

Acclimation of *Juglans mandshurica* Maxim. and *Phellodendron amurense* Rupr. in the Middle Volga region

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Abstract. This research is the first attempt to analyze the results of acclimation of *J. mandshurica* and *P. amurense* in coniferous-deciduous forests under the conditions of the temperate continental climate of the Middle Volga Region. The study has been performed in the Volga-Kama Nature Reserve (Republic of Tatarstan, Russia) and demonstrated that *J. mandshurica* is a successfully acclimated species. This species naturalized in the forests of the Reserve, being distinguished by a rapid biomass production, high germination capacity of seeds and high number of pre-generative specimens. *P. amurense* can be characterized by the opposite features.

1. Introduction

The adaptation mechanisms of trees outside their native ranges and the abilities of invaders to tolerate the conditions of temperate continental climate of the Middle Volga region are currently of particular research interest. Due to the growing number of studies focused on possible use of various plant species in pharmacology, medicine, food and light industry, landscaping, the problem of searching for new sources of plant materials and their application has become increasingly important. The Far Eastern exotic genera *Juglans* and *Phellodendron* are in the focus of attention with this regard, because they are marked by high edibility characteristics and specific medicinal properties [1, 2, 3]. The purpose of current study is to investigate the ecological and physiological characteristics of *J. mandshurica* and *P. amurense* growing in the forest habitats of the Middle Volga region.

The ecological and biological characteristics of the two Far Eastern tree species under study are similar. *J. mandshurica* is deep rooted species and rarely suffers from a lack of moisture. *J. mandshurica* is a hygromesophyte and is sensitive to drought [2]. This species is light demanding. It prefers fertile, well-moistened and drained soils. *J. mandshurica* is the most frost-resistant representative of the genus *Juglans*, which was confirmed by the previous experiments on its introduction into Central Siberia, St. Petersburg, and Petrozavodsk [4, 5]. The tree blossoms in April – May. *J. mandshurica* is pollinated by wind, propagates by seeds, and regenerates by sprouting. *P. amurense* is heliophilous as is *J. mandshurica*. *P. amurense* is demanding for fertile soil as well and is wind resistant. Its root system is deep and aggressive similarly to *J. mandshurica*. This hygromesophyte prefers moistened and well-drained soils. The tree is winter hardy and regenerates from seeds and root shoots. *P. amurense* is an entomophilous species, blossoms in the first half of summer [6].

The first mass planting of exotic trees and shrubs in the Raifa forest (part of Volga-Kama Nature Reserve) began as early as 1924; the first sites of planting were forest management blocks 41, 64 and



the Arboretum of the Reserve. These plantings in blocks 41 and 64 died, the only *J. mandshurica* represented by trees which developed from the seeds brought from the Russian Far East can be found merely in the Arboretum. According to the current annotated list of tree species in the Raifa Arboretum, *Juglans mandshurica* Maxim. and *Phellodendron amurense* Rupr. are located in the “Asia” section of the botanical garden. Nowadays the biggest (up to 19 m in height) and oldest tree of *Juglans mandshurica* is about 85 years. The Arboretum has 14 exotic *Juglans mandshurica* trees aged 60 years and 17-18 m in height, which developed from the seeds of the first planted trees. Currently, *P. amurense* species is represented in the Raifa Arboretum as a single tree with a curved and hollow trunk. The estimated age of this tree is around 80 years, and height of the trunk is 6 m. On the winter hardiness scale, the *P. amurense* tree is given a score II (meaning that no more than 50% of the annual shoot length dies from frost) [4].

During the period from 1932 to 1966, the studies on acclimation and introduction of exotic species were continued in different compartments of the Raifa forest.

