia* Carr. (Juglandaceae) Category 3 e. T2 (up to 20 m high). Russian Far East (Sakhalin Island, naturalized at Kurile Islands), Japan, Korea Peninsula.
53. *Juniperus conferta* Parl. (Cupressaceae) Category 3 e. S2. Russia (Sakhalin Island), Japan.
54. *Juniperus excelsa* Bieb. (Cupressaceae) Category 2 a. T3 (up to 12 m high). Russia (Krasnodarsky krai, Black Sea Coast of Caucasus), Ukraine, Southern Europe, Asia Minor.
55. *Juniperus foetidissima* Willd. (Cupressaceae) Category 2 a. T4 (up to 10 m high). Russian Far East (south of Primorsky krai), China, Japan, Korea Peninsula.
57. *Juniperus sargentii* (A. Henry) Takeda ex Koidz. (Cupressaceae) Category 3 d. S2 (up to 1.5 m high). Russia (Krasnodarsky krai and Dagestan Republic), Ukraine, Georgia, Armenia, Azerbaijan, Balkan Peninsula, Asia Minor.
58. *Kalopanax septemlobus* (Thunb.) Koidz. (Araliaceae) Category 3 d. S2 (up to 1.5 m high). Russia (Krasnodarsky krai and Shikotan Islands), Japan, China, Korea Peninsula.
59. *Krascheninnikovia lenensis* (Kumin.) Tzvelev (Chenopodiaceae) Category 3 a. S2 (up to 70 cm high). Russia (Eastern Siberia) – endemic.
60. *Larix olgensis* A. Henry (Pinaceae) Category 2 a. T1 (up to 30 m high). Russian Far East (Primorsky krai), China, Japan, Korea Peninsula.
61. *Lepidium meyeri* Claus (Brassicaceae) Category 2 a. DSS (30–40 cm high). Endemic to the former USSR: Russia, Ukraine and Kazakhstan.
62. *Leptopus colchicus* (Fisch. et Mey.) Pojark. (Euphorbiaceae) Category 3 e. S2 (up to 1 m high). Russia (Krasnodarsky krai, environs of Sotschi), Georgia, Iran.
63. *Lespedeza cyrtobotrya* Miq. (Fabaceae) Category 3 d. S2 (up to 1.5 m high). Russian Far East (south of Primorsky krai), China, Japan, Korea Peninsula.
64. *Lespedeza tomentosa* (Thunb.) Maxim. (Fabaceae) Category 3 d. DSS (up to 80 cm high, often considered perennial). Russian Far East (Primorsky krai), Mongolia, China, India, Japan, Korea Peninsula.
65. *Lonicera etrusca* Santi (Caprifoliaceae) Category 3 d. L (4–5 m high). Russia (Krasnodarsky krai, Black Sea Coast of Caucasus), Middle Europe, Mediterranean, Asia Minor.
66. *Lonicera tolmatchevii* Pojark. (Caprifoliaceae) Category 2 a. S2 (up to 1.5–1.9 m high). Russian Far East, Sakhalin Island – endemic of Tym River floodland (Tymovsky and Nogliksky districts).
70. *Onosma polyphylla* Ledeb. (Boraginaceae) Category 3 e. DSS (10–15 cm high). Endemic to the former USSR: Russia (Krasnodarsky krai, Black Sea Coast of Caucasus) and Ukraine.
71. *Oplopanax elatus* (Nakai) Nakai (Araliaceae) Category 2 b. S2 (up to 1.8 m high, more often prostrate). Russian Far East (south of Primorsky krai), Japan, Korea Peninsula, China.
72. *Ostrya carpinifolia* Scop. (Betulaceae) Category 2 a. T2 (up to 15 (25) m high). Russia (Caucasus), Georgia, Armenia, Turkey, Western Europe, Mediterranean.
73. *Parthenocissus tricuspidata* (Siebold et Zucc.) Planch. (Vitaceae) Category 1. L (up to 4 m high). Russian Far East (south of Primorsky krai, Khasansky district), China, Japan, Korea Peninsula.
74. *Picea glehnii* (Fr.Schmidt) Mast. (Pinaceae) Category 3 e. T2, up to 20 m high. Russian
Far East (Sakhalin, Kunashir, Iturup and Shikotan Islands), Japan.

75. *Pinus densiflora* Siebold et Zucc. (Pinaceae) Category 2 a. T1 (up to 30 m high). Russian Far East (south of Primorsky krai), Japan, China, Korea Peninsula.

76. *Pinus pallasiana* D. Don (Pinaceae) Category 1. T1 (up to 45 m high). Russia (Krasnodarsky krai, Black Sea Coast of Caucasus), Ukraine, Balkan Peninsula, Asia Minor, Eastern Mediterranean.

77. *Pinus pityusa* Stev. (Pinaceae) Category 2 a. T2 (up to 25 m high). Endemic to the former USSR: Russia (Krasnodarsky krai, Black Sea Coast of Caucasus) and Georgia.

78. *Pinus sylvestris* L. var. *cretacea* Kalenicz. (Pinaceae) Category 3 c. T2–T4 (usually 6-6.5 m, seldom up to 20-25 m high). Endemic to the former USSR: Russia and Ukraine.

79. *Pistacia mutica* Fisch. et C.A. Mey. (Anacardiaceae) Category 3 d. T4 (8–10 m high). Russia (Kranodarsky krai, Black Sea Coast of Caucasus), Ukraine (Crimea), south of Middle Europe, Mediterranean, North Africa, Iran, Asia Minor.

80. *Prunsepia sinensis* (Oliv.) Bean (Rosaceae) Category 2 a. S1 (up to 3 (5) m high). Russian Far East (south of Primorsky krai), China, Korea Peninsula.

81. *Pterocarya pterocarpa* (Michx.) Kunth ex Iljinsk. (Juglandaceae) Category 3 d. S1–T4 (large shrub or tree, 4–6 m high). Russian Far East (Primorsky krai), China, Japan, Korea Peninsula.

82. *Pueraria lobata* (Willd.) Ohwi (Fabaceae) Category 3 d. L (7–10 m high). Russian Far East (south of Primorsky krai), China, Japan, Korea Peninsula.

83. *Quercus dentata* Thunb. (Fagaceae) Category 3 d. T3 (up to 12 m high). Russian Far East (south of Primorsky krai and Kunashir Island), China, Japan, Korea Peninsula.

84. *Rhododendron fauriei* Franch. (Ericaceae) Category 3 e. S1–T4 (large shrub or tree, 4–6 m high). Russian Far East (Primorsky krai), Korea Peninsula, Japan.

85. *Staphylea colchica* Stev. (Staphyleaceae) Category 3 e. T4–S1 (up to 5 m high). Russia (Krasnodarsky krai, Black Sea Coast of Caucasus), Georgia, Azerbaijan, Turkey.

86. *Stelleropsis caucasica* Pobed. (Thymelaeaceae) Category 3 a. DSS (8–15 cm high). Russia (Western Caucasus) – endemic.

87. *Taxus baccata* L. (Taxaceae) Category 2 a. T2 (up to 3 m high). Russian Far East (south of Primorsky krai), China, Korea Peninsula.

88. *Taxus cuspidata* Siebold et Zucc. (Ericaceae) Category 3 d. S2 (up to 1.2 m high). Russian Far East (Sakhalin region, south of Kunashir Island), Japan, Korea Peninsula.

89. *Taxus cuspidata* Siebold et Zucc. (Ericaceae) Category 3 d. S2 (up to 1.2 m high). Russian Far East (Sakhalin region, south of Kunashir Island), Japan, Korea Peninsula.

90. *Schizophragma hydrangeoides* Siebold et Zucc. (Hydrangeaceae) Category 1. L (up to 10 m high or more). Russian Far East (Sakhalin region, Kunashir Island), Japan, Korea Peninsula.


92. *Rhododendron fauriei* Franch. (Ericaceae) Category 3 d. T1 (up to 45 m high). Russia (Krasnodarsky krai, Black Sea Coast of Caucasus), Ukraine, Balkan Peninsula, Asia Minor, Eastern Mediterranean.

93. *Rhododendron pumilum* Maxim. (Ericaceae) Category 3 d. S2 (up to 1.2 m high). Russian Far East (Sakhalin region, south of Kunashir Island), Japan, Korea Peninsula.

94. *Staphylea pinnata* L. (Staphyleaceae) Category 3 d. T4–S1 (up to 5 m high). Russia (Caucasus), Ukraine, Moldova, Georgia, Armenia, Turkey, Western Europe, Mediterranean, Balkan Peninsula.

95. *Stapfelia pinata* L. (Staphyleaceae) Category 3 d. T4–S1 (up to 5 m high). Russia (Caucasus), Ukraine, Moldova, Georgia, Armenia, Turkey, Western Europe, Mediterranean, Balkan Peninsula.

96. *Stapfelia pinata* L. (Staphyleaceae) Category 3 d. T4–S1 (up to 5 m high). Russia (Caucasus), Ukraine, Moldova, Georgia, Armenia, Turkey, Western Europe, Mediterranean, Balkan Peninsula.

97. *Stapfelia pinata* L. (Staphyleaceae) Category 3 d. T4–S1 (up to 5 m high). Russia (Caucasus), Ukraine, Moldova, Georgia, Armenia, Turkey, Western Europe, Mediterranean, Balkan Peninsula.

