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Article

Cultivated woody plants as indicators of ongoing climate change in St. Petersburg, Russia

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Abstract

In the city of St. Petersburg, in the last three decades a substantial increase has been observed in the mean annual air temperature and in annual precipitation. The response of cultivated plants to the ongoing climate change remain poorly understood. The article reports results of a comparison of the tolerance of woody plants to climate change in St. Petersburg at the beginning of the 21st century (2001–2018) with the data compiled by E.L. Wolf (1917) for the period 1886–1916. This research was carried out for 593 species and infraspecific taxa from 164 genera belonging to 61 families. Most of the taxa (342 species and infraspecific taxa, 57.5%) perform better in the current climate than in the earlier period, the performance of 232 (39%) species and infraspecific taxa were unchanged, and only 21 species (3.5%) were less able to cope with the current climate. The trend towards a warmer climate makes it possible to expand from Wolf's time the range of geographic regions from which new species of woody plants may be successfully introduced into St. Petersburg. Thus, the number of species and forms that are promising in their winter tolerance for landscaping in St. Petersburg and other cities and towns of Northwest European Russia is expanding.

Key words: arboriculture, botanical gardens, climate warming, E.L. Wolf, hardiness, winter tolerance, woody plants

Introduction

In response to the new demands posed by the ongoing climate change botanical gardens are expected to undertake a number of actions aimed at maintaining and enhancing their living collections (Rae, 2010; Entwisle *et al*., 2017), regain their role as *ex-situ* centres for biodiversity conservation (Heywood, 2011) and contribute to climate change research (Primack and Miller-Rushing, 2009; Schulman and Lehvävirta, 2011). Studies of performance

of cultivated plants in a warming climate could support long term decision making when selecting taxa for landscaping and provide valuable insights into changes that may occur in other urban settings such as public green areas and in the wild (Primack and Miller-Rushing, 2009; Chen and Sun, 2018).

Research in botanical gardens, on cultivated plants from different places in the conditions that exist where these gardens are situated, is carried out by monitoring their performance. Most gardens had been making these observations even before the onset of the current warming trend, thus accumulating invaluable long-term observation records.

One such study was started in St. Petersburg by renowned dendrologist, Egbert Ludwig Maria Wolf, who was born on September 5, 1860 in Berlin, Germany, where in 1879 he received the title of Professional Scientific Gardener. In early 1882, at the invitation of E.L. Regel, he moved to Russia to take up the position of Head Gardener of the New Holland Greenhouse Department of the Imperial St. Petersburg Botanical Garden. On September 4, 1886 Wolf was appointed as Chief Gardener of the Imperial Forestry Institute (now St. Petersburg State Forest Technical University, SFTU). At that time, he began his long-term and fruitful research into plant introduction and cultivation, dendrology and plant taxonomy at this, the most influential forestry higher educational institution in the Russian Empire. One of Wolf's most important scientific publications, *Nabljudeniya nad morozostoikostyu derevyanistykh rasteniĭ* [*Observations on the frost resistance of woody plants*] was published in Petrograd (Wolf, 1917). This book summarizes the main results of the work he had carried out since 1886 at the Forestry Institute on the introduction of woody plants. In this publication he discussed ca. 3350 species of plants, of which he considered ca. 1650 to be winter-hardy and promising for cultivation near St. Petersburg. In the book, Wolf also used a special scale of winter hardiness of plants (actually a bioecological grouping), consisting of five groups: I – winter hardy plants; II – relatively winter-hardy; III – relatively not winter-hardy; IV – not winter-hardy and V – root does not survive freezing. In addition, the reproductive status of plants was indicated and brief notes for individual species were made. This monograph summed up the results of many years of testing woody plants of various life forms in St. Petersburg, in the oldest cultivation center in the northern latitudes, along with the Botanical Garden of the Botanical Institute of the Russian Academy of Sciences, St. Petersburg. Dendrologists all over the world have long referred to this classic book. Until the 1970s, theories concerning the winter hardiness of woody plants in Northwestern European Russia (Gursky, 1957; *Derevya i kustarniki SSSR* [*Trees and shrubs of the USSR*], 1949–1962; Kachalov, 1970; Kolesnikov, 1974) were based on Wolf's data. Wolf was the first to

observe such a large number of taxa of woody plants in the history of their introduction into St. Petersburg, and many of them have not been tested by anyone other than Wolf.

Initially, Wolf began to summarize the results of his research in separate issues of the publication *Dendrological Garden of the Imperial Forestry Institute*. He characterised each accession, especially focusing on the results of overwintering plants. At the same time, he considered the origin of plants to be an important factor in the success of their introduction. However, as he himself noted (Wolf, 1917: 1): "Thanks to slow printing, my work *The Dendrological Garden of the Imperial Forestry Institute* has lost most of its original significance because, since the first issues (including from *Acanthopanax* to *Ledum*, 1905 to 1913) much has changed, not only in the composition of the collection, but also in the life of individual plants. Considering it necessary to make up for lost time, I must for a while abandon the detailed presentation of the subject adopted in the description of the Dendrological Garden, and resort to a concise presentation, in the form of a list, which allows me to place all the accumulated material in a small article presenting a collection of my observations over thirty years of my service at the Imperial Forestry Institute," (translated from Russian by authors).

As noted by Bulygin (1994), it was a genuine feat for a scientist, worthy of being included in the Guinness Book of Records. Wolf (1929) wrote with legitimate pride: "One of the finest collections of tree species now grows in the park of the Forestry Institute, a collection that includes most of what can grow in the local climate, on the threshold of the gloomy north" (translated from Russian by the authors). Wolf continued his research after 1917 and was engaged in the introduction and cultivation of plants until he died in 1931, although his main results had been already summed up by him in 1917.

The climate of Northwest European Russia is characterized by a relatively short frost-free period (ca. 135 days a year), cold winter (mean temperature, January –7.8°C), and nearly permanent snow cover from December to March. According to some researchers (Falk, 1766; Fisher, 1837; Firsov, 2014; Byalt *et al*., 2019) the damaging effect on plants is produced by occasional falls in temperature to –20°C and lower in combination with other adverse factors. Winters with temperatures well below the average happen every decade, and the most frost sensitive species can only survive during the years in between extremely cold winters (Svyazeva, 2005; Firsov and Fadeeva, 2009). In the last three decades, a substantial increase has been observed in the mean annual air temperature from 5.0 to 6.6°C, and in annual precipitation (Figs. 1–3). The plants have responded to the milder winters and hotter summers more frequently observed recently in Saint Petersburg by increased growth rates, by producing flowers and fruits for the first time in the history of their cultivation in a different climate, and

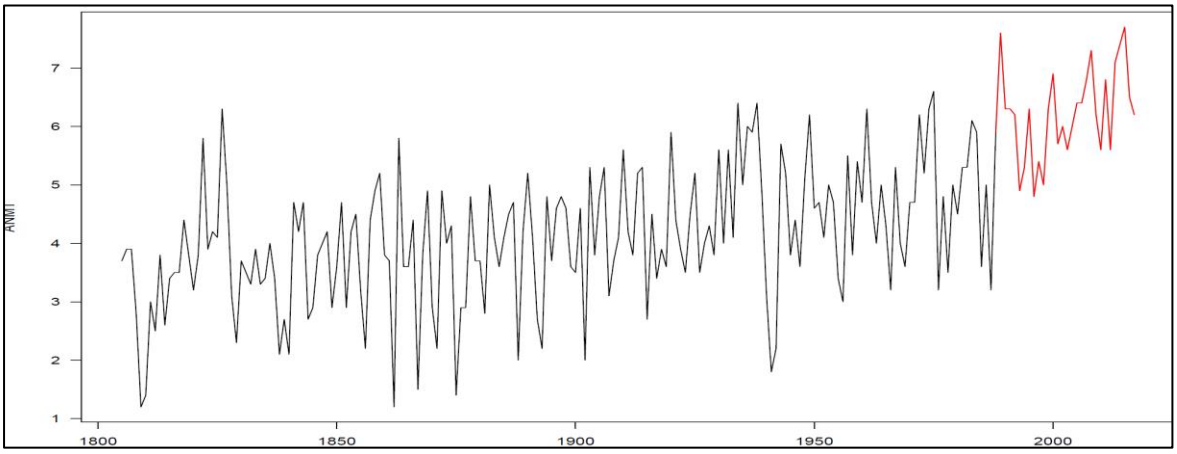

Figure 1. Annual mean temperature in St Petersburg, 1805–2017. The records for the years from 1988 to 2017 are in red.

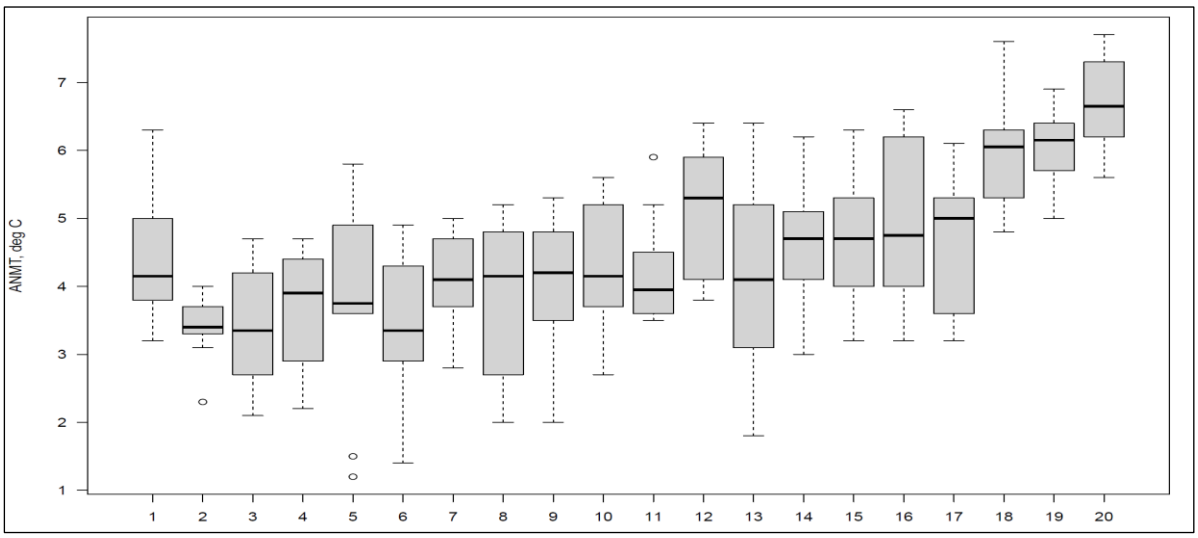

Figure 2. Annual mean temperature in St. Petersburg, averaged over decade, from 1818 to 2017. In the last three decades, i.e. from 1987 to 2017, the annual mean temperature increased by 1.6 °C (from 5.0 °C to 6.6 °C).

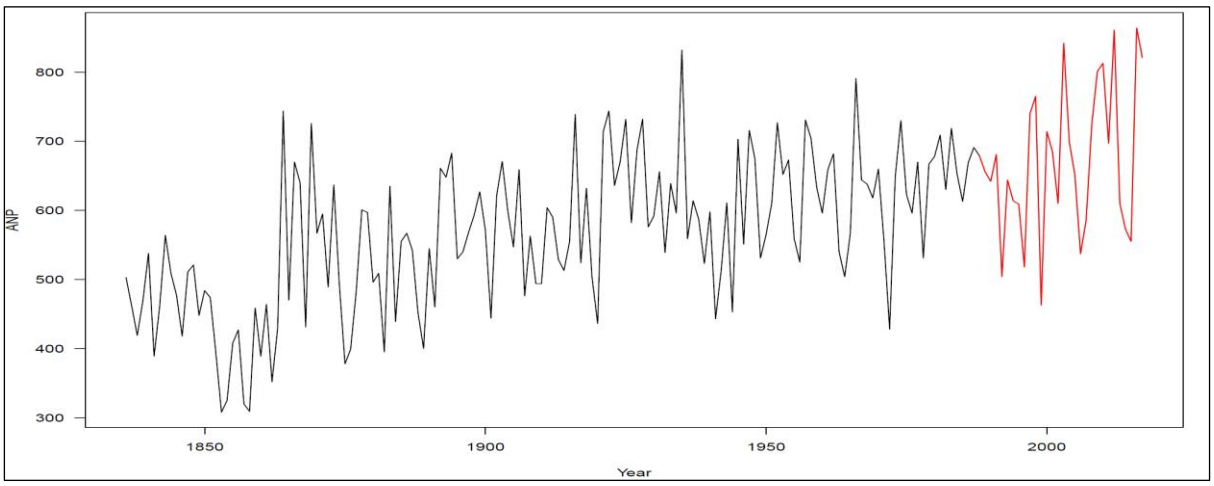

Figure 3. Annual precipitation, mm, in St Petersburg, from 1836 to 2017. The records for the years from 1988 to 2017 are in red.

by surviving outdoors (Firsov, 2019). However, the response has not been uniformly positive. When winter dormancy is interrupted by untimely warming, plants can be seriously damaged by subsequent frost. Thus, during the unusually warm winter of 2006–2007, a number of apparently frost-resistant species were damaged by frost (Firsov *et al*. 2008). Some introduced evergreen species with a short dormancy which previously survived winters under snow cover can be frost damaged if the snow cover is not deep enough. Previously uncommon outbreaks of fungal infections have also been attributed to the changing climate in St. Petersburg (Firsov *et al*., 2019).

Plant species that could be used as indicators of the warming climate should be easy to monitor and have a long observation record (Rampff *et al*. 2010). Both conditions are satisfied in the case of plants cultivated in the Botanical Gargen of the Komarov Botanical Institute of the Russian Academy of Sciences (BG BIN RAS). Therefore, the research question addressed here is: could cultivated plants be indicators of climate change?

