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Research Article

Growth and development of the introduced *Fraxinus* L. species in the taiga zone (Karelia)

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Abstract

Most species of woody plants indigenous to the Russian taiga are extremely sensitive to pollutants. However, many species of deciduous trees that grow in other geographical areas, including the genus *Fraxinus*, are fairly tolerant to progressive environmental pollution. For the introduction of cultivated plants into new environmental conditions, an impartial assessment of their introduction potential is required, which is possible only on the basis of comprehensive studies. The most important processes characterising the condition of plants are growth and development. The present study examined the introduction of three species of the *Fraxinus* L. genus to the middle taiga subzone. These were *F. excelsior* L., *F. americana* L. and *F. pennsylvanica* Marsh. The stems and leaves of the plants were measured once every 2–3 days over the course of two growth periods. Phenological observations were carried out between May and October over the course of 17 years. The introduction potential of the studied species was determined through visual assessment carried out in the autumn. The findings showed that the growth of shoots and leaves in the studied *Fraxinus* species began in late May-early June, varying between species by 1–5 days. The cessation of shoot and leaf growth in the studied *Fraxinus* species, which occurred in July, varied by up to ten days. The dates of onset and culmination of the growth of shoots and leaves appeared to be determined primarily by air temperature, with a year-by-year variability of 3–7 days. All the studied *Fraxinus* species showed a high degree of introduction potential and can be successfully used for gardening and landscaping purposes in the middle taiga subzone.

Keywords

development, *Fraxinus*, growth, introduction, leaves, phenology, phenophases, shoots

Introduction

As levels of environmental pollution grow every year, demand for access to green spaces is increasing. Most indigenous species of woody plants in the Russian taiga zone are extremely sensitive to pollutants (Plotnikova and Gubina 1986). However, many species of deciduous trees in other geographical areas, including the genus *Fraxinus*, are fairly tolerant to progressive environmental pollution (Kolesnichenko 1985). Moreover, many species of the *Fraxinus* genus are aesthetically pleasing (Chernodubov 2012) and highly resistant to the harsh conditions of the taiga zone (Kolesnichenko 1985).

Therefore, the prospective introduction of these species to the taiga zone becomes increasingly attractive. Selecting the correct species and integrating them into the local flora requires comprehensive and in-depth assessment. The degree to which the seasonal rhythms of plant growth and development correspond to the dynamics of environmental factors is one of the most informative introduction criteria (Kolesnichenko 1985). It is this integral indicator that most clearly and accurately indicates compatibility with a given set of environmental conditions, characterising the relationships between these conditions and the adaptations in the plant itself (Lapin 1967). The results of such studies permit an assessment of the adaptation of plants to new environmental conditions and the evaluation of their introduction potential.

In general, the specifics of seasonal development in deciduous woody plants are not widely addressed in Russian scientific literature. *The objective of this study* was to determine the specificities of seasonal growth and development in the introduced *Fraxinus* species and assess their introduction potential with regard to their establishment in the middle taiga subzone. Working hypothesis: the growth and development of the plants are determined both by their biology and the impact of environmental factors.

Materials and methods

The study was conducted at the Botanical Garden of Petrozavodsk State University, located in the middle taiga subzone. The soil type is arenaceous humic-illuvial-iron podzol. The subjects of the study were plants of three introduced *Fraxinus* L. species: common ash – *F. excelsior* L.; American ash – *F. americana* L. and green ash – *F. pennsylvanica* Marsh. The trees had been planted at the age of 6–8. Each species was represented by 15–30 specimens, whose ages ranged from 36–59 years. The trees of all species bore fruit. *F. excelsior* is native to Europe and Transcaucasia, from where it has spread to Iran, whereas *F. americana* and *F. pennsylvanica* grow in North America.

The increase in both shoot and leaf size was measured over the course of two growth periods. Using a ruler, the length of the stems (hereinafter referred to as 'shoots') of the second branching order were measured once every 2–3 days. They were measured from the southwestern part of the crown at a height of approximately 2 m from buds swelling to winter buds setting. The leaf area (upper segment) was also measured once every 2–3 days with a planimeter from the moment of separation to the complete cessation of growth. 25 shoot and leaf samples were taken from each plant. The daily gain was calculated as the sum of the differences in a studied parameter divided by the number of days in the period (Molchanov and Smirnov 1967).