98. *Stapfelia pinata* L. (Staphyleaceae) Category 3 d. T4–S1 (up to 5 m high). Russia (Caucasus), Ukraine, Moldova, Georgia, Armenia, Turkey, Western Europe, Mediterranean, Balkan Peninsula.

99. *Stapfelia pinata* L. (Staphyleaceae) Category 3 d. T4–S1 (up to 5 m high). Russia (Caucasus), Ukraine, Moldova, Georgia, Armenia, Turkey, Western Europe, Mediterranean, Balkan Peninsula.

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103. *Stapfelia pinata* L. (Staphyleaceae) Category 3 d. T4–S1 (up to 5 m high). Russia (Caucasus), Ukraine, Moldova, Georgia, Armenia, Turkey, Western Europe, Mediterranean, Balkan Peninsula.

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108. *Stapfelia pinata* L. (Staphyleaceae) Category 3 d. T4–S1 (up to 5 m high). Russia (Caucasus), Ukraine, Moldova, Georgia, Armenia, Turkey, Western Europe, Mediterranean, Balkan Peninsula.

109. *Stapfelia pinata* L. (Staphyleaceae) Category 3 d. T4–S1 (up to 5 m high). Russia (Caucasus), Ukraine, Moldova, Georgia, Armenia, Turkey, Western Europe, Mediterranean, Balkan Peninsula.

110. *Stapfelia pinata* L. (Staphyleaceae) Category 3 d. T4–S1 (up to 5 m high). Russia (Caucasus), Ukraine, Moldova, Georgia, Armenia, Turkey, Western Europe, Mediterranean, Balkan Peninsula.

111. *Stapfelia pinata* L. (Staphyleaceae) Category 3 d. T4–S1 (up to 5 m high). Russia (Caucasus), Ukraine, Moldova, Georgia, Armenia, Turkey, Western Europe, Mediterranean, Balkan Peninsula.

112. *Stapfelia pinata* L. (Staphyleaceae) Category 3 d. T4–S1 (up to 5 m high). Russia (Caucasus), Ukraine, Moldova, Georgia, Armenia, Turkey, Western Europe, Mediterranean, Balkan Peninsula.

113. *Stapfelia pinata* L. (Staphyleaceae) Category 3 d. T4–S1 (up to 5 m high). Russia (Caucasus), Ukraine, Moldova, Georgia, Armenia, Turkey, Western Europe, Mediterranean, Balkan Peninsula.

114. *Stapfelia pinata* L. (Staphyleaceae) Category 3 d. T4–S1 (up to 5 m high). Russia (Caucasus), Ukraine, Moldova, Georgia, Armenia, Turkey, Western Europe, Mediterranean, Balkan Peninsula.
(Taxaceae) Category 3 e. T3 (up to 12 m high). Russian Far East (Primorsky and Khabarovsky krai, Sakhalin and Kurile Islands), China, Japan, Korea Peninsula.

   (Lamiaceae) Category 3 a. DSS (3–15 cm high). Middle and Lower Volga area, South Ural Mts. – endemic of European Part of Russia.


102. *Viburnum wrightii* Miq. (Viburnaceae) Category 3 e. S1 (up to 3 m high). Russian Far East (Sakhalin, Kunashir, Urup and Iturup Islands), Japan, Korea Peninsula.
PECCUARITIES OF THE INTRODUCTION OF WOODY PLANTS IN NORTH-WESTERN RUSSIA DURING THE AGE OF CLIMATE CHANGE

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Abstract

Since the early years of introduction of exotic woody plants to St. Petersburg, winter hardiness has been the main limiting factor for their outdoor cultivation, with minimum temperatures and the duration of hard frosts being most important. Exotic ligneous plants cultivated in botanic gardens of the Komarov Botanical Institute RAS (established in 1714) and of the Forest-Technical Academy (since 1833) in St. Petersburg have been influenced by abnormally cold winters, for example in 1939–40, 1941–42, 1955–56, 1978–79 and 1986–87. Climate warming at the end of the 20th century, especially during the 1990s, has provided new opportunities to enlarge collections in arboreta, public parks and gardens of the city with less hardy plants, although warming is not always beneficial to plants. Currently the recurrence of cold winters is declining, but may not be eliminated altogether in the future. The investigation of short-term climatic oscillation and its influence on woody plants is urgent since previously hardy species have started to show frost damage due to early spring growth. In the future, tolerance to summer heat and fires may be of importance in determining the suitability of a certain plant for the St. Petersburg region.

The oldest centre of introduction

St. Petersburg is the oldest centre of introduction of plants in North-Western Russia, a result of the establishment of Aptekarsky Ogorod (Pharmaceutical Garden, now Botanic Garden of the Komarov Botanical Institute of Russian Academy of Sciences, BIN). The establishment of Aptekarsky Ogorod in 1714 laid the foundation for the development of botany in Russia (Baranov 1957). Work on the introduction of woody plants in St. Petersburg intensified considerably after transformation of the Pharmaceutical Garden into the Imperial St.-Petersburg Botanic Garden in 1823. Many new taxa were obtained and described from expeditions to the Far East, Siberia, Central Asia and the Caucasus. These plants were cultivated in the garden and distributed throughout the world. Many well-known woody species (Caragana arborescens Lam., Picea obovata Ledeb., Pinus pumila (Pall.) Regel, Pyrus ussuriensis Maxim.) were introduced into cultivation via St. Petersburg’s Botanic Garden (ca. 200 woody species). The collection was created and replenished due to the efforts of many outstanding researchers and gardeners, such as F. Fischer, E. Regel and C. Maximowicz, and later in the 20th century by botanists such as V.L. Komarov, V.V. Ukhanov, B.N. Zamjatnin, A.G. Golovach, A.A. Knjazev and V.P. Kaverznev. The Arboretum (Park-Dendrarium) was planned in the 1820s and it has stayed essentially the same until present. Trees and shrubs were regularly planted in the oldest part of the park. The oldest existing trees (Larix sibirica Ledeb., L. dahurica Laws., L. decidua Mill., and Tilia cordata Mill.) are about 200 years of age and several trees of Quercus robur L. are even older. Today, the Park-Dendrarium is a memorial of the historical landscape architecture, and is one of the oldest parks of the city. There are 3 400 taxa of trees, shrubs and lianas that have been tested and cultivated in the Botanic Garden BIN since their first year of introduction (Svjazeva 2005).

Arboretum of the FTA

The arboretum of the Imperial Forest Institute (now St. Petersburg State Forest-Technical Academy, FTA) was founded in 1833. R Schroeder (1861) was a dendrologist and researcher who summarized the first results
of the introduction of woody plants over an extended period, paying particular attention to the exceptionally severe winter of 1860–61. Egbert Wolf worked in the FTA from 1886 to his death in 1931. According to his notes, he tested about 3 350 taxa – the largest number of plants in the history of introduction in NW Russia, 1 650 of which he considered as promising for further cultivation (Wolf 1917). The main practical result of Wolf’s work was the creation of a unique collection of plants at the Arboretum FTA before the Second World War (Buligin and Firsov 1994 a, b). The 5th of September 2010 was the 150th anniversary of Wolf’s birthday. To commemorate his work, the International Scientific Readings were held on 6–8 October 2010 in FTA, where his contribution to science and problems of present-day dendrology were discussed (Lavrentjev 2010).

In addition to the third botanical garden, i.e. the St. Petersburg State University’s garden, there are several other tree and shrub collections in the city and in the surrounding of the Leningrad region, but they are much smaller. Since their establishment, the Botanic Gardens BIN and FTA have been, and still are, the leading centres of plant introductions in NW Russia.

Living laboratories

Arborescent collections were seriously damaged during the Second World War and the Siege of Leningrad. Before the war in 1936 there were 1 212 woody taxa in the FTA Arboretum, but less than 800 remained in 1947 (Buligin 1994). However, by 1967 the number of species and varieties reached 1 400 (Andronov 1967). During the Second World War the number of species in the Arboretum BIN declined to 198, or 30 percent of the original number (Svjazeva 2005). After the war and due to efforts of B.N. Zamjatnin and A.G. Golovach, the collection expanded beyond the pre-war level, and its quality improved considerably with the appearance of botanically interesting species such as Ginkgo biloba L. and Metasequoia glyptostroboides Hu et Cheng.

Tree and shrub collections of the city are living laboratories. Many different research projects and investigations have been conducted on them in the fields of botany, dendrology, plant physiology, selection, forestry, floriculture, phytopathology, soil science and meteorology. However, the leading branch of research is the introduction of woody plants and continuous uninterrupted phenological monitoring, which has been carried out since 1829–1841 (Buligin 1994). Moreover, the coordination of prolonged phenological investigations together with research on new plant introductions allowed for the development of the new branch of bioclimatic indication, which pays attention to the responses of plants to short-term oscillations in climate (Buligin 1982).

Curatorial tasks

Initially, the shared opinion of curators was that the collection of woody plants must include all species and as many taxa as possible that can tolerate local climatic conditions. Such a task is hardly possible to accomplish. Later on collection policies changed to include those species that are most typical of the boreal zone and the most interesting ones from a scientific point of view. More recently, conservation-centered views have gained ground. Principles of the maintenance and replenishment of collections can be presented as follows: a) conservation of the essential parts of the collections, which have been established during many years; b) enrichment with rare and endemic plants as well as with decorative and economically important taxa; c) tests of new and formerly unknown species, or new tests of those taxa that have been cultivated but are currently absent from the collections (Svjazeva et al. 1989). Continuous and uninterrupted monitoring, phenological observations and biometrical measurements make it possible to identify the adaptability of plants to local climatic conditions and provide the means by which to evaluate the hardiest and most suitable taxa for city plantings and for cultivation at a wider scale.