Material and methods

Plants selected for the study (Table 1) consisted of trees and shrubs listed in Wolf's book (1917) that were observed by him in the collection of the Peter the Great Botanical Garden at Aptekarsky Island in St. Petersburg, as well as city gardens and parks.

The names of families (Table 2) are given as in APG IV (2016), with an asterisk by the names of families which are still under review in the *World Checklist of Vascular Plants* (WCVP, 2020). All species are ordered alphabetically in each group. The names of accepted taxa are in bold. Taxonomy mostly follows the WCVP (2020). In those cases where taxonomic opinion in WCVP was missing, other taxonomic databases, such as *Catalogue of Life* (CoL, 2020), *Plants of the World Online* (POWO, 2020) and *Tropicos* (2020) were used and references to them were given accordingly as hyperlinks. Abbreviations of author's names are cited as in the nomenclatural database, *International Plant Names Index* (IPNI, 2020).

We used the results of our own observations of woody plants for the period 2001–2018 in comparison with the data published for the same taxa by Wolf for the period 1886–1916.

We have analysed changes in air temperature over the 132-year period 1886–2018, with an assessment of the possible impact of such changes on the performance of woody plants from the introduced and local dendroflora. Data from the St. Petersburg Center for Hydrometeorology and Environmental Monitoring were used.

According to the results of long-term tests, the species belonged to one or another group of frost resistance according to Wolf's scale (1917) explained in the introduction of the current

paper. Wolf's scale of plant performance was based predominantly on winter hardiness. However, in the current situation of climate change this scale also could be used while evaluating general performance of plants in the current climate, not necessarily only their resistance to frost. Nowadays, Wolf's scale could be modified to a similar scale: I – completely tolerant plant that does not suffer from current climatic conditions; II – tolerant plant under current conditions; III – less tolerant plant, but still acceptable for cultivation; IV – surviving plant; V – plant that is completely unsuitable for cultivation, extremely short-lived or dying in the very first year of introduction.

Results and discussion

The climate of St. Petersburg during Wolf's time was colder than now (Meleshko *et al*., 2010; Firsov, 2014), particularly for 1892 and 1893 with February temperatures of –17°C, December 1907 (–13.3^{o}C) and December 1913 (–13.2^{o}C). Average annual air temperature for the period 1886–1916 according to the data of the St. Petersburg weather station was 4.1^{o}C while in the first 18 years of the 21st Century it was 6.4^{o}C. An increase of 2.3^{o}C is very significant, it roughly corresponds to an increase in the growing season of 4 weeks (Fadeeva and Firsov, 2010). Climate warming in St. Petersburg became noticeable from 1972 with a sharp increase from 1988–1989. The temperatures in May, June and July 1988 were higher than average long-term values: in May and June by 2.1^{o}C, and in July by 2.5^{o}C, which caused phenological anomalies. According to the indicators of the nature calendar, they became obvious starting from the first phenological stage in the early summer of 1988. Climate warming increased after the abnormally warm winter of 2006–2007. The winter of 2013–2014 was the shortest (only 29 days) of the entire observation period with an average temperature in December 2013 above zero (0.9^{o}C) and February 2014 (0.0^{o}C) being the warmest February in the entire period. The temperatures in March 2007 (3.7^{o}C), July 2010 (24.4^{o}C), November 2013 (4.4^{o}C) and December 2006 (3.0^{o}C) were record-breaking for the entire period of observations since 1752 and the average annual air temperature in 2015 was a record for the observation period (7.7^{o}C). Such changes in atmospheric temperature could not but affect the performance of introduced woody plants. Therefore, it seemed relevant to us to compare the winter tolerance and reproductive state of the same species under modern conditions as those used during the introduction tests of E.L. Wolf.

Table 1 shows the data on the performance of the same species of woody plants cultivated in St. Petersburg from 1886 to 2018. Comparison of performance over 132 years in

St. Petersburg were made for 629 species from 173 genera of 68 families, according to Wolf (1917) and 593 species and infraspecific taxa from 164 genera of 61 families, according to current taxonomy (APG IV, 2016; WCVP, 2020) listed in Tables 1 and 2.

Plants for which such comparison was possible are arranged in three categories: (1) plants whose performance is unchanged in the current climate; (2) plants that perform better in the current climate than in Wolf's time; (3) plants that are less able to cope with the current climate (Table 1).

Table 1. Comparison of tolerance and reproductive state of woody plants in St. Petersburg at the time of E.L. Wolf (1886–1916) and in the 21st Century (2001–2018).

Explanation: column 1 – plant names as given by Wolf (1917) with currently accepted names in bold and names of families (*families still under review in WCVP, 2020; †taxa that appear in two groups because of change their taxonomy); column 2 – the group of winter hardiness and the reproductive state according to Wolf (1917); column 3 – performance according to our modified scale (see Material and methods). Fr. – plants bear fruits; Fl. – only flowers, Veg. – in a vegetative state. All Figures mentioned in Table 1 are included in the Appendix.

1	2	3
Plant names	1886–1916	2001–2018
(1) Plants whose performance is unchanged in the current climate		
Abies balsamea (L.) Mill. (Pinaceae)	I, Fr	I, Fr
Abies sibirica Ledeb. (Pinaceae) [Fig. 4]	I, Fr	I, Fr
Acanthopanax divaricatus (Siebold & Zucc.) Seem. ≡ ***Eleutherococcus divaricatus*** (Siebold & Zucc.) S.Y.Hu (Araliaceae)	II, Fl	II, Fr
Acanthopanax sessiliflorus (Rupr. & Maxim.) Seem. ≡ ***Eleutherococcus sessiliflorus*** (Rupr. & Max.) S.Y.Hu (Araliaceae)	I, Fr	I, Fr
Acer platanoides L. (Sapindaceae*)	I, Fr	I,Fr
Acer rubrum L. † (Sapindaceae*) [Fig. 5]	I, Fl	I, Fr
Acer spicatum Lam. (Sapindaceae*)	I, Fr	I,Fr
Acer tataricum L. (Sapindaceae*) [Fig. 6]	I, Fr	I,Fr
Actinidia kolomikta (Maxim.) Maxim. (Actinidaceae*) [Fig. 7]	I, Fr	I,Fr
Alnus glutinosa (L.) Gaertn. (Betulaceae)	I, Fr	I, Fr
Alnus hirsuta (Spach) Turcz. ex Rupr. (Betulaceae) [Fig. 8]	I, Veg	I, Fr
Alnus incana (L.) Moench † (Betulaceae)	I, Fr	I, Fr

Amelanchier florida Lindl. = ***Amelanchier alnifolia*** (Nutt.) Nutt. ex M.Roem. var. ***semi-integrifolia*** (Hook.) C.L.Hitchc. (Rosaceae*)	I, Fr	I, Fr
Amelanchier spicata (Lam.) K.Koch (Rosaceae*)	I, Fr	I, Fr
Amygdalus nana L. = ***Prunus tenella*** Batsch (Rosaceae*) [Fig. 9]	I-II, Fr	I-II, Fr
Atragene speciosa Weinm. = ***Clematis alpina*** (L.) Mill. subsp. ***sibirica*** (L.) Kuntze (Ranunculaceae*) [Fig. 10]	I, Fr	I, Fr
Berberis amurensis Rupr. (Berberidaceae*) [Fig. 11]	I, Fr	I, Fr
Berberis sphaerocarpa Kar. & Kir. = ***Berberis heteropoda*** Schrenk (Berberidaceae*) [Fig. 12]	II, Fr	II, Fr
Berberis vulgaris L. (Berberidaceae*)	I, Fr	I, Fr
Betula davurica Pall. (Betulaceae) [Fig. 13]	I, Fr	I, Fr
Betula ermanii Cham. (Betulaceae)	I, Fr	I, Fr
Betula humilis Schrank (Betulaceae)	I, Fr	I, Fr
Betula × kusmisscheffii (Regel) Sukacz. ≡ ***Betula pubescens*** Ehrh. nothovar. ***kusmisscheffii*** (Regel) Gürke (Betulaceae) [Fig. 14]	I, Veg	I, Fr
Betula papyrifera Marshall (Betulaceae) [Fig. 15]	I, Fr	I, Fr
Betula pendula Roth (Betulaceae)	I, Fr	I, Fr
Betula pubescens Ehrh. (Betulaceae)	I, Fr	I, Fr
Betula pumila L. (Betulaceae)	I, Fr	I, Fr
Bruckenthalia spiculifolia (Salisb.) Rchb. ≡ ***Erica spiculifolia*** Salisb. (Ericaceae*)	I, Fr	I, Fr
Buxus sempervirens L. (Buxaceae*) [Fig. 16]	II, Veg	II, Fr
Calluna vulgaris (L.) Hull (Ericaceae*)	I, Fr	I, Fr
Calocedrus decurrens (Torr.) Florin (Cupressaceae)	V	V
Caragana arborescens Lam. (Fabaceae*) [Fig. 17]	I, Fr	I, Fr
Caragana frutex (L.) K.Koch (Fabaceae*) [Fig. 18]	I, Fr	I, Fr
Caragana pygmaea (L.) DC. (Fabaceae*) [Fig. 19]	I, Fr	I, Fr
Carpinus caroliniana Walter (Betulaceae)	II-III, Fr	II-III, Fr
Castanea sativa Mill. (Fagaceae)	IV, Veg	IV, Veg
Chamaedaphne calyculata (L.) Moench (Ericaceae*)	I, Fr	I, Fr
Chionanthus virginicus L. (Oleaceae)	II-III, Fl	II-III, Fr
Clematis serratifolia Rehder (Ranunculaceae*)	I-II, Fl	I-II, Fr
Clerodendrum trichotomum Thunb. (Lamiaceae)	V	V
Colutea orientalis Mill. (Fabaceae*) [Fig. 20]	III-IV, Fr	III-IV, Fr

Corylus avellana L. (Betulaceae)	I, Fr	I, Fr
Corylus cornuta Marsh. (Betulaceae)	I, Fr	I, Fr
Corylus mandshurica Maxim. ≡ ***Corylus sieboldiana*** Blume var. ***mandshurica*** (Maxim.) C.K.Schneid. (Betulaceae) [Fig. 21]	I, Fl	I, Fr
Cotoneaster ignavus E.L.Wolf (Rosaceae*) [Fig. 22]	I, Fr	I, Fr
Cotoneaster integerrimus Medik. (Rosaceae*)	I, Fr	I, Fr
Cotoneaster lucidus Schlecht. = ***Cotoneaster acutifolius*** Turcz. (Rosaceae*) [Fig. 23]	I, Fr	I, Fr
Cotoneaster melanocarpus Fisch. ex Blytt = ***Cotoneaster laxiflorus*** J.Jacq. ex Lindl. (Rosaceae*)	I, Fr	I, Fr
Cotoneaster racemiflorus (Desf.) K.Koch (Rosaceae*) [Fig. 24]	II, Fr	II, Fr
Cotoneaster tomentosus (Aiton) Lindl. (Rosaceae*)	I, Fr	I, Fr
Cotoneaster uniflorus Bunge (Rosaceae*)	I, Fr	I, Fr
Crataegus chlorocarpa Lenné & K.Koch (Rosaceae*)	I, Fr	I, Fr
Crataegus chlorosarca Maxim. (Rosaceae*)	I, Fr	I, Fr
Crataegus douglasii Lindl. (Rosaceae*)	I, Fr	I, Fr
Crataegus flabellata (Bosc ex Spach) K.Koch (Rosaceae*)	I, Fr	I, Fr
Crataegus holmesiana Ashe (Rosaceae*)	I, Fr	I, Fr
Crataegus horrida Medik. = ***Crataegus chrysocarpa*** Ashe (Rosaceae*)	I, Fr	I, Fr
Crataegus jackii Sarg. = ***Crataegus lumaria*** Ashe (Rosaceae*)	I, Fr	I, Fr
Crataegus korolkowii L.Henry = ***Crataegus altaica*** (Loudon) Lange (Rosaceae*) [Fig. 25]	I, Fr	I, Fr
Crataegus laurentiana Sarg. = ***Crataegus jonesae*** Sarg. (Rosaceae*)	I, Fr	I, Fr
Crataegus macracantha Lodd. ex Loudon (Rosaceae*)	I, Fr	I, Fr
Crataegus maximowiczii C.K.Schneid. (Rosaceae*) [Fig. 26]	I, Veg	I, Fr
Crataegus sanguinea Pall. (Rosaceae*)	I, Fr	I, Fr
Crataegus submollis Sarg. (Rosaceae*)	I, Fr	I, Fr
Diervilla rivularis Gatt. (Caprifoliaceae*)	II, Fr	II, Fr
Duschekia alnobetula (Ehrh.) Pouzar ≡ ***Alnus alnobetula*** (Ehrh.) K.Koch (Betulaceae)	I, Fr	I, Fr
Duschekia fruticosa (Rupr.) Pouzar ≡ ***Alnus alnobetula*** (Ehrh.) K.Koch subsp. ***fruticosa*** (Rupr.) Raus (Betulaceae) [Fig. 27]	I, Veg	I, Fr
Elaeagnus commutata Bernh. ex Rydb. (Elaeagnaceae*)	I, Fr	I, Fr
Eleutherococcus senticosus (Rupr. & Maxim.) Maxim. (Araliaceae) [Fig. 28]	I, Fr	I, Fr
Eucommia ulmoides Oliv. (Eucommiaceae)	V	V