Phenological observations were carried out over the course of 17 years from April to October once every 3 days using the technique described by E. N. Bulygin (1979). These observations served to record the beginning of such phenophases as swelling and bursting of vegetative and reproductive buds, beginning and end of shoot growth, segregation, flushing, growth cessation, colouring and shedding of leaves, corking of shoots, budding, blossoming, fruit inception, ripening and drop. A given phenophase was considered to have occurred if it was observed in at least 30% of the shoots of all specimens.

The introduction potential of the plants was assessed visually using the methods of P. I. Lapin and S. V. Sidneva (Lapin and Sidneva 1973).

Meteorological data was acquired from the Sulazhgora weather station (Karelian Hydrometeorological Observatory), located 3 km south-west of the Botanical Garden. Mathematical processing of the study results was carried out with the use of the STATISTICA software. The correlation coefficients and differences between the mean values were verified to determine their reliability. The elementary statistics obtained demonstrated, among other things, that the experiment accuracy rate was fairly high (5–6%), while the variation coefficient was low (18–22%).

Results

Shoot growth

The present study demonstrates that shoot growth in the *Fraxinus* species starts in late May/early June and may vary from year to year by 7–12 days. Differences in shoot growth initiation between different species, however, does not exceed 4–5 days (Table 1).

The termination of shoot growth varied from year to year by, at most, 5–12 days. The onset of this phenophase in various *Fraxinus* species, occurring in late June and early July, differed by only 6 days. According to N. V. Shkutko, species adapt more readily to new climatic conditions when the variability of the start and end dates of their phenophases are low (Shkutko 1991). According to our data, the greatest variability in the dates of shoot growth cessation (12 days) was present in the species *F. americana* and *F. pennsylvanica*.

Year-by-year changes in the start and end dates of shoot growth had an impact on the duration of shoot formation, which varied between 23 and 29 days depending on the plant species (Table 2).

The culmination of shoot growth in the studied *Fraxinus* species, which took place in mid-late June, was found to vary little over the years of observation (3–7 days). The maximum daily gain in shoot size in the studied *Fraxinus* species varied significantly between the years of study. Both its smallest value (1 mm / day) and its largest value (16 mm / day) were found in individuals of the same species, *F. excelsior*. The year-by-year change in the maximum increase in shoot size of the studied species also varied greatly (50–160%) (Table 2).

The observed variability in the duration of growth and growth rate of *Fraxinus* shoots had a corresponding effect on their annual total growth. While year-by-year variability of the shoot length in all the studied *Fraxinus* species did not exceed 100%, Table 2 demonstrates that *F. pennsylvanica* had the longest shoots (an average of 5 cm).

Results obtained during this study suggest that the annual growth rate of shoots is determined not by duration of growth, but in fact by differences in growth intensity. In 2012, the shoot length in *F. pennsylvanica* was 4 times that of *F. americana*, despite the duration of growth in these species being the same.

Leaf growth

These studies allowed us to establish that the initiation of leaf growth (phenophase 'leaf segregation on

Table 1. Temperature regime during the growth of shoots (in the numerator) and leaves (in the denominator) in various *Fraxinus* species