In the age of climate change, the significance of botanic gardens is increasing. They should re-evaluate their collections from a conservation point of view and should play a more prominent role in ex situ conservation (Firsov et al. 2010b).
Microclimatic features of St. Petersburg

The climate of St. Petersburg is intermediate between maritime and continental (Pokrovskaya and Bychkova 1967). Because of the extensive urban area, there are considerable microclimatic differences in the city (Shver et al. 1982). The BIN and University Botanic Gardens are situated in the centre of the city, which is often warmer than the surroundings. Arboretum FTA is located in the northern part of the city, which is characterized by a colder microclimate. Heat-loving exotic trees and shrubs in FTA are damaged by frost more often than in BIN (Buligin and Firsov 1998a). Some species are only cultivated in FTA, while others only in BIN, but quite many species are cultivated in both arboreta.

Temperature within St. Petersburg is warmer than in the surroundings (Pokrovskaya and Bychkova 1967; Shver et al. 1982; Firsov and Fadeyeva 2009). This means that work on the cultivation of exotic taxa throughout the surrounding territory should be interpreted with caution. In selecting promising taxa for wider cultivation we should rely on hardy species and carry out additional tests at the fringes of the warmer urban environment.

The territory of BIN is situated on Aptekarsky Island, at the mouth of the Neva River, only 2–3 m above sea level. A micro-relief is absent and the territory is subjected to inundations (Lovelius and Firsov 1990). The territory of Arboretum FTA, which is situated further from the Neva River and the Gulf of Finland, and at a higher elevation (10–15 m), is not subjected to inundations. The location of St. Petersburg at the mouth of the Neva River is unique in Russia. A tenth of the city’s territory is prone to inundation – at times catastrophic – which makes it essential to select an assortment of hardy taxa used in city plantings.

Winter hardiness and abnormally cold winters

Winter hardiness is the main limiting factor in the cultivation of trees and shrubs. Abnormally cold winters are especially important. During the second half of the 20th century, cold winters occurred on average every 8–13 years, and certain heat-loving plants may only survive between such two winters. The survival of trees and shrubs depends considerably on the absolute minimum temperature and the duration of heavy frosts. After cold winters, abnormally warm winters injure flowering and fruiting. Some damaged plants do not die immediately but may survive for 2–3 years or even longer. Others stop flowering and fruiting for decades and tree-like growth may change to shrub-like (e.g. Acer trautvetteri Medw. after the winter of 1986–87 in Arboretum BIN). During the 20th century, very cold winters occurred in 1939–40, 1941–42, 1955–56, 1962–63, 1965–66, 1978–79 and 1986–87. During the three centuries of history of St. Petersburg, many colder winters occurred, for example the winter of 1739–40 (Pokrovskaya and Bychkova 1967).

The comparatively young age of many cultivated trees and shrubs in St. Petersburg is a result of severe winters, after which new plantings had to be made. A selection of heat-loving exotic plants exists in St. Petersburg only during interval periods between abnormally cold winters. In some cases the cultivation of such species is acceptable. However, in more permanent city plantings only the hardiest trees and shrubs should be used. Therefore, continuous monitoring of woody plants in botanic gardens covering mild to severe years is of special value. As climate is warming, such severe winters will occur more seldom, but are unlikely to cease altogether. The last severe winter in St. Petersburg (1986–87) resulted in massive frost damage to trees and shrubs.

Global warming and warming in St. Petersburg

The climate has been warming at an unprecedented rate during recent years and decades (Grimshaw and Bayton 2009). About half of the global warming of the last century (ca. 0.6 °C for the entire 20th century) occurred during the 1990s. During the period of instrumental observations, the 10 globally warmest winters were observed during the last two decades of the 20th century and of the beginning of the 21st century. Since the mid 1980s the level of changes in global anomalies of the average yearly temperature has considerably increased when compared to data from the first half of the 20th century (Golubiatnikov and Denisenko 2004).
Such warming may result in profound changes in the composition of the indigenous vegetation, in seasonal dynamics of ecosystems, and in changes in the assortment of woody plants suitable for city landscaping.

Data confirm global changes of climate in different parts of the world, including Russia (Gruza and Ránková 2003). Prof. Nikolai Buligin paid attention to climate warming of St. Petersburg as early as the beginning of the 1970s (Buligin and Dovgulevich 1974). In 1982 he introduced the term bioclimatic cyclicity, which he developed into the field of ecological dendrology (Buligin 1982). In studies on the bio-ecological peculiarities of maples, Buligin et al. (1986) illustrated the tendency of climate warming and compared two periods: 1886–1916 and 1953–1983. Experts in climatology who analyzed the average yearly temperatures of St. Petersburg for the whole period of instrumental observations since 1751, showed a tendency of slow and continuous rising of temperatures (Shver et al. 1982). Climate warming and its effects on trees and shrubs was confirmed by later investigations of Firsov and Buligin (1998) and Firsov et al. (2008, 2010a).

After the winter of 1986–87 in St. Petersburg (1987–2008), the minimum temperature has not been lower than -29 °C (11 January 2003). There were four cold winters (1995–96, 1998–99, 2002–03, 2005–06) and two normal ones (1993–94, 1997–98). The other 14 winters were warmer than average. Thus, during the first years of the 21st century there were six warm and only two cold winters (comparing with data averages for 1947–2008), which confirms gradual warming of the climate.

Climate warming may allow for an increase in the assortment of woody plants to be used in city plantings. Winter hardiness and reproductive ability of the woody flora of St. Petersburg should, therefore, be reassessed (Firsov et al. 2010a).

Anomalies of 1989-1990

Komarova and Firsov (1995) carried out an investigation on the responses of woody plants in St. Petersburg to meteorological anomalies of 1989 and 1990. Both winters were very warm and short. In 1989 the warmest January for the last 35 years was registered (-0.7 °C), which nearly reached the absolute record for the whole period of observations (-0.5 °C in 1925). After such warm winters, the majority of cultivated plants survived without injuries, while 10–15 percent had small bud and shoot tip injuries, and only few showed injuries on shoots older than one year. Such warm winters mainly have an effect on flowering and fruiting, and are especially damaging to plants with short periods of rest, including those that are hardy under normal weather conditions.

Climatic situation in the 21st century

The analysis of original results from phenological observations and of recent data of the meteorological station of St. Petersburg (Centre of Hydrometeorology and Environmental Monitoring) confirms that climatic warming continues, and that the impacts of this change on trees, both introduced and native, have increased. The mean annual temperature of Leningrad in the middle of the 20th century was +4.3 °C (Pokrovskaya and Bychkova 1967; Konjukova et al. 1971). In characterizing the climate of the Leningrad region, Evteeva and Koronatova (1983, p. 19) pointed out that in the western part of the region the yearly mean air temperature reached +4 °C, while in the east +2–3 °C only. These values, which have earlier been considered as anomalies (Pokrovskaya and Bychkova 1967), are now regarded as normal.

According to data from the meteorological station of St. Petersburg, warm winters started to occur in 1988–89, which co-occurs with the real warming of the city since the beginning of the summer of 1988. In addition, 1989 was the warmest year in meteorological history (+7.6 °C). Conclusions made by Komarova and Firsov (1995) have been confirmed: events that were considered anomalies during the 20th century are considered the norm under current, 21st century conditions. The mean temperature of 2008 was nearly as warm as in 1989, i.e. +7.3 °C. The last three winters of the analyzed period (2006–2009) were also warm; the winter of 2007–2008 set a record for the whole period of meteorological observations. According to some predictions, the mean yearly temperature of St. Petersburg may surpass 7–8 °C, even up to 10 °C in some years during the second half of the 21st century.
Response of plants

Many woody species not considered to be hardy in the past are nowadays successfully cultivated in St. Petersburg (e.g. Akebia quinata (Houtt.) Decne., Ginkgo biloba L., Platycladus orientalis (L.) Franco). Walnuts (Juglans regia L.), which are highly sensitive to frost, flower and fruit regularly nowadays and have been propagated from their own seed. Some rare tree species, which in the past were in a vegetative state or only produced flowers, nowadays fruit and their seeds are viable producing second generation plants (e.g. Quercus alba L.). The self-sowing of silver maple (Acer saccharinum L.) was observed for the first time in the history of introduction in 2007 (Firsov and Lavrentjev 2008).

At the same time, as a result of more frequent winter thaws and a subsequent lack of snow cover, the winter hardiness of certain species, which were considered to be quite hardy in the past, has diminished (Juniperus davurica Pall., Microbiota decussata Kom.). This is true even for trees of the local flora, such as Tilia cordata Mill. There is also an increase in frostbite injuries in species that have short periods of winter rest. These plants may start growing very early in mid winter when abnormally warm winters with long thaws occur, and may be injured severely even by small frost events (e.g. Prunus avium L.).