Euonymus europaeus L. (Celastraceae*)	I, Fr	I, Fr
Euonymus japonicus Thunb. (Celastraceae*)	V	V
Euonymus macropterus Rupr. (Celastraceae*)	I?, Veg	I, Fr
Euonymus verrucosus Scop. (Celastraceae*) [Fig. 29]	I, Fr	I, Fr
Frangula alnus Mill. (Rhamnaceae*)	I, Fr	I, Fr
Fraxinus excelsior L. (Oleaceae)	I, Fr	I, Fr
Fraxinus pennsylvanica Marshall (Oleaceae)	I, Fr	I, Fr
Grossularia divaricata (Douglas) Coville et Britton ≡ ***Ribes divaricatum*** Dougl. (Grossulariaceae*)	I, Fr	I, Fr
Grossularia reclinata (L.) Mill. = ***Ribes uva-crispa*** L. (Grossulariaceae*)	I, Fr	I, Fr
Hamamelis virginiana L. (Hamamelidaceae*)	II, Veg	II, Fr
Hippophae rhamnoides L. (Elaeagnaceae)	I, Fr	I, Fr
Holodiscus discolor (Pursh) Maxim. (Rosaceae*) [Fig. 30]	III, Fl	III, Fr
Hovenia dulcis Thunb. (Rhamnaceae*)	V	V
Hydrangea heteromalla D.Don (Hydrangeaceae*)	I, Fr	I, Fr
Idesia polycarpa Maxim. (Salicaceae*)	V	V
Ilex aquifolium L. (Aquifoliaceae*)	V	V
Juniperus communis L. † (Cupressaceae)	I, Fr	I, Fr
Juniperus horizontalis Moench (Cupressaceae)	I, Fr	I, Fl
Juniperus sabina L. (Cupressaceae) [Fig. 31]	I, Fr	I, Fr
Juniperus sibirica Burgsd. = ***Juniperus communis*** var. ***saxatilis*** Pall. † (Cupressaceae)	I, Fr	I, Fr
Kalmia angustifolia L. (Ericaceae*)	I, Veg	I, Fr
Koelreuteria paniculata Laxm. (Sapindaceae*)	V	V
Larix dahurica Laws. = ***Larix gmelinii*** (Rupr.) Kuzen. (Pinaceae) [Fig. 32]	I, Fr	I, Fr
Larix decidua Mill. (Pinaceae)	I, Fr	I, Fr
Larix kamtschatica (Rupr.) Carr.) = ***Larix gmelinii*** (Rupr.) Kuzen. (Pinaceae)	I, Fr	I, Fr
Larix laricina (Du Roi) K.Koch (Pinaceae)	I, Fr	I, Fr
Larix occidentalis Nutt. (Pinaceae)	I, Fr	I, Fr
Larix sibirica Ledeb. (Pinaceae)	I, Fr	I, Fr
Ledum palustre L. = ***Rhododendron tomentosum*** Harmaja (Ericaceae*)	I, Fr	I, Fr
Leptopus colchicus (Fisch. & C.A.Mey. ex Boiss.) Pojark. = ***Leptopus chinensis*** (Bunge) Pojark. (Phyllanthaceae) [Fig. 33]	II, Fr	II, Fr

Leycesteria formosa Wall. (Caprifoliaceae*)	V	V
Lonicera caerulea L. (Caprifoliaceae*)	I, Fr	I, Fr
Lonicera caprifolium L. (Caprifoliaceae*)	II-III, Fr	II-III, Fr
Lonicera chrysantha Turcz. ex Ledeb. (Caprifoliaceae*)	I, Fr	I, Fr
Lonicera dioica L. (Caprifoliaceae*)	I-II, Fr	I-II, Fr
Lonicera glaucescens Rydb. = ***Lonicera dioica*** L. (Caprifoliaceae*)	I-II, Fr	I-II, Fr
Lonicera maackii (Rupr.) Maxim. (Caprifoliaceae*)	I-II, Fr	I-II, Fr
Lonicera maximowiczii (Rupr.) Regel (Caprifoliaceae*)	I, Fr	I, Fr
Lonicera nigra L. (Caprifoliaceae*)	I, Fr	I, Fr
Lonicera × notha Zabel (Caprifoliaceae*)	I, Fr	I, Fr
Lonicera olgae Regel & Schmalh. (Caprifoliaceae*)	II? Veg	II, Fr
Lonicera prolifera (G.Kirchn.) Rehder = ***Lonicera reticulata*** Raf. (Caprifoliaceae*)	I-II, Fr	I-II, Fr
Lonicera ruprechtiana Regel (Caprifoliaceae*)	I, Fr	I, Fr
Lonicera tatarica L. (Caprifoliaceae*)	I, Fr	I, Fr
Lonicera xylosteum L. (Caprifoliaceae*)	I, Fr	I, Fr
Mahonia aquifolium (Pursh) Nutt. = ***Berberis aquifolium*** Pursh (Berberidaceae*)	I, Fr	I, Veg
Malus baccata (L.) Borkh. (Rosaceae*)	I, Fr	I, Fr
Malus prunifolia (Willd.) Borkh. (Rosaceae*)	I, Fr	I, Fr
Malus sylvestris Mill. (Rosaceae*)	I, Fr	I, Fr
Malus cerasifera Spach = ***Malus baccata*** (L.) Borkh. (Rosaceae*)	I, Fr	I, Fr
Menispermum dauricum DC. (Menispermaceae*)	II-III, Veg	II-III, Fl
Menziesia ferruginea Sm. = ***Rhododendron menziesii*** Craven (Ericaceae*)	I, Fr	I, Fr
Mespilus germanica L. ≡ ***Crataegus germanica*** (L.) Kuntze (Rosaceae*)	II-III, Fr	II-III, Fr
Morus alba L. (Moraceae*)	III, Fr	III, Fr
Myrica gale L. † (Myricaceae*)	I, Fr	I, Fr
Ostrya virginiana (Mill.) K.Koch (Betulaceae)	I-II, Veg	I-II, Fr
Padus avium Mill. ≡ ***Prunus padus*** L. (Rosaceae*)	I, Fr	I, Fr
Padus maackii (Rupr.) Kom. & Aliss. ≡ ***Prunus maackii*** Rupr. (Rosaceae*)	I, Fr	I, Fr
Padus virginiana (L.) Mill. ≡ ***Prunus viginiana*** L. (Rosaceae*)	I, Fr	I, Fr
Pentaphylloides fruticosa (L.) O.Schwarz ≡ ***Dasiphora fruticosa*** (L.) Rydb. (Rosaceae*)	I, Fr	I, Fr

Pentaphylloides glabrata (Willd. ex Schlecht.) O.Schwarz ≡ ***Dasiphora glabrata*** (Willd. ex Schlecht.) Soják (Rosaceae*)	I, Fr	I, Fr
Pentaphylloides × *friedrichsenii* (Späth ex C.K.Schneid.) Soják = ?***Dasiphora fruticosa*** (L.) Rydb. (Rosaceae*)	I, Fr	I, Fr
Philadelphus coronarius L. (Hydrangeaceae*)	I, Fr	I, Fr
Philadelphus incanus Koehne (Hydrangeaceae*)	II, Fr	II, Fr
Philadelphus lewisii Pursh † (Hydrangeaceae*)	I-II, Fr	I-II, Fr
Philadelphus satsumi Siebold ex Lindl. & Paxton (Hydrangeaceae*)	II, Fr	II, Fr
Philadelphus schrenkii Rupr. (Hydrangeaceae*)	I, Fr	I, Fr
Philadelphus tenuifolius Rupr. & Maxim. (Hydrangeaceae*)	I, Fr	I, Fr
Physocarpus amurensis (Maxim.) Maxim. (Rosaceae*)	I, Fr	I, Fr
Physocarpus opulifolius (L.) Maxim. (Rosaceae*)	I, Fr	I, Fr
Picea abies (L.) Karst. (Pinaceae)	I, Fr	I, Fr
Picea engelmannii Parry ex Engelm.	I, Fr	I, Fr
Picea glauca (Moench) Voss = ***Picea laxa*** (Münchh.) Sarg. (Pinaceae)	I, Fr	I, Fr
Picea jezoensis (Siebold & Zucc.) Carrière (Pinaceae)	I, Veg	I, Fr
Picea obovata Ledeb. (Pinaceae)	I, Fr	I, Fr
Picea omorika (Pancic) Purk. (Pinaceae)	I, Fr	I, Fr
Picea pungens Engelm. (Pinaceae)	I, Fr	I, Fr
Pinus banksiana Lamb. (Pinaceae)	I, Fr	I, Fr
Pinus cembra L. (Pinaceae)	I, Fr	I, Fr
Pinus mugo Turra (Pinaceae)	I, Fr	I, Fr
Pinus peuce Griseb. (Pinaceae)	I, Fr	I, Fr
Pinus pumila (Pall.) Regel (Pinaceae)	I, Fr	I, Fr
Pinus resinosa Aiton (Pinaceae)	I, Fr	I, Fr
Pinus sibirica Du Tour (Pinaceae)	I, Fr	I, Fr
Pinus strobus L. (Pinaceae)	I, Fr	I, Fr
Pinus sylvestris L. (Pinaceae)	I, Fr	I, Fr
Pinus uncinata Ramond ex DC. (Pinaceae)	I, Fr	I, Fr
Populus alba L. (Salicaceae*)	I, Fl	I, Fr
Populus laurifolia Ledeb. (Salicaceae*)	I, Fl	I, Fr
Populus maximowiczii A.Henry = ***Populus suaveolens*** Fisch. ex Poit. & A.Vilm. (Salicaceae*)	I, Veg	I, Veg

Populus nigra L. (Salicaceae*)	I, Fl	I, Fr
Populus tremula L. (Salicaceae*)	I, Fr	I, Fr
Prunus spinosa L. (Rosaceae)	I-II, Fl	I-II, Fr
Quercus robur L. (Fagaceae)	I, Fr	I, Fr
Rhamnus cathartica L. (Rhamnaceae*)	I, Fr	I, Fr
Rhamnus japonica Maxim. (Rhamnaceae*)	I, Fr	I, Fr
Rhododendron aureum Georgi (Ericaceae*)	I, Fr	I, Fr
Rhododendron brachycarpum D.Don ex G.Don (Ericaceae*)	I, Fr	I, Fr
Rhododendron camtschaticum Pall. (Ericaceae*)	I, Fr	I, Fr
Rhododendron caucasicum Pall. (Ericaceae*)	I, Fr	I, Fr
Rhododendron ferrugineum L. (Ericaceae*)	I, Fr	I, Fr
Rhododendron hirsutum L. (Ericaceae*)	I, Fr	I, Fr
Rhododendron luteum Sweet (Ericaceae*)	I, Fr	I, Fr
Rhododendron occidentale (Torr. & Gray) Gray (Ericaceae*)	III, Fl	III, Fr
Rhododendron parvifolium Adams (Ericaceae*)	I, Fr	I, Fr
Ribes atropurpureum C.A.Mey. (Grossulariaceae*)	I, Fr	I, Veg
Ribes aureum Pursh (Grossulariaceae*)	I, Fr	I, Fr
Ribes biebersteinii Berland. ex DC. (Grossulariaceae*)	I, Fr	I, Fr
Ribes mandshuricum (Maxim.) Kom. (Grossulariaceae*)	I, Fr	I, Fr
Ribes maximoviczianum Kom. (Grossulariaceae*)	I, Fl	I, Fr
Ribes nigrum L. (Grossulariaceae*)	I, Fr	I, Fr
Ribes rubrum L. (Grossulariaceae*)	I, Fr	I, Fr
Ribes scandicum Hedl. = ***Ribes spicatum*** E.Robson (Grossulariaceae*)	I, Fr	I, Fr
Ribes spicatum E.Robson (Grossulariaceae*)	I,Veg	I, Fr
Ribes triste Pall. (Grossulariaceae*)	I, Veg	I, Fl
Rosa acicularis Lindl. (Rosaceae*)	I, Fr	I, Fr
Rosa amblyotis C.A.Mey. = ***Rosa davurica*** Pall. (Rosaceae*)	I, Fr	I, Fr
Rosa davurica Pall. (Rosaceae*)	I, Fr	I, Fr
Rosa glauca Pourr. (Rosaceae*)	I, Fr	I, Fr
Rosa majalis Herrm. (Rosaceae*)	I, Fr	I, Fr
Rosa pimpinellifolia L. = ***Rosa spinosissima*** L. (Rosaceae*)	I, Fr	I, Fr