Species	Years of observation	Beginning of growth			Growth culmination			End of growth		
		Date	Daily average air temperature, °C	Accumulated positive temperatures, °C	Date	Daily average air temperature, °C	373 679	Date	Daily average air temperature, °C	Accumulated positive temperatures, °C
Fraxinus excelsior	2008	6VI	10.7	329	12 VI–16 VI	11.8	402	29 VI	17.0	609
		20VI	18.1	474	23 VI–25VI	20.9	402	9 VII	13.7	764
	2012	19 V	14.0	150	25 V–22 VI	13.9	353	4 VII	18.7	346
		19 V	11.9	254	3VI–1VII	13.9	566	8 VII	16.5	777
F. americana	2008	2VI	13.5	286	9 VI–12 VI	10.4	314	29 VI	17.0	609
		20VI	18.1	474	26 VI–29VI	13.6	437	9 VII	13.7	764
	2012	14 V	12.6	113	25 V–18 VI	13.7	373	11 VII	16.0	450
		19 V	11.9	254	5VI–4VII	14.6	566	14 VII	16.4	311
F. pennsylvanica	2008	2VI	13.5	286	12 VI–16 VI	11.8	402	29 VI	17.0	609
		20VI	18.1	474	26 VI–29VI	13.6	470	9 VII	13.7	764
	2012	14 V	12.6	113	25 V–22 VI	13.9	373	11 VII	16.0	450
		19 V	11.9	254	5VI–6VII	14.6	679	20 VII	16.4	278

Table 2. Some characteristics of the growth of shoots (in the numerator) and leaves (in the denominator) in various *Fraxinus* species

Species	Years of observation	Maximum daily gain, mm/mm^2	Annual growth, cm/cm^2	Growth duration, days
Fraxinus excelsior	2008	16±1.0	4.7±0.2	24±1
		6±0.2	16±0.7	20±1
	2012	1±0.1	1.9±0.1	23±1
		9±0.4	19±1.0	51±2
F. americana	2008	12±0.5	2.6±0.1	28±1
		12±0.4	36±1.9	20±1
	2012	2±0.1	1.5±0.1	29±1
		10±0.4	14±0.8	57±2
F. pennsylvanica	2008	10±0.3	3.4±0.2	28±1
		9±0.3	26±0.9	20±1
	2012	5±0.2	6.5±0.3	29±1
		8±0.3	11±0.5	63±3

shoots') in the studied *Fraxinus* species commences on the 19th or 20th of May with little variation (Table 1).

The year-by-year variability in the cessation of leaf growth in *Fraxinus*, which occurs in July, was 1–11 days. However, in 2008 there were no differences between the species, and in 2012, leaf growth in the *F. excelsior* species ended 1–2 weeks earlier than the other species.

Year-by-year differences in the start and end dates of leaf growth in certain *Fraxinus* species also lead to corresponding changes in their formation duration, which varied between 20 and 63 days (Table 2).

It was found that the culmination of leaf growth (late June–early July) did not necessarily correspond to the species biology. However, in *F. excelsior*, this phenophase occurred 2–3 days earlier than in the other species. These differences, which reached a maximum of 6 days, were traceable over the years of study.

The maximum leaf growth in different *Fraxinus* species also varied significantly. Its greatest value (10–2 mm^2 / day) was found in *F. americana*, with leaf growth in other species measured at 1.5–2 times less. It should be noted that the maximum leaf growth in the studied *Fraxinus* species over the years of the study had a variability of 10%.

Significant variability in the intensity of leaf growth leads to corresponding differences in annual growth. The area of the lamina formed during different growth periods varied by a factor of 1.5–2. Table 2 demonstrates that the leaf area scarcely differed across the different species.

Plant development

A review of statistical analysis results showed that the average phenophase date error over long time periods was insignificant, in most cases not exceeding 1–2 days (Table 3). Only in *F. americana* did this value increase for 3.9 days for the fruit ripening phase, while in *F. pennsylvanica* the corresponding value for the fruit drop phase was up to 8.8 days.

The fruit ripening phase had the highest phenophase date variability in *F. americana*, with a standard deviation of 42.9 days. For the phenophases of other species, the standard deviation was only 4–7 days. Many authors (Bulygin 1979; Shkutko 1991) have found that the higher the degree of adaptation of introduced species to new climatic conditions, the lower the year-by-year variability of the phenophase date.

The present study demonstrates that the rhythm of seasonal development in *Fraxinus* species has certain peculiarities. According to the average long-term data, the fastest (11 V) swelling of vegetative buds began in *F. americana*, with other species following suit 1–6 days later. The bursting of vegetative buds also occurred sooner in this species (21 V), as compared with *F. pennsylvanica* and *F. excelsior* (26 V).