To evaluate the susceptibility of woody plants to frost, the bio-ecological division of cultivated species into groups is used (Wolf 1917). It recommends the division of tested trees into five groups according to degree of winter hardiness, from quite hardy (I) to completely non-hardy, frost-sensitive (V) (Table 1). Data in Table 1 show the gradual increase in adaptation of species of woody plants in St. Petersburg during the last 120 years. This is confirmed by a decrease in frost injuries, by an increase in the number of species that have reached the reproductive stage and of species that have produced seedlings. Some hardy species, however, have retained their ability to reproduce since the end of the 19th to the beginning of the 21st century (Acer rubrum L.).

Changes in reproductive ability

Changes in reproductive capability can be seen very clearly. In earlier years Ptelea trifoliata L. was in bloom periodically and seldom produced fruits. At present it fruits profusely every year, and is propagated from local seeds. The fruits of Magnolia acuminata L. never ripened, but now it forms viable seeds. Different species of rhododendrons are currently grown from local seeds (Rhododendron catawbiense Michx., R. schlippenbachii Maxim., R. vaseyi A. Gray, R. viscosum (L.) Torr.), but in Wolf’s time they were only flowering. This also holds true for Pterocarya pterocarpa (Michx.) Kunth. ex I. Iljinsk. and Abies semenovii B. Fedtsch. (both fruiting since 2000). Seedlings have been observed for the first time for Carpinus betulus L., Cerasus maximowiczii (Rupr.) Kom., Spiraea betulifolia Pall. and Tripterygium regelii Sprague et Takeda. The number of tree and shrub taxa reaching their reproductive stage has increased, thus providing opportunities to grow more species from local seed and to promote their acclimatization.

Winter of 2006–07

The winter of 2006–07 deserves special attention among abnormally warm winters and all-year observations of the 21st century (Firsov et al. 2008). The average duration of winter is 121 ±3 days (1947–2007), but in 2006–07 it was the shortest recorded; 20 January to 2 March – only 41 days. However, the preceding autumn lasted nearly 5 months. The uniqueness of the winter of 2006–07 was based on abnormally warm temperatures in December and in the first half of January, and resulted in the abnormal early development of buds and the appearance of blossoms on many trees and shrubs. This development was interrupted by rather severe, although not long-lasting frosts. The mean monthly temperature in December 2006 was +3.0 °C, which was a record not only for the last 30 years, but also for the whole observation period since 1743, and is much higher than the earlier records. The very late start of the phenological winter on 20 January 2007 was unparalleled for the whole period of observation. Despite the short winter, frosts on certain days reached -20 °C, with an absolute minimum of -23 °C.
Table 1. Examples of winter hardiness and reproductive state of species of introduced woody plants in St. Petersburg. Data from two periods 1978-2007, 1948-1977 and Egbert Wolf’s (1917) own data from the years between 1886 and 1916 are compared. Abbreviations are as follows: Veg – plants in vegetative state, Fl – only flowers, Fr – fruit, S – seedling production.

<table>
<thead>
<tr>
<th>Taxon</th>
<th>Hardiness classes according to Wolf (1917) and reproductive state</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abies holophylla Maxim.</td>
<td>1886-1916, Wolf (1917)</td>
</tr>
<tr>
<td>Abies nordmanniana (Stev.) Spach</td>
<td>I, Veg</td>
</tr>
<tr>
<td>Acer barbinerve Maxim.</td>
<td>II, IV, Veg</td>
</tr>
<tr>
<td>Acer cissifolium (Siebold et Zucc.) C. Koch</td>
<td>IV, Veg</td>
</tr>
<tr>
<td>Acer japonicum</td>
<td>V</td>
</tr>
<tr>
<td>Acer manshuricum Maxim.</td>
<td>II, Fr</td>
</tr>
<tr>
<td>Acer palmatum Thunb.</td>
<td>V</td>
</tr>
<tr>
<td>Acer rubrum L.</td>
<td>I, II, Fr</td>
</tr>
<tr>
<td>Acer teffigum Maxim.</td>
<td>II, Fl</td>
</tr>
<tr>
<td>Acer triflorum Kom.</td>
<td>V</td>
</tr>
<tr>
<td>Aesculus hippocastanum L.</td>
<td>II, Fr</td>
</tr>
<tr>
<td>Ampelopsis aconitifolia Bunge</td>
<td>V</td>
</tr>
<tr>
<td>Aristolochia manshuriensis Kom.</td>
<td>II-III, Veg</td>
</tr>
<tr>
<td>Carpinus betulus L.</td>
<td>IV-V, Veg</td>
</tr>
<tr>
<td>Carpinus japonica Blume</td>
<td>II-III, Fr</td>
</tr>
<tr>
<td>Cerasus maximowiczii (Rupr.) Kom.</td>
<td>IV-V, Veg</td>
</tr>
<tr>
<td>Deutzia amurensis (Regel) Airy-Shaw</td>
<td>III, Veg</td>
</tr>
<tr>
<td>Fraxinus rhynchophylla Hance</td>
<td>III, Veg</td>
</tr>
<tr>
<td>Juglans regia L.</td>
<td>III, Fr</td>
</tr>
<tr>
<td>Laurocerasus officinalis M. Roem.</td>
<td>V</td>
</tr>
<tr>
<td>Lonicera nigr a</td>
<td>I, Fr</td>
</tr>
<tr>
<td>Maackia amurensis Maxim. et Rupr.</td>
<td>II-III, Fr</td>
</tr>
<tr>
<td>Magnolia acuminata L.</td>
<td>III, Fr</td>
</tr>
<tr>
<td>Morus alba L.</td>
<td>III, Fr</td>
</tr>
<tr>
<td>Ptelea trifoliata L.</td>
<td>III, Fr</td>
</tr>
<tr>
<td>Pterocarya rhoifolia Siebold et Zucc.</td>
<td>II, Veg</td>
</tr>
<tr>
<td>Quercus alba L.</td>
<td>III, Veg</td>
</tr>
<tr>
<td>Quercus rubra L.</td>
<td>III, Veg</td>
</tr>
<tr>
<td>Rhododendron catawbiense Michx.</td>
<td>III, Fl</td>
</tr>
<tr>
<td>Sorbus sambucifolia (Cham. et Schlech.) M. Roem.</td>
<td>I, Veg</td>
</tr>
<tr>
<td>Spiraea betulifolia Pall.</td>
<td>I, II, Fr</td>
</tr>
<tr>
<td>Syringa reflexa C.K. Schneid.</td>
<td>II-III, Veg</td>
</tr>
<tr>
<td>Tilia x euchlora C. Koch</td>
<td>II, Veg</td>
</tr>
</tbody>
</table>

At the end of December 2006 – beginning of January 2007 there was a remarkable natural phenomenon in parks and gardens of St. Petersbrug: certain shrubs, such as Daphne mezereum L., Lonicera praeflorens Batal. and Lonicera caerulea L. were in bloom, new growth and leaves appeared in Abelia coreana Nakai and in Prunsepia sinensis (Oliv.) Bean, flowering buds of Rhododendron mucronulatum Turcz. were coloured, and the buds of Atragene sibirica L. and many other woody species began to swell intensively. Injuries on many plants after the winter of 2006–07 were small or absent. However, some species that had been considered completely hardy before were frost bitten due to the very early growth before the subsequent cold weather. The winter of 2006–07 affected meteorological station of St. Petersburg).
the flowering and fruiting of many tree species considerably. No injuries were seen in rare and exotic species such as *Laurocerasus officinalis* M. Roem., *Ginkgo biloba* L., and *Liriodendron tulipifera* L. The majority of sensitive and heat-loving species passed the winter of 2006–07 without or with very small injuries in the tips of annual growth (*Acer cissifolium* (Siebold et Zucc.) C. Koch, *A. henryi* Pax, *Ailanthus altissima* (Mill.) Swingle). Even peach (*Prunus persica* Mill.) wintered successfully, even though it had earlier been regarded as non-hardy in St. Petersburg (Wolf 1917). At the same time, a group of trees and shrubs that were considered to be quite winter hardy, were seriously injured by frost in 2007. Many flower buds and main branches of *Daphne mezereum* L. were killed by frost despite the fact that the species belongs to the indigenous flora. Many of the seriously injured plants were from the Russian Far East, for instance *Betula schmidtii* Regel (severe injuries of main branches), *Rhododendron sitchensis* Pojark., *Populus koreana* Rehd. (severe injuries of annual shoots and loss of decorative value during the first half of the growing season) and *Prunus sinensis* (with injuries on more than 90% of the crown). Trees of *Rhamnus alpina* L. and *Crataegus maximowiczii* C.K. Schneid. died after the winter of 2006–07. Some trees and shrubs are regarded as quite hardy in normal and cold winters. However, after warm winters during the 21st century, rotting of the cambium and the bark – especially near the soil surface – was observed. At the same time, flowering (*Carya ovata* (Mill.) C. Koch) and fruiting (*Acer cissifolium* (Siebold et Zucc.) C. Koch, *Carpinus japonica* Blume, *Acer palmatum* Thunb., *Abies gracilis* Kom. and *Ilex verticillata* (L.) A. Gray) were observed for the first time in some plants.