Rosa rugosa Thunb. (Rosaceae*)	I, Fr	I, Fr
Rosa* × *gorenkensis Bess. (Rosaceae*)	I, Fr	I, Fr
Rosa kamtchatica Vent. = ***Rosa rugosa*** Thunb. (Rosaceae*)	I, Fr	I, Fr
Rubus idaeus L. (Rosaceae*)	I, Fr	I, Fr
Rubus phoenicolasius Maxim. (Rosaceae*)	II-III, Fr	II-III, Fr
Salix acutifolia Willd. (Salicaceae*)	I, Fl	I, Fl
Salix alba L. (Salicaceae*)	I, Fl	I, Fr
Salix caprea L. (Salicaceae*)	I, Fl	I, Fr
Salix cinerea L. (Salicaceae*)	I, Fl	I, Fr
Salix × *fragilis* auct., non L. = ***Salix euxina*** I.V.Belyaeva (Salicaceae*)	I, Fl	I, Fr
Salix myrsinifolia Salisb. (Salicaceae*)	I, Fl	I, Fr
Salix pseudomedemii E.L.Wolf (Salicaceae*)	II, Fl	II, Fl
Salix repens L. (Salicaceae*)	I, Fl	I, Fr
Salix rorida Laksch. (Salicaceae*)	I-II, Fl	I-II, Fl
Salix rosmarinifolia L. (Salicaceae*)	I-II, Fl	I-II, Fl
Sambucus canadensis L. (Viburnaceae*)	II-III, Fr	II-III, Fr
Sambucus nigra L. (Viburnaceae*)	II, Fr	II, Fr
Sambucus pubens Michx. ≡ ***Sambucus racemosa*** L. subsp. ***pubens*** (Michx.) Hultén (Viburnaceae*)	I-II, Fr	I-II, Fr
Schisandra chinensis (Turcz.) Baill. (Schisandraceae)	II, Fr	II, Fr
Shepherdia argentea (Pursh) Nutt. (Elaeagnaceae*)	I, Fl	I, Fl
Sibiraea laevigata (L.) Maxim. (Rosaceae*)	I, Fr	I, Fl
Sorbaria sorbifolia (L.) A.Braun (Rosaceae*)	I, Fr	I, Fr
Sorbus aucuparia L. (Rosaceae*)	I, Fr	I, Fr
Sorbus aucuparia L. subsp. *amurensis* (Koehne) Nedoluzhko = ***Sorbus aucuparia*** L. **subsp. *pohuashanensis*** (Hance) McAll. (Rosaceae*)	I, Fr	I, Fr
Sorbus hybrida (L.) L. ≡ ***Hedlundia hybrida*** (L.) Sennikov & Kurtto (Rosaceae*)	I, Fr	I, Fr
Sorbus intermedia (Ehrh.) Pers. ≡ ***Scandosorbus intermedia*** (Ehrh.) Sennikov (Rosaceae*)	I, Fr	I, Fr
Sorbus matsumurana (Makino) Koehne (Rosaceae*)	I, Fr	I, Fr
Sorbus reflexipetala Koehne = ***Sorbus commixta*** Hedl. † (Rosaceae*)	I, Veg	I, Fr
Sorbus sambucifolia (Cham. & Schltdl.) M.Roem. (Rosaceae*)	I, Veg	I, Fr
Sorbus* × *splendida Hedl. (Rosaceae*)	I, Fr	I, Fr

Spiraea betulifolia Pall. (Rosaceae*)	I-II, Fr	I-II, Fr
Spiraea chamaedryfolia L. (Rosaceae*)	I, Fr	I, Fr
Spiraea crenata L. (Rosaceae*)	I-II, Fr	I-II, Fr
Spiraea douglasii Hook. (Rosaceae*)	I-II, Fr	I-II, Fr
Spiraea hypericifolia L. (Rosaceae*)	I-II, Fr	I-II, Fr
Spiraea latifolia (Aiton) Borkh. ≡ ***Spiraea alba*** Du Roi **var. *latifolia*** (Aiton) Dippel †(Rosaceae*)	I, Fr	I, Fr
Spiraea media Schmidt (Rosaceae*)	I, Fr	I, Fr
Spiraea salicifolia L. (Rosaceae*)	I, Fr	I, Fr
Spiraea × billardii Hérincq (Rosaceae*)	I-II, Fr	I-II, Fr
Staphylea colchica Steven (Staphyleaceae*)	IV-V, Veg	IV-V, Veg
Stephanandra incisa (Thunb.) Zabel ≡ ***Neillia incisa*** (Thunb.) S.H.Oh (Rosaceae*)	II-III, Fl	II-III, Fr
Swida alba (L.) Opiz ≡ ***Cornus alba*** L. (Cornaceae)	I, Fr	I, Fr
Swida sericea (L.) Holub ≡ ***Cornus sericea*** L. (Cornaceae)	I, Fr	I, Fr
Symphoricarpos occidentalis (R.Br.) Hook. (Caprifoliaceae*)	II, Fl	II, Fr
Syringa amurensis Rupr. ≡ ***Syringa reticulata*** (Blume) H.Hara subsp. ***amurensis*** (Rupr.) P.S.Green & M.C.Chang (Oleaceae)	II, Fl	II, Fr
Syringa josikaea Jack. ex Rchb. (Oleaceae)	I, Fr	I, Fr
Syringa villosa Vahl (Oleaceae)	I, Fr	I, Fr
Syringa vulgaris L. (Oleaceae)	I, Fr	I, Fr
Syringa wolfii C.K.Schneid. ≡ ***Syringa villosa*** Vahl subsp. ***wolfii*** (C.K.Schneid.) Jin Y.Chen & D.Y.Hong (Oleaceae)	I, Fr	I, Fr
Taxus brevifolia Nutt. (Taxaceae)	II, Veg	II, Fr
Taxus canadensis Marshall (Taxaceae)	I-II, Fr	I-II, Fr
Thuja occidentalis L. (Cupressaceae)	I, Fr	I, Fr
Tilia amurensis Rupr. (Malvaceae*)	I, Veg	I, Fr
Tilia cordata Mill. (Malvaceae*)	I, Fr	I, Fr
Tilia × europaea L. (Malvaceae*)	I, Fr	I, Fr
Toxicodendron radicans (L.) Kuntze (Anacardiaceae*)	I-II, Fl	I-II, Fr
Ulmus glabra Huds. (Ulmaceae*)	I, Fr	I, Fr
Ulmus laevis Pall. (Ulmaceae*)	I, Fr	I, Fr
Viburnum lantana L. (Viburnaceae*)	I, Fr	I, Fr
Viburnum lentago L. (Viburnaceae*)	I, Fr	I, Fr

Weigela middendorffiana (Carrière) K.Koch (Caprifoliaceae*)	I-II, Fr	I-II, Fr
(2) Plants that perform better in the current climate than in Wolf's time		
Abies alba Mill. (Pinaceae) [Fig. 34]	III-IV, Veg	I, Fr
Abies amabilis (Dougl. ex Loudon) J.Forbes (Pinaceae)	IV-V, Veg	I, Veg
Abies arizonica Merr. ≡ ***Abies lasiocarpa*** (Hook.) Nutt. var. ***arizonica*** (Merriam) Lemmon (Pinaceae)	III-IV, Veg	I, Veg
Abies cephalonica Loudon (Pinaceae)	IV, Veg	II-III, Veg
Abies concolor (Gordon & Glend.) Lindl. ex Hildebr. (Pinaceae)	II-III, Veg	I, Fr
Abies firma Siebold & Zucc. (Pinaceae)	V	II, Veg
Abies fraseri (Pursh) Poir. (Pinaceae)	III-IV Veg	I, Fr
Abies grandis (Douglas ex D.Don) Lindl. (Pinaceae)	IV, Veg	II-III, Veg
Abies holophylla Maxim. (Pinaceae) [Fig. 35]	II?, Veg	I, Fr
Abies homolepis Siebold & Zucc. (Pinaceae)	IV-V?, Veg	I, Veg
Abies lasiocarpa (Hook.) Nutt. (Pinaceae)	III-IV, Veg	I, Fr
Abies mariesii Mast. (Pinaceae)	V	IV, Veg
Abies nephrolepis (Trautv.) Maxim. (Pinaceae)	I-II, Fr	I, Fr
Abies nordmanniana (Steven) Spach (Pinaceae)	III-IV, Veg	II-III, Veg
Abies procera Rehder (Pinaceae)	IV, Veg	I, Veg
Abies sachalinensis (F.Schmidt) Mast. (Pinaceae)	II-III, Veg	I, Fr
Abies veitchii Lindl. (Pinaceae)	II-III, Veg	I, Fr
Acer barbinerve Maxim. (Sapindaceae*) [Fig. 36]	II, Fr	I, Fr
Acer buergerianum Miq. (Sapindaceae*)	V	III, Veg
Acer campestre L. (Sapindaceae*)	II, Fr	I, Fr
Acer cappadocicum Gled. (Sapindaceae*)	IV, Veg	I, Fr
Acer carpinifolium Siebold & Zucc. (Sapindaceae*) [Fig. 37]	IV, Veg	II-III, Veg
Acer cissifolium (Siebold & Zucc.) K.Koch (Sapindaceae*)	IV, Veg	I, Fr
Acer ginnala Maxim. (Sapindaceae*) ≡ ***Acer tataricum*** subsp. ***ginnala*** (Maxim.) Wesmael	I-II, Fr	I, Fr
Acer glabrum Torr. (Sapindaceae*)	III, Fr	I, Fr
Acer hyrcanum Fisch. & C.A.Mey. (Sapindaceae*)	IV, Veg	I, Fr
Acer mandshuricum Maxim. (Sapindaceae*) [Fig. 38]	II, Fr	I, Fr

Acer miyabei Maxim. (Sapindaceae*)	II, Veg	I, Fr
Acer mono Maxim. ≡ ***Acer pictum*** Thung. subsp. ***mono*** (Maxim.) H.Ohashi (Sapindaceae*)	II-IV, Fr	I, Fr
Acer monspessulanum L. (Sapindaceae*)	IV, Veg	II, Veg
Acer negundo L. (Sapindaceae*)	II, Fr	I, Fr
Acer opalus Mill. (Sapindaceae*)	IV, Veg	III, Fr
Acer palmatum Thunb. (Sapindaceae*)	V	II, Fr
Acer pensylvanicum L. (Sapindaceae*)	II, Veg	I, Fl
Acer pseudoplatanus L. (Sapindaceae*)	II, Fr	I,Fr
Acer pseudosieboldianum (Pax) Kom. (Sapindaceae*)	IV, Veg	I, Fr
Acer rubrum L. var. *drummondii* (Hook. & Arn. ex Nutt.) Sarg. = ***Acer rubrum*** L. † (Sapindaceae*)	IV, Veg	I, Fr
Acer saccharinum L. (Sapindaceae*)	II, Fl	I, Fr
Acer saccharum Marshall (Sapindaceae*)	II, Veg	I, Fr
Acer saccharum Marshall subsp. ***nigrum*** (F.Michx.) Desmarais (Sapindaceae*)	IV, Veg	I, Fr
Acer tegmentosum Maxim. (Sapindaceae*)	II, Fr	I, Fr
Acer trautvetteri Medw. ≡ ***Acer heldreichii*** subsp. ***trautvetteri*** (Medw.) A.E.Murray (Sapindaceae*)	III-IV, Veg	II, Fr
Acer triflorum Kom. (Sapindaceae*)	V?	II, Fr
Acer ukurunduense Trautv. & C.A.Mey. (Sapindaceae*)	II, Fr	I, Fr
Acer velutinum Boiss. (Sapindaceae*)	V	I, Fr
Actinidia arguta (Siebold & Zucc.) Planch. ex Miq. (Actinidiaceae*)	III, Veg	II-III, Fr
Actinidia polygama (Siebold & Zucc.) Planch. ex Miq. (Actinidiaceae*) [Fig. 39]	III-IV, Veg	II, Fr
Aesculus glabra Willd. (Sapindaceae*)	I-II, Fr	I, Fr
Aesculus hippocastanum L. (Sapindaceae*)	II, Fr	I, Fr
Aesculus octandra Marshall = ***Aesculus flava*** Sol. (Sapindaceae*)	II, Fr	I, Fr
Ailanthus altissima (Mill.) Swingle (Simaroubaceae*) [Fig. 40]	V	III, Fr
Akebia quinata (Houtt.) Decne. (Lardizabalaceae) [Fig. 41]	V	III, Fl
Amelanchier asiatica (Siebold & Zucc.) Endl. ex Walp. (Rosaceae*)	IV-V, Veg	I, Fr
Amelanchier utahensis Koehne (Rosaceae*)	II-III, Fr	I, Fr
Amorpha fruticosa L. (Fabaceae*)	IV, Veg	III (IV), Fr
Ampelopsis aconitifolia Bunge (Vitaceae*) [Fig. 42]	V	III, Fl
Aralia elata (Miq.) Seem. (Araliaceae) [Fig. 43]	II, Fl	I, Veg

Aristolochia macrophylla Lam. (Aristolochiaceae*)	II, Fl	I, Fr
Aristolochia manshuriensis Kom. (Aristolochiaceae*) [Fig. 44]	II-III, Veg	I, Fr
Armeniaca mandshurica (Maxim.) Skvortzov ≡ ***Prunus manshurica*** (Maxim.) Koehne (Rosaceae*)	IV-V, Veg	II-III, Fr
Armeniaca vulgaris Lam. ≡ ***Prunus armeniaca*** L. (Rosaceae*)	V	III, Fl
Aronia arbutifolia (L.) Pers. (Rosaceae*)	III, Veg	I, Fr
Berberis integerrima Bunge (Berberidaceae*)	III, Fr	II (III), Fr
Berberis koreana Palib. (Berberidaceae*) [Fig. 45]	II-III, Veg	I, Fr
Berberis sibirica Pall. (Berberidaceae*) [Fig. 46]	III, Fr	I, Fr
Berberis thunbergii DC. (Berberidaceae*)	I-II, Fr	I, Fr
Betula medwediewii Regel (Betulaceae)	II-III, Fr	I, Fr
Betula occidentalis Hook. (Betulaceae)	I-II, Veg	I, Fr
Betula populifolia Marshall (Betulaceae)	I-II, Veg	I, Fr
Buxus sinica (Rehder & E.H.Wilson) M.Cheng (Buxaceae*)	II?, Veg	I, Fr
Calycanthus floridus L. (Calycanthaceae)	V (IV), Fl	II, Fl
Campsis radicans (L.) Bureau (Bignoniaceae)	V	IV, Veg
Caragana jubata (Pall.) Poir. (Fabaceae*)	I-II, Fr	I, Fr
Carpinus betulus L. (Betulaceae) [Fig. 47]	II-III, Fr	I, Fr
Carpinus cordata Blume (Betulaceae) [Fig. 48]	III (II), Veg	I (II), Fr
Carpinus japonica Blume (Betulaceae)	V	II-III, Fr
Carpinus orientalis Mill. (Betulaceae)	V	II, Fr
Carya cordiformis (Wangenh.) K.Koch (Juglandaceae*)	V	I, Fr
Carya ovata (Mill.) K.Koch (Juglandaceae*) [Fig. 49]	IV-V, Veg	I, Fr
Catalpa ovata G.Don (Bignoniaceae)	V	III, Fr
Catalpa speciosa Teas (Bignoniaceae) [Fig. 50]	V	II, Fr
Celastrus orbiculatus Thunb. (Celastraceae*) [Fig. 51]	IV, Veg	II, Fr
Celtis australis L. (Cannabaceae*)	V	III-IV, Veg
Celtis occidentalis L. (Cannabaceae*)	V	II (III), Veg
Cephalanthus occidentalis L. (Rubiaceae)	III-IV, Fl	III, Fl
Cerasus avium (L.) Moench. ≡ ***Prunus avium*** L. (Rosaceae*)	III, Fr	I, Fr
Cerasus fruticosa (Pall.) Woronow ≡ ***Prunus fruticosa*** Pall. (Rosaceae*)	I-II, Fr	I, Fr
Cerasus glandulosa (Thunb.) Loisel. ≡ ***Prunus glandulosa*** Thunb. (Rosaceae*)	IV-V, Veg	III, Fl