Linear shoot growth began 21–28 days after the onset of vegetative bud swelling. In *F. pennsylvanica*, this phenophase could be observed 3 days earlier than in the other species (5–8 VI). Shoot growth in this species ended later than in the other species (22 VII).

F. excelsior had the earliest dates (9 VII) of shoot base corking, while in other species this occurred 4 days later. The process of shoot corking along the entire length ended (7 VIII) 4–8 days earlier in *F. americana* than in the other studied species.

Leaf segregation in the studied species began in *F. pennsylvanica on* 28 V, while *F. americana* and *F. excelsior* entered this phase 4 days later. Leaf growth ended most quickly (15 VII) in *F. americana*; in the other species – 18 VII.

Table 3. Statistical indicators of the seasonal development of various species of the genus *Fraxinus**

Phenophases and statistical indicators		Species		
		Fraxinus americana	*F. pennsylvanica*	*F. excelsior*
1		2	3	4
Ki[1]	M	11 V	12 V	17 V
	m_M	0.4	0.5	0.5
	G	5.3	7.2	7.3
Ki[2]	M	21 V	22 V	26 V
	m_M	0.4	0.4	0.4
	G	5.1	6.1	6.1
Sh[1]	M	5 VI	2 VI	8 VI
	m_M	0.4	0.8	0.6
	G	5.8	10.6	8.2
Sh[2]	M	19 VII	22 VII	16 VII
	m_M	0.9	0.9	0.6
	G	12.8	13.1	8.5
Lig[1]	M	12 VII	12 VII	9 VII
	m_M	0.6	0.5	0.4
	G	9.1	7.8	6.2
Lig[2]	M	7 VIII	3 VIII	30 VII
	m_M	0.5	1.1	0.5
	G	8.2	14.2	7.5
Le[1]	M	28 V	28 V	1 VI
	m_M	0.4	0.4	0.7
	G	6.7	6.4	8.7
Le[2]	M	5 VI	5 VI	10 VI
	m_M	0.5	0.5	0.7
	G	7.3	6.7	9.4
Le[3]	M	15 VII	18 VII	18 VII
	m_M	0.5	0.8	1.1
	G	6.9	11.5	15.8
Le[4]	M	10 IX	11 IX	15 IX
	m_M	0.4	0.5	2.1
	G	6.5	7.2	29.5
Le[5]	M	1 X	28 IX	6 X
	m_M	0.5	0.5	0.5
	G	7.4	7.3	5.9
Bl[1]	M	20 V	20 V	ND
	m_M	0.5	0.5	
	G	6.9	6.1	
Bl[2]	M	27 V	27 V	ND
	m_M	0.4	0.4	
	G	5.7	4.6	
Bl[3]	M	29 V	29 V	ND
	m_M	0.5	0.3	
	G	5.8	4.1	
Bl[4]	M	1 VI	2 VI	ND
	m_M	0.7	0.3	
	G	9.5	4.4	
Bl[5]	M	14 VI	15 VI	ND
	m_M	0.6	0.4	
	G	7.7	5.8	
Fr[1]	M	10 VI	10 VI	ND
	m_M	0.5	0.4	
	G	6.6	5.4	
Fr[2]	M	24 VII	26 VII	ND
	m_M	1.2	0.8	
	G	14.7	10.6	
Fr[3]	M	2 IX	5 IX	ND
	m_M	3.9	1.4	
	G	42.9	15.1	
Fr[4]	M	10 X	3 X	ND
	m_M	2.3	8.8	
	G	11.7	17.7	

*Note: Phenophase notation: Ki[1] – vegetative bud swelling; Ki[2] – vegetative bud bursting; Sh[1] and Sh[2] – beginning and end of linear growth of shoots; Lig[1] – corking of shoot bases; Lig[2] – corking along the entire leading shoots; Le[1] – leaf segregation on shoots; Le[2] – leaves do not reach normal sizes; Le[3] – end of leaf growth and maturation; Le[4] – colouring of leaves; Le[5] – leaf drop; Bl[1] – reproductive bud swelling; Bl[2] – reproductive bud bursting; Bl[3] – budding; Bl[4] – beginning of blossoming; Bl[5] – end of blossoming; Fr[1] – fruit inception; Fr[2] – fruit growth to ripe size; Fr[3] – fruit ripening; Fr[4] – dropping of ripe fruits.
M – average phenophase date; m_M – average phenophase date error, days; G – standard phenophase date deviation, days

F. americana and *F. pennsylvanica* entered the leaf colouring phase simultaneously (10 IX and 11 IX), with *F. excelsior* following 5 days later. Leaf shedding began first in *F. pennsylvanica* (28 IX), occurring some 2–8 days later in the other species.