**Bioclimatic cycles**

When evaluating the suitability of woody plants for forestry and urban landscaping, we have to bear in mind their response to unfavorable so-called bioclimatic cycles (Buligin 1982, 1996). A bioclimatic cycle is the response of arborescent plants to the short-term oscillations of climate – from two years up to centuries (Buligin and Firsov 1998b). Even with climatic warming in the second half of the 20th century there were fluctuations of ‘early-warm’ (such as 1959–1961 and 1972–1975) and ‘late-cold’ (1968–1969, 1984–1987) bioclimatic cycles. Initial results should be interpreted with caution if the introduced plants have not experienced at least one abnormally severe winter. Climate warming does not exclude the occurrence of cold winters. This means that the investigation of short-term oscillations of climate, their prospective forecast and the study of the consequences of their effects on introduced and native woody flora is of considerable importance (Fadeyeva et al. 2009; Fadeyeva and Firsov 2010).

**Changes in phenology, in the duration of seasons, and in the limits of winter hardness zones**

Under present climatic conditions (1978–2007) the number of warm winters has increased from 6 to 16, and phenological spring is starting 12 days earlier than in the past (1948–1977). Because of the shortening of the cold period of the year, the duration of the growing season and the frost-free period has lengthened considerably. Even though warming of the climate is not always beneficial for introduced plants, it opens up new possibilities in the field of gardening. Apparently, the winter hardiness zones of woody plants will change considerably (Firsov 2003).

**Changes in assortment**

Elms used to be recommended for landscaping (Andronov 1953; Buligin 2000), but at present are subjected to elm disease (*Grafium ulmi* Schwarz.), which was first registered in St. Petersburg in 1998 (Dorofeeva 1998) apparently because of the shift of the northern border of the insect-carrier of this disease (*Scolitus multistratus*, *S. scolitus*). Today we witness the mass dying of young and old elm trees (*Ulmus glabra* Huds., *U. laevis* Pall., *U. americana* L. and other species).

In connection with global climatic changes, meteorologists and climatologists foresee different scenarios in the development of climatic conditions (Kolomyts 2003). Due to the tendency of the climate to become drier, with long summer droughts throughout large parts of Russia, xerophytic species (from
Central Asia and other arid regions) might be of considerable importance in city plantings, such as Elaeagnus angustifolia L., Lonicera microphylla Roem. et Schult., Lycium depressum Stocks and Tamarix ramosissima Ledeb. On the other hand, an increase in precipitation may result in the occurrence of more fungal diseases (which was observed in St. Petersburg during the rainy summer of 2008) and pests. As such, some species sensitive to moisture and fungal diseases may not be used in cultivation. Many new species from other parts of the globe may, however, be selected for cultivation. Given climate warming, new methods of cultivation should be elaborated. This requires careful and uninterrupted monitoring and assessment of the woody flora.

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A COMPARATIVE AND STATISTICAL ANALYSIS OF PINOPSIDA IN THE COLLECTIONS OF RUSSIA’S BOTANIC GARDENS, UNDER VARYING CLIMATIC CONDITIONS


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Abstract

This study aimed to evaluate the use of the information system «Botanical collections of Russia» for a comparative analysis of collections in botanical gardens. The analysis includes an estimation of the taxonomic diversity of these collections in comparison to a global diversity of coniferous plants, and an estimation of the influence of key climatic factors on plant distributions in cultivation. The influence of minimum winter temperatures, duration of the frost-free period, sunshine duration, the average annual number of days with temperatures above 30 °C, and average July temperatures on the diversity in collections is studied. The information system gives an opportunity to develop the collection policy of the Council of botanical gardens of Russia, and certain botanical gardens in particular, in order to create the most representative national botanical collections.

Keywords: collections of botanical gardens, climatic change, ecological factors, electronic database, information systems, plant cultivation, conservation of plant genetic resources


Introduction

Botanical gardens (BGs) keep and maintain a diverse range of plant genetic resources valuable to mankind. It concerns both species of economic value, which have been traditionally preserved in BGs, and rare and endangered plants, which are preserved in the framework of the tasks of the Global Strategy for Plant Conservation (Wyse Jackson 2001). Information technologies provide a unique opportunity to coordinate plant conservation ex situ, taking into account the climatic conditions of territories in which the plants are cultivated.

Outdoor collections include plants that are tolerant to various climatic conditions. A garden's conditions often differ from those in the species' native habitats, potentially resulting in the preservation of a wide range of ecotypes of the species. Under climate change, introduction potentialities in botanical gardens will change as well, so too will the conditions for plants already kept in collections.

The analysis of certain taxonomic groups in the national database (here Pinopsida) along a gradient of various climatic factors allows us not only to summarise the results of introductions of these plants but also to establish a collection policy of BGs. The latter can be done by comparison of climates in a species' native habitats with the climate of regions of Russia in order to define optimal locations for their cultivation.
Material and methods

The present research utilises the methodology developed in Prokhorov (2004). The taxonomic diversity of Russian botanical collections was evaluated from the IS, available at http://garden.karelia.ru/look/ru/index.htm (Prokhorov et al. 2005). Information resources for the vascular plant collections in the BGs of Russia (Prokhorov and Nesterenko 2001a) were created on the basis of local collection databases that support the International Transfer Format for Botanic Garden Plant Records (ITF) (Wyse Jackson 1997), including the database ‘Calypso’ (Prokhorov and Nesterenko 2001b).

Combining these databases, we encountered inconsistencies in plant identifications and nomenclature even within a single BG. Misidentifications were very frequent. A common approach was needed to override differences in taxonomic concepts. Even typing errors were numerous and this was a serious obstacle.

The spelling of plant names and plant authors’ names was partly corrected automatically. A variety of taxonomies were automatically standardised according to Takhtajan (1997), with the inclusion of generic synonyms. A data scanner (Andryusenko 2005), which uses the nomenclature resources of IPNI (2004) and IOPI (1996), processed the original information to facilitate the experts’ work of tracing accepted names and synonyms. The verification of records of the gymnosperm collections, made by Yu. N. Karpun and A. V. Bobrov, revealed that synonyms and misspelt names comprised 18 percent of the total number of recorded names.

Table 1. Climatic factors used in IS “Botanical collections of Russia”

<table>
<thead>
<tr>
<th>Source</th>
<th>Symbol</th>
<th>Climatic factor</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plantideas.com</td>
<td>HZ</td>
<td>Average annual minimum temperature (Table 2, Fig. 1)</td>
<td>°C</td>
</tr>
<tr>
<td>Figure II. 4.29, p. 470</td>
<td>FF</td>
<td>Average annual number of frost-free days (Table 3, Fig. 2)</td>
<td>days</td>
</tr>
<tr>
<td>Figure II. 3.1, p. 435</td>
<td>SL</td>
<td>Mean annual sunshine duration (Table 4, Fig. 3)</td>
<td>hrs per year</td>
</tr>
<tr>
<td>Figure II. 4.26, p. 467</td>
<td>HT</td>
<td>Annual normal amount of days of above 30 °C (Table 5, Fig. 4)</td>
<td>days</td>
</tr>
<tr>
<td>Figure II. 4.3, p. 444</td>
<td>JT</td>
<td>Average July temperature (Table 6, Fig. 5)</td>
<td>°C</td>
</tr>
</tbody>
</table>

BGs of Russia along a gradient of climatic factors

Prior knowledge suggests that the main limiting factors of plant cultivation in the open are temperature ranges and the frost-free period. However, more reliable results on limiting factors may be obtained (Karpun 2005) as the number of factors analysed increases.

We mapped five climatic variables: average annual minimum temperature, frost-free period, sunshine duration, the average annual number of days with temperatures above 30 °C and average July temperatures (Tables 1–6, Figs 1–5). We assumed that average annual minimum winter temperature and the length of the frost-free period are the most significant climatic factors for arboreal plants, because the former is used to determine hardiness zones and the latter to determine the length of the growing season. Hardiness zones (HZ) are defined according to A. Rehder (1949) and the hardiness zones maps (www.plantideas.com). The zone boundaries coincide with isotherms of the average minimum winter temperatures observed for a long-term period at 5 Fahrenheit intervals. There are nine hardiness zones in Russia, from HZ1 to HZ9. BGs are located in eight zones, excluding HZ8. HZ1 coincides with the subarctic climate and is considered to be the coldest zone; HZ9 includes the Black Sea coast, south of the town Tuapse, and is the warmest zone (Table 2, Fig. 1). Eight frost-free period (FF) zones were delimited in Russia (Kobysheva 2001). BGs are situated in zones FF3–FF8 (Table 3, Fig. 2). We prepared geoinformation resources, which allowed for the arrangement of BGs according to these climatic parameters.
Table 2. Characteristics of the plant hardiness zones.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Average annual minimum temperature, °C</th>
<th>BG</th>
</tr>
</thead>
<tbody>
<tr>
<td>HZ1</td>
<td>below -45.5</td>
<td>3</td>
</tr>
<tr>
<td>HZ2</td>
<td>-40.0... -45.5</td>
<td>6</td>
</tr>
<tr>
<td>HZ3</td>
<td>-34.5... – 39.9</td>
<td>34</td>
</tr>
<tr>
<td>HZ4</td>
<td>-28.9...-34.4</td>
<td>41</td>
</tr>
<tr>
<td>HZ5</td>
<td>-23.4...-28.8</td>
<td>17</td>
</tr>
<tr>
<td>HZ6</td>
<td>-17.8...-23.3</td>
<td>13</td>
</tr>
<tr>
<td>HZ7</td>
<td>-12.3...-17.7</td>
<td>11</td>
</tr>
<tr>
<td>HZ9</td>
<td>-1.2...-6.6</td>
<td>6</td>
</tr>
</tbody>
</table>

Total number of BGs 131

Table 3. Characteristics of the frost-free period zones.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Average annual number of frost-free days</th>
<th>BG</th>
</tr>
</thead>
<tbody>
<tr>
<td>FF1</td>
<td>&lt; 45</td>
<td>0</td>
</tr>
<tr>
<td>FF2</td>
<td>45-59</td>
<td>0</td>
</tr>
<tr>
<td>FF3</td>
<td>60-89</td>
<td>8</td>
</tr>
<tr>
<td>FF4</td>
<td>90-119</td>
<td>37</td>
</tr>
<tr>
<td>FF5</td>
<td>120-149</td>
<td>46</td>
</tr>
<tr>
<td>FF6</td>
<td>150-179</td>
<td>20</td>
</tr>
<tr>
<td>FF7</td>
<td>180-199</td>
<td>18</td>
</tr>
<tr>
<td>FF8</td>
<td>more than 200</td>
<td>2</td>
</tr>
</tbody>
</table>

Total number of BGs 131

Figure 1. Plant hardiness zones map.