Cerasus maximowiczii (Rupr.) Kom. & Klob. ≡ ***Prunus maximowiczii*** Rupr. (Rosaceae*) [Fig. 52]	II, Fr	I, Fr
Cerasus sachalinensis (F.Schmidt) Kom. = ***Prunus sargentii*** Rehder (Rosaceae*)	III-IV, Veg	I, Fr
Cerasus tomentosa (Thunb.) Masam. & S.Suzuki ≡ ***Prunus tomentosa*** Thunb. (Rosaceae*)	III, Fl	I, Fr
Cerasus vulgaris Mill. = ***Prunus cerasus*** L. (Rosaceae*)	II, Fr	I, Fr
Cercidiphyllum japonicum Siebold & Zucc. ex J.J.Hoffm. & J.H.Schult.bis (Cercidiphyllaceae)	II-III, Veg	I, Fr
Chaenomeles cathayensis (Hemsl.) C.K.Schneid. (Rosaceae*)	V	IV, Veg
Chaenomeles japonica (Thunb.) Lindl. ex Spach (Rosaceae*)	II-III, Fr	II, Fr
Chamaecyparis lawsoniana (A.Murray) Parl. (Cupressaceae)	IV-V, Veg	III, Fr
Chamaecyparis pisifera (Siebold & Zucc.) Endl. (Cupressaceae)	II-III, Veg	I, Fr
Cladrastis kentukea (Dum.Cours.) Rudd (Fabaceae*)	II, Veg	I, Fr
Clematis vitalba L. (Ranunculaceae*)	III-IV, Veg	II, Fr
Cornus mas L. (Cornaceae)	III-IV, Fl	III, Fr
Corylus colurna L. (Betulaceae) [Fig. 53]	II-III, Veg	I, Fr
Corylus heterophylla Fisch. ex Trautv. (Betulaceae)	II, Veg	I, Fr
Corylus maxima Mill. (Betulaceae)	IV, Veg	II, Fr
Corylus sieboldiana Blume (Betulaceae)	II, Veg	I, Fl
Cotinus coggygria Scop. (Anacardiaceae*)	V	II (III), Fr
Cotoneaster dammeri C.K.Schneid. (Rosaceae*) [Fig. 54]	III, Fr	I, Fr
Cotoneaster dielsianus E.Pritz. (Rosaceae*)	V	II-III, Fr
Crataegus crus-galli L. (Rosaceae*)	IV, Veg	I, Fr
Crataegus monogyna Jacq. (Rosaceae*)	I-II, Fr	I, Fr
Crataegus orientalis Pall. ex M.Bieb. (Rosaceae*)	III, Fr	I, Fr
Crataegus pinnatifida Bunge (Rosaceae*) [Fig. 55]	I-IV, Fr	I, Fr
Crataegus × persimilis Sarg. 'Prunifolia' (Rosaceae*)	I-III, Veg	I-II, Fr
Cryptomeria japonica (Thunb. ex L.f.) D.Don (Cupressaceae) [Fig. 56]	V	III-IV, Fr
Cydonia oblonga Mill. (Rosaceae*)	IV, Veg	II (III), Fr
Decaisnea fargesii Franch. (Lardizabalaceae)	V	IV, Fl
Deutzia amurensis (Regel) Airy-Shaw = ***Deutzia parviflora*** Bunge (Hydrangeaceae*)	III, Veg	I (II), Fr
Deutzia × lemoinei Lemoine (Hydrangeaceae*)	III, Fl	I, Fr
Duschekia firma (Siebold & Zucc.) Pouzar ≡ ***Alnus firma*** Siebold & Zucc. (Betulaceae)	IV, Veg	III, Fr
Eleutherococcus henryi Oliv. (Araliaceae)	V	II, Fr

Enkianthus cernuus (Siebold & Zucc.) Benth. & Hook. ex Makino (Ericaceae*)	V	II, Veg
Euonymus latifolius (L.) Mill. (Celastraceae*)	III, Fr	I, Veg
Euonymus maackii Rupr. (Celastraceae*)	II, Fr	I-II, Veg
Euonymus nanus M.Bieb. (Celastraceae*)	II-III, Fr	I, Fl
Euonymus planipes (Koehne) Koehne = ***Euonymus sachalinensis*** (F.Schmidt) Maxim. (Celastraceae*)	I-II? Veg	I, Fr
Euonymus sieboldianus Blume = ***Euonymus hamiltonianus*** Wall. (Celastraceae*)	III?, Veg	II, Fr
Fagus grandifolia Ehrh. (Fagaceae)	IV, Veg	I, Veg
Fagus orientalis Lipsky (Fagaceae) [Fig. 57]	III-IV, Veg	I (II), Fr
Fagus sylvatica L. (Fagaceae)	III-IV, Veg	I, Fr
Forsythia europaea Degen & Bald. (Oleaceae)	II, Fr	I (II), Fr
Forsythia viridissima Lindl. (Oleaceae)	V	I, Fr
Forsythia × intermedia Zabel (Oleaceae)	III-IV, Fl	II-III, Fr
Fraxinus americana L. (Oleaceae)	I-IV, Veg	I, Veg
Fraxinus latifolia Benth. (Oleaceae)	IV, Veg	II-III, Veg
Fraxinus mandshurica Rupr. (Oleaceae)	II-III, Veg	I, Fr
Fraxinus oxycarpa M.Bieb. ex Willd. ≡ ***Fraxinus angustifolia*** subsp. ***oxycarpa*** (M.Bieb. ex Willd.) Franco & Rocha Alfonso (Oleaceae)	IV, Veg	III-IV, Fr
Fraxinus quadrangulata Michx. (Oleaceae)	IV, Veg	II, Fr
Fraxinus rhynchophylla Hance ≡ ***Fraxinus chinensis* subsp. *rhynchophylla*** (Hance) A.E.Murray (Oleaceae) [Fig. 58]	V	I (II), Fr
Gaultheria procumbens L. (Ericaceae*)	III, Fl	I, Fr
Ginkgo biloba L. (Ginkgoaceae)	IV-V, Veg	II, Veg
Gleditsia triacanthos L. (Fabaceae*)	V	III-V, Veg
Grossularia stenocarpa (Maxim.) A.Berger ≡ ***Ribes stenocarpum*** Maxim. (Grossulariaceae*)	III, Fr	II, Fr
Gymnocladus dioicus (L.) K.Koch (Fabaceae*)	IV-V, Veg	IV, Veg
Hamamelis japonica Siebold & Zucc. (Hamamelidaceae*) [Fig. 59]	III, Veg	I, Fl
Hedera colchica (K.Koch) K.Koch (Araliaceae)	V	IV, Veg
Hedera helix L. (Araliaceae)	V	IV, Veg
Hydrangea arborescens L. (Hydrangeaceae*)	II-III, Fr	II, Fr
Hydrangea cinerea Small (Hydrangeaceae*)	III-IV, Veg	II, Fr
Hydrangea paniculata Siebold (Hydrangeaceae*)	II, Fr	I, Fr
Hypericum patulum Thunb. (Hypericaceae)	V	III, Veg
Iberis gibraltarica L. (Brassicaceae*)	V	III, Fr

Ilex verticillata (L.) A.Gray (Aquifoliaceae*)	II, Fl	I, Fr
Itea virginica L. (Iteaceae*)	IV-V, Veg	IV, Veg
Juglans ailanthifolia Carrière (Juglandaceae*) [Fig. 60]	III-IV, Veg	I, Fr
Juglans cinerea L. (Juglandaceae*)	I-II, Fr	I, Fr
Juglans cordiformis Maxim. = ***Juglands mandshurica*** Maxim. (Juglandaceae*)	II-III, Fr	I, Fr
Juglans mandshurica Maxim. (Juglandaceae*)	II-III, Fr	I, Fr
Juglans nigra L. (Juglandaceae*)	IV-V, Veg	I, Veg
Juglans regia L. (Juglandaceae*)	IV, Veg	I-III, Fr
Juniperus chinensis L. (Cupressaceae)	IV-V, Veg	I, Fr
Juniperus oblonga Bieb. = ***Juniperus communis*** L. var. ***saxatilis*** Pall. † (Cupressaceae)	V?	I, Fr
Juniperus pseudosabina Fisch. & C.A.Mey. (Cupressaceae)	III, Veg	I, Veg
Juniperus rigida Siebold & Zucc. (Cupressaceae)	V?	I, Fr
Juniperus scopulorum Sarg. (Cupressaceae)	III-IV, Veg	I, Fr
Juniperus virginiana L. (Cupressaceae)	II-III, Veg	I, Fr
Kalmia latifolia L. (Ericaceae*)	IV-V, Veg	I, Fr
Kalopanax septemlobus (Thunb.) Koidz. (Araliaceae) [Fig. 61]	II?, Veg	I, Fr
Kerria japonica (L.) DC. (Rosaceae*)	V	III, Fr
Laburnum alpinum (Mill.) Bercht. & J.Presl (Fabaceae*)	III, Fr	II, Fr
Laburnum anagyroides Medik. (Fabaceae*)	IV, Veg	III, Fr
Larix kaempferi (Lamb.) Carrière (Pinaceae)	I-II, Fr	I, Fr
Lauro-cerasus officinalis M. Roem. = ***Prunus laurocerasus*** L. (Rosaceae*)	V	III, Fl
Lavandula angustifolia Mill. (Lamiaceae)	V	III, Fl
Ligustrum obtusifolium Siebold & Zucc. (Oleaceae)	III-IV, Veg	II-III, Fr
Ligustrum ovalifolium Hassk. (Oleaceae)	IV-V, Veg	II, Fr
Ligustrum vulgare L. (Oleaceae)	II-IV, Fr	II-III, Fr
Liriodendron tulipifera L. (Magnoliaceae)	V	II, Fr
Lonicera chamissoi Bunge (Caprifoliaceae*)	I-II, Fr	I, Fr ?
Lonicera etrusca Santi (Caprifoliaceae*)	V	III, Fl
Lonicera ferdinandi Franch. (Caprifoliaceae*)	IV-V, Veg	II, Fr
Lonicera floribunda Boiss. & Buhse (Caprifoliaceae*)	IV-V?, Veg	II, Fr
Lonicera henryi Hemsl. = ***Lonicera acuminata*** Wall. (Caprifoliaceae*)	V	III, Fr

Lonicera hispida Pall. ex Roem. & Schult. (Caprifoliaceae*)	I-II, Fr	I, Fr
Lonicera ledebourii Eschsch. ≡ ***Lonicera involucrata*** var. ***ledebourii*** (Eschsch.) Jeps. (Caprifoliaceae*)	III-IV, Fl	II, Fr
Lonicera morrowii A.Gray (Caprifoliaceae*)	III, Fr	I-II, Fr
Lonicera nervosa Maxim. (Caprifoliaceae*)	II-III, Fr	I, Fr
Lonicera orientalis Lam. ≡ ***Lonicera caucasica*** subsp. ***orientalis*** (Lam.) D.F.Chamb. & D.G.Long (Caprifoliaceae*)	II-III, Fr	I, Fr
Lonicera periclymenum L. (Caprifoliaceae*)	III, Fl	II-III, Fr
Lonicera pileata Oliv. (Caprifoliaceae*)	II, Fr	I, Veg
Louiseania triloba (Lindl.) Pachom. ≡ ***Prunus triloba*** Lindl. (Rosaceae*)	III-IV?, Veg	II, Fl
Lycium depressum Stocks (Solanaceae*)	V?	II, Fr
Maackia amurensis Maxim. & Rupr. (Fabaceae*)	II-III, Fl	I, Fr
Magnolia acuminata (L.) L. (Magnoliaceae)	II-III, Fl	I, Fr
Magnolia kobus DC. (Magnoliaceae)	II-IV, Veg	II, Fr
Magnolia obovata Thunb. & C.Y.Wu (Magnoliaceae)	III-IV, Veg	I, Veg
Magnolia stellata (Siebold & Zucc.) Maxim. (Magnoliaceae)	V?	I, Fl
Magnolia tripetala L. (Magnoliaceae)	V	III, Veg
Malus × floribunda Siebold ex Van Houtte (Rosaceae*)	III-IV?, Veg	I, Fr
Malus fusca (Raf.) C.K.Schneid. (Rosaceae*)	IV?, Veg	I-II, Fr
Malus halliana Koehne (Rosaceae*)	IV-V, Veg	I-II, Fr
Malus mandshurica (Maxim.) Kom. ex Skvortsov (Rosaceae*)	I-II, Fr	I, Fr
Malus niedzwetzkyana Dieck = ***Malus domestica*** (Suckow) Borkh. (Rosaceae*)	III, Veg	I, Fr
Malus praecox (Pall.) Borkh. = ***Malus domestica*** (Suckow) Borkh. (Rosaceae*)	II-III, Fr	I, Fr
Malus pumila Mill. = ***Malus domestica*** (Suckow) Borkh. (Rosaceae*)	III-IV, Veg	I, Fr
Malus sieboldii (Regel) Rehder = ***Malus toringo*** (Siebold) de Vriese (Rosaceae*)	II-III, Fr	I, Fr
Malus × zumi (Matsum.) Rehder (Rosaceae*)	II, Fr	I, Fr
Menispermum canadense L. (Menispermaceae*)	III, Veg	II-III, Fr
Myrica tomentosa (C.DC.) Asch. & Graebn. = ***Myrica gale*** L. † (Myricaceae*)	I, Veg	I, Fl
Ostrya carpinifolia Scop. (Betulaceae)	IV-V?, Veg	II-III, Fr
Padellus mahaleb (L.) Vassilcz. ≡ ***Prunus mahaleb*** L. (Rosaceae*)	III-IV, Fr	II, Fr
Paeonia lutea Delavay ex Franch. ≡ ***Paeonia delavayi*** Franch. (Paeoniaceae)	III-IV, Veg	III, Fr
Paeonia × suffruticosa Andrews (Paeoniaceae)	III-IV, Fl	I-II, Fr
Paliurus spina-christi Mill. (Rhamnaceae*)	V	IV, Veg