J. mandshurica was planted both in pure culture and in mixed stands combined with green ash (*Fraxinus pennsylvanica*), ash-leaved maple (*Acer negundo*), pine (*Pinus sylvestris*), and siberian pine (*Pinus sibirica*) in Raifa’s forest management blocks 87, 75, 76, 68, 88. Vast stands of this species were planted in 1949 (0.5 ha; block 76), as well as in 1941 and 1946 (0.4 ha; block 75). The last investigations on the state of exotic species and their naturalization were carried out in 1972-1973 by E. Deryuga and A. Murzov [7]. They showed that *J. mandshurica* in the Arboretum was in a worse state than in the forest: 1790 individuals planted in pure culture in block 76 were attributed to bonitet class II; the part of 1430 individuals planted in block 75 were classified as stand quality class I if grown in mixture with *F. pennsylvanica* and as quality class II and III if found in mixture with *P. sylvestris* and *P. sibirica*. The term “bonitet”, as used herein, can be defined as an estimate of tree productivity, so the quality class of bonitet I corresponds to tree stands having good access to water and nutrients.

P. amurense was mainly planted in Raifa’s forest management blocks 85, 75, 76. Most of *P. amurense* trees found in block 75 were dead, as discovered by [4] in 1973. In a *P. amurense* stand of 0.1 ha (block 75) mixed with *F. pennsylvanica*, the authors [4] described 1350 surviving tree individuals (small trees) aged 24 years and classified as quality class III bonitet. Analyzing the pure culture stand of 600 m² in block 76, 2779 trees aged 24 years were attributed to stand quality class II [4].

The massive planting of exotic species in the Raifa forest stopped in 1964 when the Volga-Kama Nature Reserve was founded. Since then naturalization of the introduced species proceeded without any economic influence of humans, which is a unique situation. The planted forest stands were inhabited by natural forest tree species *Tillia cordata* and *Acer platanoides*.

The current article summarizes results of investigations of *J. mandshurica* and *P. amurense* that resumed in 2012. The study represents an analysis of the invasion of exotic species into natural communities, assessment of their naturalization and regeneration, and mapping of their distribution in the nature reserve.

2. Material and methods

The investigation was performed in the Raifa area of the Volga-Kama State Nature Biosphere Reserve. The territory under consideration is unique in the diversity of forests and represents the main variants of taiga, mixed, and deciduous communities. The nature reserve is geographically located in the northwest of the Tatarstan Republic. According to the natural zoning [8], its territory lies within the borders of the western Kazan terrace-valley region of Eastern European pine and deciduous-pine forests on high terraces above the floodplain of the Volga River, where sod-podzolic sandy loam soils prevail. The climate is temperate continental. The average temperature is –13.8°C in January and +19.1°C in July. The annual precipitation amount is 509 mm. The Raifa forest district was a scientific experimental station of the higher forest school in the Volga region since 1919. In the years 1922-1964

in Raifa, various forestry studies were carried out, including forest planting and acclimation of exotic tree species [9].

The study was done in Raifa blocks 76 and 75. Living individuals of *J. mandshurica* and *P. amurense* were exposed to an extensive analysis including (i) assessment of the morphometry of vegetative and generative organs to describe ontogenesis; (ii) dendrochronological analysis to specify the calendar age and tree-ring widths by the method described in [9], (iii) dendroclimatic analysis of tree-ring data to reveal the influence of climate on wood growth; (iv) analysis of the survival rate of tree specimens in different age groups; (v) assessment of the population growth and state.

3. Result and discussions

Ontogenetic groups (stages of plant development) and calendar age of examined individuals of *J. mandshurica* and *P. amurense* were determined using the morphological, dendrochronological and statistical methods. This allowed identifying of ontogenetic structure of their modern populations, as well as tree abundance and density of *J. mandshurica* and *P. amurense* generations that appeared in certain years [11].

Table 1. Average height and diameter of *J. mandshurica* and *P. amurense* trunks under various growth conditions.