Figure 2. Map of frost-free period zones.
Table 4. Characteristics of the zones according to the duration of annual sunshine.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Mean annual sunshine duration, hrs per year</th>
<th>BG</th>
</tr>
</thead>
<tbody>
<tr>
<td>SL03</td>
<td>1200-1400</td>
<td>1</td>
</tr>
<tr>
<td>SL04</td>
<td>1400-1600</td>
<td>11</td>
</tr>
<tr>
<td>SL05</td>
<td>1600-1800</td>
<td>38</td>
</tr>
<tr>
<td>SL06</td>
<td>1800-2000</td>
<td>30</td>
</tr>
<tr>
<td>SL07</td>
<td>2000-2200</td>
<td>39</td>
</tr>
<tr>
<td>SL08</td>
<td>2200-2400</td>
<td>10</td>
</tr>
<tr>
<td>SL09</td>
<td>2400-2600</td>
<td>1</td>
</tr>
<tr>
<td>SL10</td>
<td>&gt; 2600</td>
<td>1</td>
</tr>
</tbody>
</table>

Total number of BGs 131

Table 5. Characteristics of the zones according to the annual number of days above 30 °C.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Annual normal number of days above 30 °C</th>
<th>BG</th>
</tr>
</thead>
<tbody>
<tr>
<td>HT02</td>
<td>0-1</td>
<td>10</td>
</tr>
<tr>
<td>HT03</td>
<td>1-5</td>
<td>42</td>
</tr>
<tr>
<td>HT04</td>
<td>5-10</td>
<td>35</td>
</tr>
<tr>
<td>HT05</td>
<td>10-15</td>
<td>13</td>
</tr>
<tr>
<td>HT06</td>
<td>15-20</td>
<td>6</td>
</tr>
<tr>
<td>HT07</td>
<td>20-30</td>
<td>8</td>
</tr>
<tr>
<td>HT08</td>
<td>30-40</td>
<td>4</td>
</tr>
<tr>
<td>HT09</td>
<td>40-50</td>
<td>12</td>
</tr>
<tr>
<td>HT10</td>
<td>50-60</td>
<td>1</td>
</tr>
</tbody>
</table>

Total number of BGs 131

Figure 3. Map of zones according to the duration of average annual sunshine.

Figure 4. Map of zones according to annual normal number of days above 30 °C.
Results

Altogether there are 110 functioning BGs and arboreta included in IS. Lists of cultivated taxa are available from 79 BGs. Separate statistics are kept for open grounds and greenhouses, since outdoor conditions are a natural limiting factor in cultivation. This separation is not provided in other information systems, i.e. Multisite (O’Neal and Walter 1997) and SysTax (Hoppe et al. 1996).

Table 6. Characteristics of zones according to average July temperatures.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Average July temperature °C</th>
<th>BG</th>
</tr>
</thead>
<tbody>
<tr>
<td>JT07</td>
<td>12-14</td>
<td>5</td>
</tr>
<tr>
<td>JT08</td>
<td>14-16</td>
<td>4</td>
</tr>
<tr>
<td>JT09</td>
<td>16-18</td>
<td>35</td>
</tr>
<tr>
<td>JT10</td>
<td>18-20</td>
<td>42</td>
</tr>
<tr>
<td>JT11</td>
<td>20-22</td>
<td>24</td>
</tr>
<tr>
<td>JT12</td>
<td>22-24</td>
<td>17</td>
</tr>
<tr>
<td>JT13</td>
<td>&gt;24</td>
<td>4</td>
</tr>
</tbody>
</table>

Total number of BGs 131

According to Farjon (2001), the class Conifers (Pinopsida) comprises ca. 630 species belonging to 8 families and 69 genera. There are 43 native and more than 394 introduced species of conifers cultivated in Russian BGs (Prokhorov et al. 2007). In open areas, Pinopsida is represented by 7 orders, 8 families, 41 genera, 335 species, 56 infraspecific taxa, and 599 cultivars.

More than 50 Russian BGs possess Pinus sylvestris L., P. sibirica Mayr., Thuja occidentalis L. and Picea abies (L.) H. Karst. Some 41–50 BGs cultivate Larix sibirica Ledeb., Picea pungens Engelm., P. pungens ‘Glaucra’, P. glauca Regel, Juniperus sabina L., Abies sibirica Ledeb. and Pseudotsuga menziesii (Mirb.) Franco. The largest number of taxa is found in 2–10 BGs, mostly on account of the diversity in cultivars. One BG in Russia has 386 taxa of conifers in cultivation (Table 7).

The analysis of cultivation according to the gradient of climatic factors shows that the frequent occurrence of a certain taxon in BGs is not necessarily connected with a high plasticity of this taxon and its ability to be cultivated under
Table 8. Widely represented species of Pinopsida in BGs of the Russian Federation.

<table>
<thead>
<tr>
<th>Genus</th>
<th>Species</th>
<th>Sets of climatic zones defined by different climatic variables</th>
<th>Occurrence**</th>
<th>BG</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>HZ1-HZ7, HZ9, FF3-FF8, SL4-SL9, HT2-HT9, JT7-JT13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Larix</td>
<td>gmelinii Ledeb. ex Gordon</td>
<td>+ *FF8 + + +</td>
<td>4</td>
<td>33</td>
</tr>
<tr>
<td>Larix</td>
<td>sibirica</td>
<td>+ *FF8 + + +</td>
<td>4</td>
<td>47</td>
</tr>
<tr>
<td>Picea</td>
<td>jezoensis Maxim.</td>
<td>+ *FF8 + + +</td>
<td>4</td>
<td>35</td>
</tr>
<tr>
<td>Picea</td>
<td>obovata Ledeb.</td>
<td>+ *FF8 + + +</td>
<td>4</td>
<td>37</td>
</tr>
<tr>
<td>Pinus</td>
<td>sibirica</td>
<td>+ + + *HT6 +</td>
<td>4</td>
<td>52</td>
</tr>
<tr>
<td>Pinus</td>
<td>sylvestris</td>
<td>+ *FF8 + + +</td>
<td>4</td>
<td>55</td>
</tr>
<tr>
<td>Picea</td>
<td>abies</td>
<td>*HZ1 + *SL9 +</td>
<td>3</td>
<td>52</td>
</tr>
<tr>
<td>Juniperus</td>
<td>communis L.</td>
<td>*HZ1,2 *FF8 +</td>
<td>2</td>
<td>28</td>
</tr>
<tr>
<td>Picea</td>
<td>pungens</td>
<td>*HZ1 + *SL9 +</td>
<td>3</td>
<td>44</td>
</tr>
<tr>
<td>Abies</td>
<td>holophylla Maxim.</td>
<td>*HZ1,2 *FF8 +</td>
<td>2</td>
<td>36</td>
</tr>
<tr>
<td>Picea</td>
<td>kaempferi Fortune ex Gordon</td>
<td>*HZ1,2 *FF8 +</td>
<td>2</td>
<td>43</td>
</tr>
<tr>
<td>Pinus</td>
<td>banksiana Lamb.</td>
<td>*HZ1,2 *FF3,8 *SL9 +</td>
<td>2</td>
<td>29</td>
</tr>
<tr>
<td>Pinus</td>
<td>mugoTurra</td>
<td>*HZ1,2 *FF3,8 *SL9 +</td>
<td>2</td>
<td>34</td>
</tr>
<tr>
<td>Pseudotsuga</td>
<td>menziesii</td>
<td>*HZ1,2 *FF3,8 *SL9 +</td>
<td>2</td>
<td>42</td>
</tr>
<tr>
<td>Thuja</td>
<td>occidentalis</td>
<td>*HZ1,2 *FF8 *SL9 +</td>
<td>2</td>
<td>52</td>
</tr>
<tr>
<td>Juniperus</td>
<td>sargentii (Henry) Takeda ex Nakai</td>
<td>*HZ1,2 *FF3 +</td>
<td>2</td>
<td>21</td>
</tr>
<tr>
<td>Juniperus</td>
<td>sibirica Burgsd.</td>
<td>*HZ1,2 *FF8 +</td>
<td>2</td>
<td>24</td>
</tr>
<tr>
<td>Pinus</td>
<td>pumila Regel.</td>
<td>*HZ7,2 *FF8 +</td>
<td>1</td>
<td>28</td>
</tr>
<tr>
<td>Abies</td>
<td>sibirica</td>
<td>*HZ1,2 *FF8 *SL8 +</td>
<td>1</td>
<td>42</td>
</tr>
<tr>
<td>Chamaecyparis</td>
<td>Lawsoniana Parl.</td>
<td>*HZ1,3 *FF8 *SL9 +</td>
<td>1</td>
<td>23</td>
</tr>
<tr>
<td>Chamaecyparis</td>
<td>pisifera (Siebold &amp; Zucc.)Enl.</td>
<td>*HZ1,2 *FF3,8 *SL9 +</td>
<td>1</td>
<td>23</td>
</tr>
<tr>
<td>Juniperus</td>
<td>horizontalis Moench</td>
<td>*HZ1,2 *FF8 *SL9 +</td>
<td>1</td>
<td>22</td>
</tr>
<tr>
<td>Juniperus</td>
<td>sabina</td>
<td>*HZ1,2 *FF8 *SL9 +</td>
<td>1</td>
<td>42</td>
</tr>
<tr>
<td>Juniperus</td>
<td>virginiana L.</td>
<td>*HZ1,2 *FF3,8 *SL9 +</td>
<td>1</td>
<td>35</td>
</tr>
<tr>
<td>Larix</td>
<td>decidua Mill.</td>
<td>*HZ1,2 *FF8 *SL8 +</td>
<td>1</td>
<td>34</td>
</tr>
<tr>
<td>Picea</td>
<td>omorika (Pancic) Mast.</td>
<td>*HZ1,2 *FF8 *SL9 +</td>
<td>1</td>
<td>27</td>
</tr>
<tr>
<td>Pinus</td>
<td>cembra L.</td>
<td>*HZ1,2 *FF8 *SL9 +</td>
<td>1</td>
<td>21</td>
</tr>
<tr>
<td>Pinus</td>
<td>koraensis Siebold &amp; Zucc.</td>
<td>*HZ1,2 *FF3,8 +</td>
<td>1</td>
<td>36</td>
</tr>
<tr>
<td>Pinus</td>
<td>strobus L.</td>
<td>*HZ1,2 *FF3,8 *SL8,9 +</td>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td>Platycladus</td>
<td>orientalis (L.) Franco</td>
<td>*HZ1,3 *FF3,8 *SL9 +</td>
<td>1</td>
<td>27</td>
</tr>
<tr>
<td>Taxus</td>
<td>baccata (L.)</td>
<td>*HZ1,3 *FF3,8 *SL9 +</td>
<td>1</td>
<td>38</td>
</tr>
</tbody>
</table>