Parthenocissus inserta (A.Kern.) Fritsch = ***Parthenocissus quinquefolia*** (L.) Planch. (Vitaceae*)	I-II, Fr	I,Fr
Parthenocissus quinquefolia (L.) Planch. (Vitaceae*)	III-IV, Veg	I, Fr
Parthenocissus tricuspidata (Siebold & Zucc.) Planch. (Vitaceae*)	V	III-IV, Veg
Paulownia tomentosa (Thunb.) Steud. (Paulowniaceae*)	V	IV, Veg
Paxistima canbyi A.Gray (Celastraceae*)	I-II, Fl	I, Fl
Periploca graeca L. (Apocynaceae)	IV-V, Veg	III-IV, Veg
Persica vulgaris Mill. = ***Prunus persica*** (L.) Batsch (Rosaceae*)	V	IV (V), Fl
Phellodendron amurense Rupr. (Rutaceae*)	II, Fr	I, Fr
Phellodendron chinense C.K.Schneid. (Rutaceae*)	V	II, Fr
Phellodendron japonicum Maxim. = ***Phellodendron amurense*** Rupr. (Rutaceae*) [Fig. 62]	V	I, Fr
Phellodendron sachalinense (F.Schmidt) Sarg. = ***Phellodendron amurense*** Rupr. (Rutaceae*)	II-III, Fl	I, Fl
Philadelphus magdalenae Koehne ≡ ***Philadelphus subcanus*** var. ***magdalenae*** (Koehne) S.Y.Hu (Hydrangeaceae*)	II-III, Fr	I-II, Fr
Philadelphus × lemoinei Lemoine 'Avalanche' (Hydrangeaceae*)	III (II), Fl	II, Fr
Photinia villosa (Thunb.) DC. ≡ ***Pourthiaea villosa*** (Thunb.) Decne. (Rosaceae*)	III-IV, Fr	I, Fr
Physocarpus capitatus (Pursh) Kuntze (Rosaceae*)	III, Veg	II, Fr
Picea breweriana S.Watson (Pinaceae)	II-III, Veg	I, Veg
Picea glehnii (F.Schmidt) Mast. (Pinaceae)	II, Veg	I, Fr
Picea mariana (Mill.) Britton, Sterns & Poggenb. (Pinaceae)	II, Veg	I, Fr
Picea orientalis (L.) Peterm. (Pinaceae)	IV, Veg	I, Fr
Picea rubens Sarg. (Pinaceae)	II-III, Fr	I, Fr
Picea schrenkiana Fisch. & C.A.Mey. (Pinaceae)	III-IV, Veg	I, Veg
Picea sitchensis (Bong.) Carrière (Pinaceae)	IV, Veg	I, Fr
Pinus contorta Douglas ex Loudon (Pinaceae)	II, Veg	I, Fr
Pinus densiflora Siebold & Zucc. (Pinaceae)	IV-V, Veg	I, Fl
Pinus koraiensis Siebold & Zucc. (Pinaceae)	II, Veg	I, Fr
Pinus monticola Douglas ex D.Don (Pinaceae)	III-IV, Veg	I, Fr
Pinus pallasiana Lamb. ≡ ***Pinus nigra*** J.F.Arnold subsp. ***pallasiana*** (Lamb.) Holmboe (Pinaceae)	IV, Veg	I, Fr
Pinus parviflora Siebold & Zucc. (Pinaceae)	V	I, Veg
Pinus ponderosa Douglas ex C.Lawson (Pinaceae)	IV, Veg	I, Veg
Pinus wallichiana A.B.Jacks. (Pinaceae)	V	I, Veg
Platycladus orientalis (L.) Franco (Cupressaceae)	V	II-III, Fr

Populus balsamifera L. (Salicaceae*)	II, Veg	I, Fr
Populus deltoides W.Bartram ex Marshall (Salicaceae*)	II, Veg	I, Fr
Populus* × *berolinensis K.Koch (Salicaceae*)	IV, Veg	I, Fr
Populus × *petrowskiana* (R.I.Schröd. ex Regel) Dippel = ***Populus* × *petrovskoe*** R.I.Schröd. ex Wolkenst. (Salicaceae*)	II, Fl	I, Fr
Prunus americana Marshall (Rosaceae*)	III, Veg	I, Fr
Prunus divaricata Ledeb. = ***Prunus cerasifera*** Ehrh. (Rosaceae*)	III, Veg	II, Fr
Prunus domestica L. (Rosaceae*)	III, Fr	II, Fr
Pseudotsuga menziesii (Mirb.) Franco (Pinaceae)	I-IV, Veg	I, Fr
Ptelea trifoliata L. (Rutaceae*)	III, Fr	II, Fr
Pterocarya fraxinifolia (Poir.) Spach (Juglandaceae*)	III-IV, Veg	II, Fr
Pterocarya rhoifolia Siebold & Zucc. (Juglandaceae*)	II, Veg	I, Fr
Pyrus communis L. (Rosaceae*)	I-II, Fr	I, Fr
Pyrus ussuriensis Maxim. (Rosaceae*)	II-IV, Fr	I, Fr
Quercus alba L. (Fagaceae)	III, Veg	II, Fr
Quercus castaneifolia C.A.Mey. (Fagaceae)	V (IV), Veg	III, Veg
Quercus crispula Blume ≡ ***Quercus mongolica*** Fisch. ex Ledeb. **subsp. *crispula*** (Blume) Menitsky (Fagaceae)	IV?, Veg	I, Fl
Quercus dentata Thunb. (Fagaceae)	V	II-III, Fl
Quercus frainetto Ten. (Fagaceae)	IV-V, Veg	I, Veg
Quercus macranthera Fisch. & C.A.Mey. ex Hohen. (Fagaceae)	IV, Veg	I, Veg
Quercus macrocarpa Michx. (Fagaceae)	III-IV, Veg	II, Veg
Quercus mongolica Fisch. ex Ledeb. (Fagaceae)	V	I,Veg
Quercus rubra L. (Fagaceae)	II-III, Fr	I, Fr
Rhododendron albrechtii Maxim. (Ericaceae*)	IV? Veg	I, Fr
Rhododendron calendulaceum (Michx.) Torr. (Ericaceae*)	II, Fl	I, Fr
Rhododendron canadense (L.) Torr. (Ericaceae*)	I-II, Fr	I, Fr
Rhododendron catawbiense Michx. (Ericaceae*)	III, Fl	I, Fr
Rhododendron ledebourii Pojark. ≡ ***Rhododendron dauricum*** L. subsp. ***ledebourii*** Alexandrova & P.A.Schmidt (Ericaceae*)	I-II, Fr	I, Fr
Rhododendron macrophyllum D.Don (Ericaceae*)	III, Fl	I, Fr
Rhododendron maximum L. (Ericaceae*)	III-IV, Veg	I, Fr
Rhododendron minus Michx. (Ericaceae*)	III, Fl	I, Fr
Rhododendron mucronulatum Turcz. (Ericaceae*)	II-IV, Fr	I, Fr

Rhododendron myrtifolium J.Forbes = ***Rhododendron ponticum*** L. (Ericaceae*)	II-III, Fl	I, Fr
Rhododendron ponticum L. (Ericaceae*)	IV, Veg	II (III), Fr
Rhododendron schlippenbachii Maxim. (Ericaceae*)	III (II?), Veg	I, Fr
Rhododendron smirnowii Trautv. ex Regel (Ericaceae*)	I-II, Fr	I, Fr
Rhododendron vaseyi A.Gray (Ericaceae*)	II, Fl	I, Fr
Rhododendron viscosum (L.) Torr. (Ericaceae*)	II-III, Fl	I, Fr
Rhus typhina L. (Anacardiaceae*)	V	III, Fl
Ribes alpinum L. (Grossulariaceae*)	II, Fr	I, Fr
Ribes diacantha Pall. (Grossulariaceae*)	III, Fl	I, Fl
Ribes latifolium Jancz. (Grossulariaceae*)	II-III, Veg	I, Fr
Ribes sanguineum Pursh (Grossulariaceae*)	V	III, Fr
Robinia pseudoacacia L. (Fabaceae*)	IV-V, Veg	III (IV), Fr
Rosa multiflora Thunb. (Rosaceae*)	V	III (IV), Fr
Rosa villosa L. = *Rosa pomifera* Herrm. (Rosaceae*)	II, Fr	I, Fr
Rubus caesius L. (Rosaceae*)	III, Fr	II, Fr
Rubus crataegifolius Bunge (Rosaceae*)	III, Fr	II, Fr
Rubus parvifolius L. (Rosaceae*)	III, Fl	I-II, Fr
Salix gracilistyla Miq. (Salicaceae*)	IV-V, Veg	III, Fr
Salix ledebouriana Trautv. (Salicaceae*)	III, Fl	II, Fr
Schizophragma hydrangeoides Siebold & Zucc. ≡ ***Hydrangea hydrangeoides*** (Siebold & Zucc.) Bernd Schulz (Hydrangeaceae*)	IV-V, Veg	IV, Veg
Securinega suffruticosa (Pall.) Rehder ≡ ***Flueggea suffruticosa*** (Pall.) Baill. (Phyllanthaceae)	IV, Veg	III-IV, Fr
Smilax excelsa L. (Smilacaceae)	V	II-III, Veg
Sorbaria kirilowii (Regel) Maxim. (Rosaceae*)	IV (V?), Veg	II, Fr
Sorbus latifolia (Lam.) Pers. ≡ ***Karpatiosorbus latifolia*** (Lam.) Sennikov & Kurtto (Rosaceae*)	II-III, Fr	I, Veg
Sorbus alnifolia (Siebold & Zucc.) K.Koch (Rosaceae*)	II, Fr	I, Fr
Sorbus aria (L.) Crantz = ***Aria edulis*** (Willd.) M.Roem. (Rosaceae*)	II, Fr	I, Fr
Sorbus commixta Hedl. (Rosaceae*)	II-III, Fr	I, Fr
Sorbus domestica L. (Rosaceae*) ≡ ***Cormus domestica*** (L.) Spach	IV, Veg	I, Veg
Sorbus graeca (Spach) Lodd. ex Schauer = ***Aria graeca*** (Lodd. ex Spach) M.Roem. (Rosaceae*)	II, Fr	I, Fr
Sorbus mougeotii Soy-Will. & Godr. ≡ ***Hedlundia mougeotii*** (Soy.-Will. & Godr.) Sennikov & Kurtto (Rosaceae*)	I-II, Fr	I, Fr

Sorbus serotina Koehne = ***Sorbus commixta*** Hedl. † (Rosaceae*)	II, Veg	I, Fr
Sorbus tianschanica Rupr. (Rosaceae*)	II, Fr	I, Fr
Sorbus torminalis (L.) Crantz = ***Torminalis glaberrima*** (Gand.) Sennikov & Kurtto (Rosaceae*)	III-IV, Fr	I, Fr
Spiraea japonica L.f. (Rosaceae*)	III, Fr	I, Fr
Spiraea rosthornii E.Pritz. (Rosaceae*)	II-III, Veg	II, Fr
Spiraea trilobata L. (Rosaceae*)	II-III, Fr	I, Fr
Spiraea veitchii Hemsl. (Rosaceae*)	III-IV, Veg	II, Fr
Spiraea virgata Franch. = ***Spiraea myrtilloides*** Rehder (Rosaceae*)	III-IV, Veg	I, Fr
Spiraea × semperflorens Zabel (Rosaceae*)	II-III, Fr	II, Fr
Spiraea × vanhouttei (Briot) Carrière (Rosaceae*)	III, Fr	II (III), Fr
Staphylea pinnata L. (Staphyleaceae*)	III-IV, Veg	II-III, Fr
Stephanandra tanakae (Franch. & Sav.) Franch. & Sav. ≡ ***Neillia tanakae*** (Franch. & Sav.) Franch. & Sav. ex S.H.Oh (Rosaceae*)	III-IV, Veg	III, Fr
Styrax japonicus Siebold & Zucc. (Styracaceae*)	V	III, Veg
Swida alternifolia (L. f.) Small ≡ ***Cornus alternifolia*** L.f. (Cornaceae)	II-III, Fr	I-II, Fr
Swida amomum (Mill.) Small ≡ ***Cornus amomum*** Mill. (Cornaceae)	III, Veg	II, Fr
Swida australis (C.A. Mey.) Pojark. ex Grossh. = ***Cornus sanguinea*** subsp. ***australis*** (C.A.Mey.) Jáv. (Cornaceae)	III, Veg	II-III, Fr
Swida sanguinea (L.) Opiz ≡ ***Cornus sanguinea*** L. (Cornaceae)	II, Fr	I, Fr
Syringa oblata Lindl. (Oleaceae)	II-III, Fr	I, Fr
Syringa reflexa C.K.Schneid. = ***Syringa komarowii*** C.K.Schneid. (Oleaceae)	II-III? Veg	I, Fr
Syringa reticulata (Blume) H.Hara (Oleaceae)	II-III, Fl	II, Fr
Syringa velutina Kom. = ***Syringa pubescens*** Turcz. subsp. ***patula*** (Palib.) M.C.Chang & X.L.Chen (Oleaceae)	II, Fr	I, Fr
Syringa × chinensis Willd. (Oleaceae)	III, Fl	I, Fl
Tamarix ramosissima Ledeb. (Tamaricaceae*)	III-IV, Fl	II, Fr
Taxodium distichum (L.) Rich. (Cupressaceae)	V	IV, Veg
Taxus baccata L. (Taxaceae)	IV-V, Veg	II-III, Fr
Taxus cuspidata Siebold & Zucc. (Taxaceae)	II, Fl	I, Fr
Thuja plicata Donn ex D.Don (Cupressaceae)	IV-V, Veg	II, Fr
Thuja standishii (Gordon) Carrière (Cupressaceae)	IV-V, Veg	I, Fr
Thujopsis dolabrata (L.f.) Siebold & Zucc. (Cupressaceae)	III-IV, Veg	II (III), Fr
Thymus serpyllum L. (Lamiaceae)	II-III, Veg	I, Fr
Tilia americana L. (Malvaceae*)	III-IV, Veg	I, Fr