Location	Calendar age (ontogenetic group)	Trunk height, m	Trunk diameter, cm
<i>Juglans mandshurica</i>			
Far East [2], native habitat	8 years (im)	2	4
	20 years (v)	6	8
	50 years (g)	14	20
Raifa, block 76 [7], data obtained in 1973	24 years (g1), generation 1	13	11
Raifa, block 76, pure culture [11], data obtained in 2015	7 years (im), generation 3	2	2
	14 years (v), generation 3	8	9
	24 years (g1), generation 2	14	26
	31 years (g1), generation 2	17	40
	37 years (g1), generation 2	20	49
Raifa, block 75, mixed planted stand [7], data obtained in 1973	60 years (g2), generation 1	22	55
	28 years (g1), generation 1	11	10
	35 years (g1), generation 1	14	30
	32 years (g1), generation 1	17	17
Raifa, block 75, mixed planted stand [11], data obtained in 2015-2016	7 years (im), generation 3	2	2
	30 years (g1), generation 2	16	22
	35 years (g1), generation 2	19	27
Raifa, Dendrological Garden, block 31 [4], data obtained in 2015	86 years (g2) generation 1	20	55
	60 years (g1) generation 1	17	38
<i>Phellodendron amurense</i>			
Far East [6], native habitat	100 years (g2-g3)	20-25	70
Raifa, block 85, mixed planted stand	45 years (g2), generation 1	16	19
Raifa, block 75, mixed planted stand	24 years (g1), generation 1	8	8
Raifa, block 76, pure culture [6] data obtained in 1973	24 years (g1), generation 1	11	8
Raifa, block 76, pure culture [12], data obtained in 2015	67 years (g2), generation 1	23	28
	50 years (g2), generation 2	18	23
Raifa, Dendrological Garden, block 31 [4], data obtained in 2016	80 years (g3), generation 1	6	22

As a result of the dendrochronological analysis of 26 model trees of *J. mandshurica*, we found first-generation trees aged 60-65 years, second-generation trees aged 30-37 years, and third-generation trees aged 1-14 years (table 1). Examining 10 model trees of *P. amurense*, we found first-generation trees aged 65-67 years (forest plantation of 1949) and trees aged about 50 years (seed germination in 1964, possibly the second generation of trees) [12].

Although the ecological demands of the two Far Eastern species are similar, their acclimation was significantly dependent on the biological characteristics. *J. mandshurica* blossoms in May and has wind pollination, these characteristics are favorable for fruit setting: May is a leafless period for most of the native species, this is the time when leaves of the main forest-forming species (linden and maple) just beginning to open, which considerably reduces competition for light and wind. On the contrary, *P. amurense* blossoms in June when deciduous trees (linden and maple) have developed leafy crowns, which limits the amount of light and affects blossoming. *P. amurense* has no natural pollinators in the Middle Volga; this in fact reduces the success of fruit setting, because pollination occurs with the help of occasional insects.

According to the current measurements and to the analysis of published data, generative individuals of *J. mandshurica* undergoing acclimation to the temperate conditions of the Middle Volga region are higher and have bigger diameter of trunks than individuals studied in the natural habitats of the Russian Far East. The third-generation immature trees seem less adapted to the temperate climate: their average height is 1.8 m (maximum height is 2.5 m, registered in block 76), while the diameter varies from 1.7 to 2.3 cm, which often leads to breaking of trunks during the autumn-winter period.

Several sample plots of 200-400 m² covered the area studied (both forest blocks 75 and 76). The abundance and density of tree specimens belonging to different plant developmental groups were assessed. The population of *J. mandshurica* (block 75 and 76) has trees of all stages of development: germinating seedlings and juvenile individuals account for 45-55% of the total population (calculated in average over 5 years data), immature and virginile trees account for 10-15%, young generative individuals for 20-30%, and mature generative specimens for about 5%. On the whole, to date, the density of *J. mandshurica* trees representing the first generation in the pure culture plantings (block 76) decreased by 30 times, from 0.36 trees/m² to 0.012 trees/m². In the mixed stand (block 75), the density of *J. mandshurica* was 0.71 trees/m² in 1973, no mature generative trees survived until the present time.

The population of *P. amurense* is declining. There are almost no young trees. In 2016, two shoots were registered at the base of a fallen and decaying tree. In 2015, the density of *P. amurense* was 0.005 trees/m², although the density of this species in 1973 [7] reached 0.21 trees/m², which means that the population has considerably decreased. Most first-generation trees of *J. mandshurica* and *P. amurense* died in the cold winter of 1978-1979 when the temperature did not rise above -40°C during 7-10 days. As a result, natural forest-forming species began to expand, which led to the forest regeneration process finalized by forming of linden forest with goutweed (*Aegopodium podagraria*) and hazelwort (*Asarum europaeum*). This type of forests is characterized by intense competition and poor lightning conditions, which is crucial for successful development of immature and virginile specimens of *J. mandshurica* and germinating seedlings of *P. amurense*.