Footnote: HZ = hardiness zones; FF = zones defined by length of frost-free period; SL = zones defined by annual sunshine duration; HT = zones defined by annual number of days with a temperature above 30 °C; JT = zones defined by average July temperature; + = the species occurs in all zones of this climatic parameter; * the species occurs fragmentarily and is absent in the marked zones; ** denotes in how many of the sets of climatically defined zone types the species occurs in all zones; BG = number of botanic gardens holding the species.
various conditions. The analysis also allows for the identifying of limiting climatic factors and other reasons for the absence of a certain species in particular zones.

Analysis of the distribution of Pinopsida with respect to various climatic factors revealed that 32 species are widespread according to one or several parameters (Table 8). These species belong to 10 genera (Abies Mill. – 2 species, Chamaecyparis Spach – 2, Juniperus L. – 6, Larix Mill. – 4, Picea A. Dietr. - 6, Pinus L. – 8, Platycladus Spach – 1, Pseudotsuga Carrière – 1, Taxus L. – 1 and Thuja L. – 1).

Limiting factors for the most widespread species include extremes of the frost-free period, average temperatures, and the duration of average annual sunshine. At present, the smallest number of gardens is established in zones of extreme climatic characteristics. For instance, in FF8 zone (Table 9) there is only one comparatively young garden – the Mountain Botanical Garden of the Dagestan Research Centre of RAS (founded in 1986). It possesses nine taxa of conifers: Juniperus communis L. A. S. Johnson, J. foetidissima L., J. oblonga (Regel) C. K. Schneid., J. sabina 'Cupressifolia', J. × sargentii Rehd., Picea pungens Fleischer, Pinus kochiana Trautv., P. pallasiana (Stev.) Losinsk. and P. sibirica. The absence of a certain plant between the zones of known cultivation suggests that the taxon could be grown here but is absent by chance alone. For example, conditions of the HT6 zone are favourable for Pinus sibirica but this species is absent in the BGs situated in this zone.

Our analysis of climatic factors supports the importance of the average minimum annual temperature (HZ) and the frost-free period (FF) in introductions, since the number of conifer species that are widespread along the gradient of these two parameters is low (Fig. 6). The analysis of conifers in collections according to hardiness zones showed that a higher number of taxa is present in HZ9, followed by HZ3 and HZ6 (Table 10). The comparison of species composition according to the hardiness zones using the Jaccard index (Jaccard 1901) (Table 11) revealed a greater similarity in the pairs HZ6–HZ4, HZ6–HZ5, HZ5–HZ4, HZ5–HZ3, HZ4–HZ3,

Table 9. Taxonomic composition of Pinopsida collections in FF-zones.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Average annual number of frost-free days</th>
<th>BG</th>
<th>Orders</th>
<th>Families</th>
<th>Genera</th>
<th>Species</th>
<th>Sub-species</th>
<th>Cultivars</th>
</tr>
</thead>
<tbody>
<tr>
<td>FF3</td>
<td>60-89</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>7</td>
<td>37</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>FF4</td>
<td>90-119</td>
<td>19</td>
<td>3</td>
<td>4</td>
<td>17</td>
<td>112</td>
<td>16</td>
<td>176</td>
</tr>
<tr>
<td>FF5</td>
<td>120-149</td>
<td>23</td>
<td>5</td>
<td>6</td>
<td>22</td>
<td>135</td>
<td>22</td>
<td>224</td>
</tr>
<tr>
<td>FF6</td>
<td>150-179</td>
<td>9</td>
<td>5</td>
<td>6</td>
<td>22</td>
<td>103</td>
<td>8</td>
<td>144</td>
</tr>
<tr>
<td>FF7</td>
<td>180-199</td>
<td>10</td>
<td>7</td>
<td>8</td>
<td>40</td>
<td>294</td>
<td>42</td>
<td>391</td>
</tr>
<tr>
<td>FF8</td>
<td>more than 200</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>8</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 10. Taxonomic composition of Pinopsida collections in HZ-zones.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Average annual minimum temperature, °C</th>
<th>BG</th>
<th>Orders</th>
<th>Families</th>
<th>Genera</th>
<th>Species</th>
<th>Sub-species</th>
<th>Cultivars</th>
</tr>
</thead>
<tbody>
<tr>
<td>HZ1</td>
<td>below -45.5</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>HZ2</td>
<td>-40.0... -45.5</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>7</td>
<td>39</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>HZ3</td>
<td>-34.5... -39.9</td>
<td>15</td>
<td>3</td>
<td>4</td>
<td>18</td>
<td>113</td>
<td>16</td>
<td>249</td>
</tr>
<tr>
<td>HZ4</td>
<td>-28.9... -34.4</td>
<td>18</td>
<td>4</td>
<td>5</td>
<td>17</td>
<td>118</td>
<td>14</td>
<td>150</td>
</tr>
<tr>
<td>HZ5</td>
<td>-23.4... -28.8</td>
<td>9</td>
<td>5</td>
<td>6</td>
<td>21</td>
<td>124</td>
<td>18</td>
<td>120</td>
</tr>
<tr>
<td>HZ6</td>
<td>-17.8... -23.3</td>
<td>6</td>
<td>3</td>
<td>4</td>
<td>17</td>
<td>122</td>
<td>11</td>
<td>182</td>
</tr>
<tr>
<td>HZ7</td>
<td>-12.3... -17.7</td>
<td>6</td>
<td>5</td>
<td>6</td>
<td>23</td>
<td>87</td>
<td>6</td>
<td>96</td>
</tr>
<tr>
<td>HZ9</td>
<td>-1.2... -6.6</td>
<td>5</td>
<td>7</td>
<td>8</td>
<td>40</td>
<td>271</td>
<td>37</td>
<td>355</td>
</tr>
</tbody>
</table>
and HZ6–HZ3, because of a low difference in the species number (between 113 and 124) and numerous coinciding taxa (between 95 and 103). Collections situated in marginal conditions of HZ1 and HZ9 show minimal similarity to the main collections situated in the typical climatic conditions of the country (HZ3–HZ7).

The analysis of species occurrence according to hardiness zones shows that the greatest number of species (188) are cultivated in one zone only. Most of these species are present in HZ9 (81%). Amongst the other zones, 36 species occur across six zones (35 species from HZ3 to HZ9, 1 species from HZ2 to HZ8). Only seven species are present in all eight zones: *Larix gmelinii*, *L. sibirica*, *Picea abies*, *P. jezoensis*, *P. obovata* Ledeb., *Pinus sibirica* and *P. sylvestris*. They are native to a variety of habitats in Russia. In total, 28 percent of all cultivated conifers continuously occur in 2–8 zones, whereas 17 percent have scattered distributions but could potentially be cultivated in the intermediate climatic positions (Table 12).