Tilia begoniifolia Steven = ***Tilia dasystyla*** Steven subsp. ***caucasica*** (V.Engl.) Pigott (Malvaceae*)	III, Veg	I, Fr
Tilia heterophylla Vent. = ***Tilia americana*** L. (Malvaceae*)	III, Veg	I, Fr
Tilia mandshurica Rupr. & Maxim. (Malvaceae*)	III, Veg	I, Fr
Tilia mongolica Maxim. (Malvaceae*)	IV? Veg	I, Fr
Tilia platyphyllos Scop. (Malvaceae*)	I-II, Fr	I, Fr
Tilia × euchlora K.Koch (Malvaceae*)	II, Veg	I, Fr
Tsuga canadensis (L.) Carrière (Pinaceae)	III-IV, Veg	I, Fr
Tsuga mertensiana (Bong) Carrière (Pinaceae)	IV, Veg	II, Veg
Ulmus × arbuscula E.L.Wolf (Ulmaceae*)	I-II, Fr	I, Fr
Ulmus japonica (Rehder) Sarg. ≡ ***Ulmus davidiana*** Planch. var. ***japonica*** (Rehder) Nakai (Ulmaceae*)	II-III, Veg	I, Fr
Ulmus parvifolia Jacq. (Ulmaceae*)	V	IV (V), Veg
Ulmus pumila L. (Ulmaceae*)	II-IV, Fr	II, Fr
Viburnum burejaeticum Regel & Herder (Viburnaceae*)	II (III), Fr	I, Fr
Viburnum furcatum Blume ex Maxim. (Viburnaceae*)	V	I, Fr
Viburnum opulus L. (Viburnaceae*)	I-IV, Fr	I, Fr
Viburnum sargentii Koehne (Viburnaceae*)	I-II, Fr	I, Fr
Viburnum wrightii Miq. (Viburnaceae*)	III-V, Fr	I, Fr
Vinca minor L. (Apocynaceae)	II, Fl	I, Fl
Vitis amurensis Rupr. (Vitaceae*)	II-III, Fr	II, Fr
Vitis coignetiae Pulliat ex Planch. (Vitaceae*)	III-IV, Veg	II, Fr
Weigela japonica Thunb. (Caprifoliaceae*)	V	III, Fr
Wisteria sinensis (Sims) DC. (Fabaceae*)	V	IV, Veg
(3) Plants that are less able to cope with the current climate		
Alnus rugosa (Du Roi) Spreng. ≡ ***Alnus incana*** (L.) Medik. subsp. ***rugosa*** (Du Roi) R.T.Clausen † (Betulaceae)	I, Fr	II-III, Fr
Betula alleghaniensis Britton (Betulaceae)	I, Fr	I-II, Fr
Betula raddeana Trautv. (Betulaceae)	I?, Veg	II, Fr
Celastrus flagellaris Rupr. (Celastraceae*)	I, Fr	II, Veg
Chamaecytisus ratisbonensis (Schaeff.) Rothm. (Fabaceae*)	I, Fr	II, Fr
Daphne mezereum L. (Thymelaeaceae*)	I, Fr	I-II, Fr
Hydrangea petiolaris Siebold & Zucc. (Hydrangeaceae*)	II, Fr	II (III-V), Fr

Lonicera alpigena L. (Caprifoliaceae*)	I, Fr	I-II, Fr
Lonicera involucrata (Richardson) Banks ex Spreng. (Caprifoliaceae*)	I, Fr	II, Fr
Pentaphylloides mandshurica (Maxim.) Sojak ≡ ***Dasiphora mandshurica*** (Maxim.) Juz. (Rosaceae*)	I-II, Fr	II-III, Fr
Philadelphus gordonianus Lindl. = ***Philadelphus lewisii*** Pursh † (Hydrangeaceae*)	I, Fr	III, Fr
Philadelphus pubescens Loisel. (Hydrangeaceae*)	I, Fr	II, Fr
Prinsepia sinensis (Oliv.) Hallier (Rosaceae*)	II, Fl	III (IV), Fr
Rosa alberti Regel (Rosaceae*)	I-II, Fr	II, Fr
Rosa gallica L. (Rosaceae*)	I, Veg	II, Fr
Rubacer odoratum (L.) Rydb. ≡ ***Rubus odoratus*** L. (Rosaceae*)	I, Fr	II, Fr
Rubacer parviflorum (Nutt.) Rydb. = ***Rubus nutkanus*** Moc. ex Ser. (Rosaceae*)	I, Fr	II, Fr
Salix lapponum L. (Salicaceae*)	I, Fl	II, Fl
Spiraea alba Du Roi † (Rosaceae*)	I, Fr	II, Fr
Spiraea menziesii Hook. ≡ ***Spiraea douglasii*** Hook. var. ***menziesii*** (Hook.) C.Presl (Rosaceae*)	I-II,Fr	II, Fr
Symphoricarpos albus (L.) S.F.Blake (Caprifoliaceae*)	I, Fr	II, Fr

This is a very substantial number of representatives of the introduced and local dendroflora, especially those species that have been tested and cultivated in the outdoor collection. Mainly represented are the floras of the temperate latitudes of the northern hemisphere, Eurasia and North America. The studied plants belong to different life forms, from large trees (*Populus nigra* L.) to semi-shrubs (*Rubus phoenicolasius* Maxim.) and dwarf shrubs (*Rhododendron camtschaticum* Pall.), with a predominance of shrubs and small trees.

Comparing the performance of these woody plants in the first two decades of the 21st Century to their performance in Wolf's research shows that in 232 species and infraspecific taxa (39%) there was no change. The clear majority here are taxa in groups I and II of winter tolerance.

Table 2. Number of accepted taxa (genera/species and infraspecific taxa) in analysed families

n/n	Family	Group 1	Group 2	Group 3	Total
1	Actinidaceae	1/1	1/2		1/3
2	Anacardiaceae	1/1	2/2		3/3
3	Apocynaceae		2/2		2/2
4	Aquifoliaceae	1/1	1/1		1/2

5	Araliaceae	1/3	4/5		4/8
6	Aristolochiaceae		1/2		1/2
7	Berberidaceae	1/4	1/4		1/8
8	Betulaceae	5/12	5/13	2/3	5/28
9	Bignoniaceae		2/3		2/3
10	Brassicaceae		1/1		1/1
11	Buxaceae	1/1	1/1		1/2
12	Calycanthaceae		1/1		1/1
13	Cannabaceae		1/2		1/2
14	Caprifoliaceae	5/17	2/11	2/3	5/31
15	Celastraceae	1/4	3/7	1/1	3/12
16	Cercidiphyllaceae		1/1		1/1
17	Cornaceae	1/2	1/5		1/7
18	Cupressaceae	3/6	7/14		8/19
19	Elaeagnaceae	3/3			3/3
20	Ericaceae	5/15	4/17		7/32
21	Eucommiaceae	1/1			1/1
22	Fabaceae	2/4	9/10	1/1	11/15
23	Fagaceae	2/2	2/12		3/14
24	Ginkgoaceae		1/1		1/1
25	Grossulariaceae	1/11	1/5		1/16
26	Hamamelidaceae	1/1	1/1		1/2
27	Hydrangeaceae	2/7	3/9	2/3	3/19
28	Hypericaceae		1/1		1/1
29	Iteaceae		1/1		1/1
30	Juglandaceae		3/9		3/9
31	Lamiaceae	1/1	2/2		3/3
32	Lardizabalaceae		2/2		2/2
33	Magnoliaceae		2/6		2/6

34	Malvaceae	1/3	1/6		1/9
35	Menispermaceae	1/1	1/1		1/2
36	Moraceae	1/1			1/1
37	Myricaceae	1/1	1/1		1/2
38	Oleaceae	3/4	4/15		5/19
39	Paeoniaceae		1/2		1/2
40	Paulowniaceae		1/1		1/1
41	Phyllanthaceae	1/1	1/1		2/2
42	Pinaceae	4/23	6/37		6/58
43	Ranunculaceae	1/2	1/1		1/3
44	Rhamnaceae	3/4	1/1		4/5
45	Rosaceae	17/62	23/64	5/8	28/134
46	Rubiaceae		1/1		1/1
47	Rutaceae		2/3		2/3
48	Salicaceae	3/16	2/6	1/1	3/23
49	Sapindaceae	2/5	2/30		3/35
50	Schisandraceae	1/1			1/1
51	Simaroubaceae		1/1		1/1
52	Smilacaceae		1/1		1/1
53	Solanaceae		1/1		1/1
54	Staphyleaceae	1/1	1/1		1/2
55	Styracaceae		1/1		1/1
56	Tamaricaceae		1/1		1/1
57	Taxaceae	1/2	1/2		1/4
58	Thymelaeaceae			1/1	1/1
59	Ulmaceae	1/2	1/4		1/6
60	Viburnaceae	2/5	1/5		2/10
61	Vitaceae		3/5		3/5
	TOTAL	83/232	129/342	15/21	164/595

However, 342 species and infraspecific taxa (57.5%) perform better in the current climate than in Wolf's time, sometimes quite noticeably, and this group of woody plants is the largest of the three groups into which all plants in this research were divided (Tables 1 and 2). Many conifers showed less frost-damage, and some of them none at all (i.e. *Abies alba*, *A. amabilis*, *A. fraseri*, *A. lasiocarpa*). Also, *Acer saccharum*, *A. saccharinum*, and *A. tegmentosum* placed by Wolf in group II, now appearing in group I. At the same time, many species that Wolf attributed to group V (i.e. did not survive) have now been successfully grown in St. Petersburg for many years. *Carpinus japonica*, *Carya ovata*, *Celtis occidentalis* are now could be considered winter tolerant. There are also those that bear fruit and are grown from locally ripened seeds (i.e. *Acer palmatum*, *A. triflorum*). An analysis of the species from Wolf's group V shows that the area of origin, from where it is possible to obtain woody plants that can grow in the open ground in St. Petersburg is significantly expanding. A number of species from Japan and South China (i.e. *Catalpa speciosa*, *Cercidiphyllum japonicum*, *Pinus parviflora*) are now successfully cultivated here. According to Wolf (1917), the Appalachian and Balkan floristic provinces (zones according to Takhtadzhan, 1978) provided very few winter-hardy species but now these provinces can be considered a very good source for introductions into the St. Petersburg region. Along with better winter tolerance, a change in reproductive state of exotic plants is very noticeable in comparison with the period of Wolf's research. During this period, *Ptelea trifoliata* bloomed periodically, but rarely bore fruit. Now it bears fruit annually, abundantly and is propagated from the seeds of its own reproduction. *Magnolia acuminata* did not produce ripe seeds before, but now it forms viable seeds. Some rhododendrons are also grown from their own seeds (i.e. *Rhododendron catawbiense*, *R. schlippenbachii*). The lengthening of the growing season results in plants reaching and completing their reproductive cycle. Along with continuing climate warming at the end of the 20th and at the beginning of 21st Centuries, a number of species that had not previously been observed to self-seed (i.e. *Carpinus betulus*, *Prunus maximowiczii*, *Spiraea betulifolia*), are now doing so, which is an important indicator of climate change and a sign of possible future naturalization of the species in this territory.

Only 21 species and infraspecific taxa (3.5%) showed more winter damage now than in Wolf's era. As our long-term monitoring of woody plants in the Peter the Great Botanical Garden shows, after warm winters, 70-80% of species in the collections are usually free of frost-damage, 10-15% have frost damage to the buds and ends of shoots of the previous year's growth and only in some species is there more severe frost-damage. Experience shows that

such warm winters are the most dangerous for early flowering catkin-bearing plants, conifers, and all woody plants with a short dormant period, including those that are quite winter-hardy under normal weather conditions (Firsov *et al*., 2008). Considering the species that are less able to cope with the current winter climate (Table 1, group 3), it can be noted that *Betula raddeana* in Wolf's list was represented by young plants that hibernated under the snow, and he himself doubted which group this species should be assigned to. One could agree with Wolf that *Hydrangea petiolaris* belonged to group II of his scale of winter hardiness. However, over the decades after Wolf made his observations, *H. petiolaris* showed significant frost-damage of the crown and individual shoots older than one year. In addition, due to the more frequent warm winters with a simultaneous increase in the amount of precipitation, cases of death of old plants from damp were observed. In some individuals of *Daphne mezereum* in the abnormally warm winter of 2006–2007 a significant number of flower buds and skeletal branches died out, although it is a species of local flora. Although in the climate of the 20th Century *Salix lapponum* was considered promising for cultivating in St. Petersburg, it is a species of northern latitudes that does not respond well to climate change and warming. In this species, as in other willow species, flower buds began to show frost-damage due to the very early onset of annual growth, when they are then damaged by just a slight frost. In other species (i.e. *Lonicera alpigena*, *Dasiphora mandshurica*) fungal and viral diseases were observed more often following climate warming.