Table 2. Survival rate and population growth* of pre-generative *J. mandshurica* individuals.

Ontogenetic groups	Survival rate / population growth			
	Plot 1		Plot 2	
	b/t 2015 & 2013	b/t 2016 & 2015	b/t 2015 & 2013	b/t 2016 & 2015
Germinating seedlings	100 % / 96 %	97 % / -70 %	100 % / 40 %	100 % / -86 %
Juvenile	79 % / 54 %	100 % / 4 %	94 % / 28 %	100 % / 22 %
Immature	88 % / 25 %	100 % / 63 %	81 % / -19 %	71 % / -29 %

* positive population growth corresponds to increase, negative growth corresponds to decrease; in percent of population increased or decreased

Growth rate and the dependence of germinating seedlings and juvenile trees on light are the important biological characteristics of *J. mandshurica* and *P. amurense*. The survival rate and population growth over a number of years contribute to an understanding of the stability of the population and its development. The calculated survival rate of young trees in the *J. mandshurica* population is shown in table 2.

The survival rate of pre-generative groups of *J. mandshurica* is positive in general, but depends on climatic conditions. Elimination of young trees begins at the immature and virginile plant stages. Due to the lack of incoming light the young trees grow up to 2-6 m in height and develop large leaves and crowns. However, the tree radial growth is very small, thus the trunk diameter is only 2-4 cm. This leads to a situation when the trunk can not withstand the weight of a tree and breaks. Another mechanism of elimination of immature trees aged 4-5 years is death of the apical regeneration bud during the winter period. In this situation, the process of plant development resumes when a new lateral shoot is formed from the dormant lateral buds on the trunk, which prolongs their ontogenesis up to 8-10 years.

The statistical analysis of individual tree-ring chronologies of *J. mandshurica* and *P. amurense* revealed that the rates of the radial growth of *J. mandshurica* are higher than for *P. amurense* (table 3).

Table 3. Statistics of individual tree-ring chronologies for *J. mandshurica* and *P. amurense*

Species	Mean correlation with master chronology	Average tree-ring width, mm	Standard error	Average sensitivity	Autocorrelation
<i>J. mandshurica</i>	0.35	3.3	1.4	0.29	0.62
<i>P. amurense</i>	0.43	2.0	0.7	0.19	0.66

The published studies on *J. mandshurica* report that grow is most active during the first 20 years before the onset of reproduction. The current analysis done for Raifa's *J. mandshurica* shows that the radial growth of the first-generation trees over the first 20 years is 52 mm on average, as well as 89 mm for the second-generation trees, which is significantly higher ($T_{\text{Student}} = 3.48$; $p\text{-value} = 0.002$). This fact indicates that the first-generation individuals of *J. mandshurica* acclimated in the Raifa forest to produce the second-generation specimens which are characterized by a more rapid biomass development.

4. Conclusions

The research undertaken allows description of *J. mandshurica* as a successfully acclimated species to the temperate continental climate conditions of the coniferous-deciduous forests of the Middle Volga region: it has naturalized in forests of the nature reserve, has a high biomass productivity and high germination capacity of seeds, and the pre-generative specimens have a high abundance.

P. amurense species do not demonstrate successful acclimation to the conditions of forest habitats of temperate climate. Under the current circumstances, *P. amurense* does not propagate due to the intensive spreading of *Tilia cordata* and due to the development of natural secondary permanent linden forests. The radial growth, despite being stable every year, produces subtle, narrow rings. Thus, the abundance and viability of *P. amurense* decrease due to occasional droughts and cold winters typical for the temperate continental climate of the Middle Volga, due to the habitat shading, due to the low competitiveness of the species and its inability to reproduce under the conditions of the natural forest.

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