Analysis of the taxonomic composition of our collections of conifers according to the frost-free zones (FF) shows that the greatest number of taxa is cultivated in FF7, followed by FF5 (Table 9). The comparison of species composition

**Table 11.** Species composition similarity of Pinopsida collections in the HZ-zones (Jaccard index).

<table>
<thead>
<tr>
<th>Zones</th>
<th>HZ1</th>
<th>HZ2</th>
<th>HZ3</th>
<th>HZ4</th>
<th>HZ5</th>
<th>HZ6</th>
<th>HZ7</th>
<th>HZ9</th>
</tr>
</thead>
<tbody>
<tr>
<td>HZ1</td>
<td>1</td>
<td>0.21</td>
<td>0.07</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.08</td>
<td>0.03</td>
</tr>
<tr>
<td>HZ2</td>
<td>1</td>
<td>0.3</td>
<td>0.3</td>
<td>0.29</td>
<td>0.29</td>
<td>0.23</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>HZ3</td>
<td>1</td>
<td>0.63</td>
<td>0.63</td>
<td>0.63</td>
<td>0.48</td>
<td>0.29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HZ4</td>
<td>1</td>
<td>0.63</td>
<td>0.66</td>
<td>0.5</td>
<td>0.29</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HZ5</td>
<td>1</td>
<td>0.68</td>
<td>0.52</td>
<td>0.33</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HZ6</td>
<td>1</td>
<td>0.56</td>
<td>0.33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HZ7</td>
<td>1</td>
<td>0.32</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HZ9</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 12.** Occurrence of species in the HZ-zones.

<table>
<thead>
<tr>
<th>Occurrence</th>
<th>Number of HZ-zones</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous</td>
<td>0</td>
<td>96</td>
</tr>
<tr>
<td>Fragmentary</td>
<td>188</td>
<td>248</td>
</tr>
</tbody>
</table>

**Table 13.** Species composition similarity of Pinopsida collections in the FF-zones (Jaccard index).

<table>
<thead>
<tr>
<th>Zone</th>
<th>FF3</th>
<th>FF4</th>
<th>FF5</th>
<th>FF6</th>
<th>FF7</th>
<th>FF8</th>
</tr>
</thead>
<tbody>
<tr>
<td>FF3</td>
<td>1</td>
<td>0.29</td>
<td>0.26</td>
<td>0.23</td>
<td>0.11</td>
<td>0.07</td>
</tr>
<tr>
<td>FF4</td>
<td>1</td>
<td>0.58</td>
<td>0.53</td>
<td>0.30</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>FF5</td>
<td>1</td>
<td>0.56</td>
<td>0.39</td>
<td>0.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FF6</td>
<td>1</td>
<td>0.32</td>
<td>0.08</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FF7</td>
<td>1</td>
<td>0.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FF8</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 6.** Distribution of a number of widespread species according to the factor zones. HZ = hardiness zones; FF = zones defined by length of frost-free period; SL = zones defined by annual sunshine duration; HT = zones defined by annual number of days with a temperature above 30 °C; JT = zones defined by average July temperature; see Tables 2–6 for further explanation on the zones.
according to the FF-zones using the Jaccard index (Table 13) shows higher similarity in pairs FF4–FF5 and FF5–FF6. This similarity is based on a low difference in species number (between 103 and 135) and numerous coinciding taxa (between 92 and 95). Lowest similarity is observed for zone FF8 because of the low number of species. FF7 is characterized by a great number of species (294 species), and the number of species coinciding with those in FF4–FF6 ranges from 95 to 123.

The analysis of species occurrences according to FF-zones (Table 14) shows that 196 species are cultivated only in one zone, 82% of which occur in zone FF7. 47 species are continuously cultivated in four zones (44 species in FF4–FF7, 3 species in FF5–FF8), and only three species are found in six zones: the cosmopolitan *Juniperus communis*, the North American *Picea pungens* and the Siberian *Pinus sibirica*. The number of species continuously occurring in FF3–FF8 comprises 30 percent, and 13 percent of the total number have fragmentary distributions in cultivation.

**Discussion**

Our data show that the presence of certain taxa in a certain zone does not directly depend on the number of BGs in that zone. Some similarities of the zonal species compositions may be explained by the proximity of gardens, an active exchange of the introduced material and probably similar strategies in the development of collections.

In general, the greatest diversity of Pinopsida appears in the southern collections of Russia, to be explained by biological features of this group and its southern origin. Under the least favourable conditions of HZ3 and FF3, a large collection of conifers is kept in the Ufa Botanical Garden-Institute. The Main Botanical Garden of RAS (Moscow), Forest Academy (St. Petersburg), Botanical Garden of South Federal University (Rostov-on-Don) and Stavropol Botanical Garden are among 10 leading BGs under intermediate (HZ5, FF4–FF5) climatic conditions (Table 15).

Reducing the size of the collections of conifers in favorable climatic conditions HZ 6–7 and FF 4 (Table 10), in comparison with neighboring regions (FF5, HZ9 and FF3, HZ3-

<table>
<thead>
<tr>
<th>Occurrence</th>
<th>Number of FF-zones</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuously</td>
<td>1 2 3 4 5 6</td>
<td></td>
</tr>
<tr>
<td>Fragmentarily</td>
<td>196 24 15 5 1 0</td>
<td>241</td>
</tr>
<tr>
<td>Total number of species</td>
<td>196 39 26 52 28 3</td>
<td>344</td>
</tr>
</tbody>
</table>

**Table 15.** BGs of Russia with the highest taxonomic diversity of Pinopsida and their distribution in HZ- and FF-zones.

<table>
<thead>
<tr>
<th>Botanic Garden</th>
<th>Genera</th>
<th>Species</th>
<th>Sub-species</th>
<th>HZ</th>
<th>FF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sochi Arboretum of the Research Institute of Mountain Silviculture and Forest Ecology of the Federal Forestry Service of Russia</td>
<td>31</td>
<td>203</td>
<td>24</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Subtropical Botanic Garden of Cuban’</td>
<td>39</td>
<td>170</td>
<td>21</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Gardens and parks of Sochi</td>
<td>24</td>
<td>125</td>
<td>13</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Main Botanic Garden. RAS</td>
<td>16</td>
<td>102</td>
<td>10</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Stavropol’ Botanic Garden named after Skripchinskiy V.V.</td>
<td>12</td>
<td>93</td>
<td>7</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Arboretum-Park “Southern Cultures”. Sochi</td>
<td>29</td>
<td>90</td>
<td>2</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Botanic Garden of Saint-Petersburg State Forestry Academy</td>
<td>12</td>
<td>76</td>
<td>8</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Botanic Garden of the Southern Federal University. Rostov-on-Don</td>
<td>14</td>
<td>79</td>
<td>3</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Botanic Garden-Institute of Ufa Scientific Center. RAS</td>
<td>14</td>
<td>69</td>
<td>8</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>
5), shows the need for change in local collection policies. From the studied factors, we conclude that the limiting factors for collections of conifers with more than 100 species are a frost-free period of a minimum of 90 days, an average minimum winter temperature of no lower than -35 °C, an average July temperature of no less than 16 °C, and an annual average sunshine duration of at least 1400 hours per year.

Plants which are widely represented in BGs of different climatic zones may be considered indicator species in planning and in conducting experiments on climate change, since the morphological characters of plants can be different in different zone.

IS provides statistics to find BGs that are similar according to certain parameters. The comparison of collections gives an opportunity to identify species that are lacking in, but suitable to a collection. The Botanical Garden of Petrozavodsk State University (BG PetrSU) is situated in HZ3 and FF4. Currently there are more than 38 species of Pinopsida, which belong to 10 genera, 3 families and 3 orders. Compared to the collection of Pinopsida of the botanical garden PetrSU with plant collections in similar climatic zones (HZ3 and FF4), we identified the opportunity to introduce 74 species belonging to the following genera already represented in collections of other BGs in HZ3 and FF4: Abies Mill., Chamaecyparis Spach, Juniperus L., Larix Mill., Picea A.Dietr., Pinus L., Pseudotsuga Carrière, Taxus L., Thuja L., Tsuga Carrière, as well as the following genera missing from the collections: Metasequoia Miki and Platycladus Spach. Their natural habitats are outside FF4 and HZ3, but they are cultivated in other BGs similar to PetrSU in terms of climatic conditions. Thus, we conclude that the distribution of these species (Metasequoia glyptostroboides H. H. Hu and Cheng, Platycladus orientalis (L.) Franco) does not depend on climatic restrictions. The long-term cultivation of a species under atypical climatic conditions allows sampling of genetic material for its further conservation and spread in cultivation.

Conclusions

Information tools developed in this study allow for the evaluation of the suitability of plant introductions across a wide range of climatic conditions by comparing local experiences with data from all living collections. However, to make full use of the tools, coordinated strategies for collection policies both for individual BGs and collections of BGs in general need to be elaborated.

The evaluation of other limiting factors and the accumulation of more data will provide more precise predictions for the introduction of new species in BGs of Russia. On the basis of such an analytical approach, we see the opportunity for active coordination of Russian BGs in the fields of conservation and mobilization of genetic resources of vascular plants ex situ. Such coordination is necessary for conservation of threatened plants and for the optimal development of the whole national collection that makes up plant genetic resources and the research base for a wide range of scientific disciplines.

Each BG in Russia will get an opportunity to perform a comparative analysis of its collections, taking into account climatic conditions, to evaluate the taxonomic diversity and uniqueness of its collection, and to organize a collection policy in accordance with the objective to increase the importance of its collection for the region and for Russia in general.

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