Wolf just published a list of the plants he tested, and he did not analyze his own data. For a long time, nobody paid attention, discussed or summarized the huge experience in the introduction and cultivation of woody plants that was started by Wolf in St. Petersburg. Dendrologists in the Forestry Academy, even in the middle of the 20th Century, (Andropov, 1953; Akimov and Bulygin, 1961) were mainly engaged in only comparing their data on winter hardiness with Wolf's data for the same species. Some of Wolf's results in plant cultivation were summarised by Bulygin and Firsov (1994 a, b). Analysis of Wolf's and the current data showed the need for winter-hardy species and forms, primarily among tall trees, both in the past and now, for introduction into Northwestern European Russia. The number of dwarf shrubs tested by Wolf was relatively small in comparison with trees and large shrubs. Semi-woody and dwarf woody plants stand out because other dendrologists do not consider them to be objects of interest at all. Wolf also tested many woody plants from the taiga zone of Eurasia that no one had tested before him.

Out of all the woody plants listed (Table 1), the highest percentage of flowering and fruiting species and forms is found amongst shrubs, followed by dwarf shrubs, semi-woody

dwarf shrubs and lianas. Trees take the last place of these five groups of life forms. It can be assumed that Wolf's 30 years of observation was not enough time for many tree species to reach their flowering and fruiting stage. He introduced many species into culture, and they all were young individuals. In this aspect, researchers who worked after Wolf were in a better position to assess the results. Thus, it is very important to test new species introduced directly from their natural area of distribution. Wolf himself sometimes underlined that some species from the northern part of the distribution range could be more stable in the new conditions of St. Petersburg. As many individuals as possible from different parts of the distribution area should be tested. When obtaining seeds from places other than the plant's natural area of distribution, it is important to know from which geographical places of the natural area the seeds originated. The largest possibilities for using the results of the introduction of woody plants into Northwestern European Russia lie in the landscaping of populated areas. Analysis of Wolf's data makes it possible to select from the plants he tested the most interesting and suitable species that are absent currently in the collections of St. Petersburg so that they can be recommended for secondary introduction and cultivation. Many of them have not been tested here since Wolf. Ornamental plants, medicinal plants, fruit trees and other economically valuable plants could have low winter-hardiness and be rare in nature but are very important in dendrological taxonomical collections for educational purposes.

Conclusions

Observations of woody plants in St. Petersburg by Wolf from 1886 to 1916 and by the present authors from 2001 to 2018 have shown how plant performance reflects the changing climate. Thus, species that could not be grown in St. Petersburg in Wolf's time are now successfully flowering and fruiting. The results of such long-term research prove how woody plants can be real bioindicators of global warming.

For the future it is now relevant to check all old, historical and preserved trees and shrubs from the time when Wolf was working and compile an appropriate database for them. It is important to preserve them by extending the life of individual plants as much as possible as well as by propagating them in order to preserve their unique gene pools.

The species that demonstrated changes in their performance in the warming climate and thus can be considered bioindicators of climate change should be studied in a broader context. Their climatic preferences should be considered over the entire distribution range, by assembling all available georeferenced collection localities and retrieving data on the past and current climate at those locations. Such a study will allow us to infer some of the prerequisites

of successful species performance in a changing climate and identify the most suitable geographical areas and climates for plants to be introduced from.

Provenance tests demonstrated that, in the boreal zone, growth of native trees may increase with an increase in temperature, but the increase would be much less compared with that in plants originating from warmer localities (Schmidtling, 1994; Carter, 1996). In many species, growth reductions occur when they are moved to locations more than 1–2°C warmer than seed source locations, but a few taxa display positive growth responses when shifted by up to 5°C (Park *et al*., 2014).

As stated previously (Firsov and Lavrentiev, 2009), the complete scientific heritage left by Wolf still needs careful research and evaluation. It should include biometric measurements of all plants in the woodland park and arboretum of St. Petersburg State Forestry University need to be made and compared to those which were made and recorded by Wolf in his publications. Such a comparison can provide further valuable material on the results of the introduction and cultivation of woody plants in St. Petersburg. Also, it is particularly important to restore the Salicetum, a collection of willows (*Salix* L.), which was carefully created by Wolf over many years.

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Authors' contributions

Gennady A. Firsov (GF) cultivated and observed plants, prepared and analysed material, wrote the first version of the manuscript and participated in discussion of the manuscript.

Nadia O. Bystriakova (NB) initiated the project, wrote the Introduction and participated in analysing data, discussion and re-writing of the manuscript.

Irina V. Belyaeva (IB) assessed nomenclature and taxonomy of the species included according to existing nomenclatural and taxonomic databases, contributed to the chapter Materials and methods, analysed all available resources prepared by GF and NB, participated in discussion of the manuscript, re-wrote first version, prepared the final version of the manuscript and coordinated the project.

All photographs were taken by Gennady A. Firsov.

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Appendix

Plants whose performance is unchanged in the current climate (Figures 4–33)

Figure 4. ***Abies sibirica*** Ledeb

Figure 5. ***Acer rubrum*** L.

Figure 6. ***Acer tataricum*** L.

Figure 7. ***Actinidia kolomikta*** (Maxim.) Maxim

Figure 8. ***Alnus hirsuta*** (Spach) Turcz. ex Rupr.

Figure 9. ***Prunus tenella*** Batsch

Figure 10. ***Clematis alpina*** (L.) Mill. subsp. ***sibirica*** (L.) Kuntze

Figure 11. ***Berberis amurensis*** Rupr.

Figure 12. ***Berberis heteropoda*** Schrenk

Figure 13. ***Betula davurica*** Pall.

Figure 14. ***Betula pubescens*** Ehrh. nothovar. ***kusmisscheffii*** (Regel) Gürke

Figure 15. ***Betula papyrifera*** Marshall

Figure 16. ***Buxus sempervirens*** L.

Figure 17. ***Caragana arborescens*** Lam.

Figure 18. ***Caragana frutex*** (L.) K.Koch

Figure 19. ***Caragana pygmaea*** (L.) DC.

Figure 20. ***Colutea orientalis*** Mill.

Figure 21. ***Corylus sieboldiana*** Blume var. ***mandshurica*** (Maxim.) C.K.Schneid.

Figure 22. *Cotoneaster ignavus* E.L.Wolf

Figure 23. ***Cotoneaster acutifolius*** Turcz.

Figure 24. ***Cotoneaster racemiflorus*** (Desf.) K.Koch

Figure 25. ***Crataegus altaica*** (Loudon) Lange

Figure 26. ***Crataegus maximowiczii*** C.K.Schneid.

Figure 27. ***Alnus alnobetula*** (Ehrh.) K.Koch subsp. ***fruticosa*** (Rupr.) Raus

Figure 28. ***Eleutherococcus senticosus*** (Rupr. et Maxim.) Maxim.

Figure 29. ***Euonymus verrucosus*** Scop.

Figure 30. ***Holodiscus discolor*** (Pursh) Maxim.

Figure 31. ***Juniperus sabina*** L.

Figure 32. ***Larix gmelinii*** (Rupr.) Kuzen.

Figure 33. ***Leptopus chinensis*** (Bunge) Pojark.

Plants that perform better in the current climate than in Wolf's time (Figures 34–62)

Figure 34. ***Abies alba*** Mill.

Figure 35. ***Abies holophylla*** Maxim.

Figure 36. ***Acer barbinerve*** Maxim.

Figure 37. ***Acer carpinifolium*** Siebold & Zucc.

Figure 38. ***Acer mandshuricum*** Maxim.

Figure 39. ***Actinidia polygama*** (Siebold & Zucc.) Planch. ex Miq.

Figure 40. ***Ailanthus altissima*** (Mill.) Swingle

Figure 41. ***Akebia quinata*** (Houtt.) Decne.

Figure 42. ***Ampelopsis aconitifolia*** Bunge

Figure 43. ***Aralia elata*** (Miq.) Seem.

Figure 44. ***Aristolochia manshuriensis*** Kom.

Figure 45. ***Berberis koreana*** Palib.

Figure 46. ***Berberis sibirica*** Pall.

Figure 47. ***Carpinus betulus*** L.

Figure 48. ***Carpinus cordata*** Blume

Figure 49. ***Carya ovata*** (Mill.) K.Koch

Figure 50. ***Catalpa speciosa*** Teas

Figure 51. ***Celastrus orbiculatus*** Thunb.

Figure 52. ***Prunus maximowiczii*** Rupr.

Figure 53. ***Corylus colurna*** L.

Figure 54. ***Cotoneaster dammeri*** C.K.Schneid.

Figure 55. ***Crataegus pinnatifida*** Bunge

Figure 56. ***Cryptomeria japonica*** (Thunb. ex L.f.) D.Don

Figure 57. ***Fagus orientalis*** Lipsky

Figure 58. ***Fraxinus chinensis*** **subsp.** ***rhynchophylla*** (Hance) A.E.Murray

Figure 59. ***Hamamelis japonica*** Siebold & Zucc.

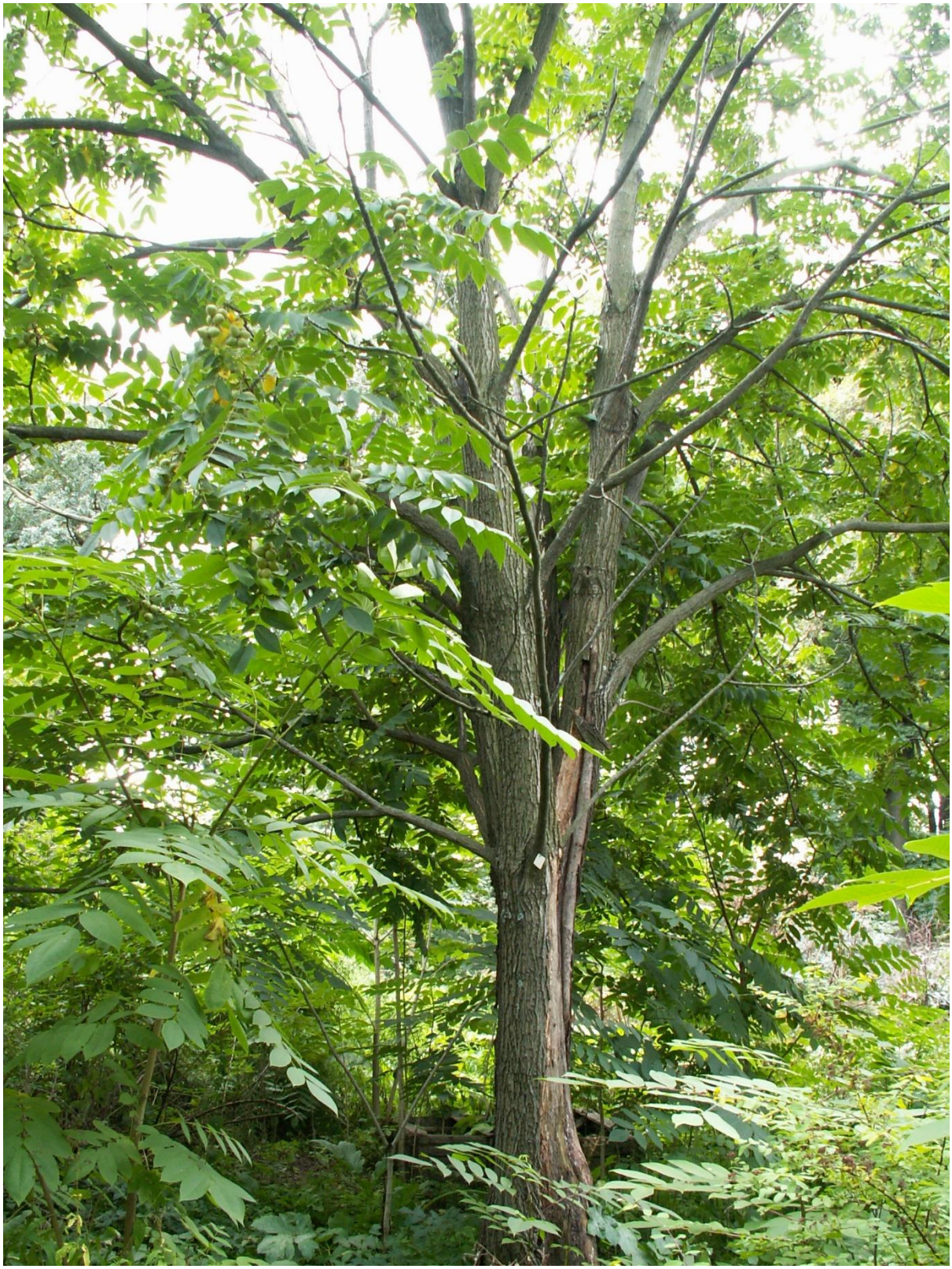

Figure 60. ***Juglans ailanthifolia*** Carrière

Figure 61. ***Kalopanax septemlobus*** (Thunb.) Koidz.

Figure 62. ***Phellodendron amurense*** Rupr.