The phase of reproductive bud segregation on shoots occurred simultaneously in *F. americana* and *F. pennsylvanica* (20 V). The bursting of buds, budding phase, beginning and end of blossoming, and fruit growth to mature size in the studied species also occurred at approximately the same time (27 V, 29 V, 1–2 VI, 14–5 VI and 24–26 VII, respectively).

The first to enter the fruit ripening phase was *F. americana* (2 IX), with *F. pennsylvanica* following 3 days later. The process of fruit drop began first in *F. pennsylvanica* (3 X), occurring 7 days later in *F. americana*.

Discussion

Physiological responses of plants, as exhibited e.g. in terms of growth, to external conditions are determined by the state of the environment and the degree of species tolerance to environmental factors (Shelford's law). Hence, through a determination of environmental factors during key growth periods, as well as observations of the plants' form and the strength of the relationship between their growth dynamics and variability, the degree of their correspondence to the plants' requirements can be determined.

The study results showed that shoot growth in the studied *Fraxinus* species began when the average daily air temperature rose to between +12 and +14 °C. The onset of this phenophase was found to weakly depend on the temperature regime in the previous period. This was supported by the fact that the accumulated positive temperatures in this time period varied significantly between 113 and 329 °C.

During the growth cessation of *Fraxinus* shoots, the average daily air temperature and accumulated positive temperatures also varied substantially from +10.4 to +13.9 °C and 164 to 609 °C respectively. These results showed that the termination of this phenophase in the *Fraxinus* species was not related to the temperature regime, but, was probably instead due to the species genotype. Therefore, in the studied region, we can conclude that the temperature is high enough for the vegetative buds of all the studied introduced species to complete their annual development cycle.

It was shown that a specific air temperature is not required for the various *Fraxinus* plant species during the period of maximum shoot growth. Growth culmination can occur as soon as an average daily air temperature of 10 °C is reached. The accumulated positive temperatures during this period were quite stable (314–402 °C), suggesting that these parameters have a significant effect on the shoot growth rate in the studied species.

Correlation analysis allowed us to establish the nature and degree of the impact of some environmental factors on the intensity of shoot formation. In general, a reliable positive weak or medium correlation (r = +0.3 to +0.6) was detected between the shoot growth rate and air temperature. A significant impact of air temperature on the development of the studied *Fraxinus* species was described previously (Chernodubov 2012).

A positive weak and medium correlation (*r* = +0.3 to +0.7) was established between the dynamics of the daily shoot growth and the variability in relative air humidity. The correlation between the shoot growth dynamics of the studied species and the amount of precipitation was much weaker. A reliable and rather noticeable dependence of the shoot growth rate on solar radiation was expressed only in *Fraxinus pennsylvanica* (r = +0.6 to +0.7). The impact of solar radiation on the development of the studied *Fraxinus* species was found to be significant in previous studies (Koltsova 1986).

Following the two-year observations, it can be concluded that the leaf growth in the studied species can begin even with an increase in the average daily air temperature up to +12 °C. Leaf formation terminates during relatively warm periods (+14 to +16 °C), when the accumulated positive temperatures reach between 300 and 700 °C.

For maximum leaf growth, these plants require a specific air temperature of +14 °C; this does not vary between the studied species. The accumulated positive temperatures during this period over the years of the study reached 400–600 °C.

Correlation analysis highlighted a weak or moderate strength positive correlation (r = +0.3 to +7) between the growth rate of leaves and the dynamics of air temperature.

The research of many authors (Lapin 1977; Plotnikova and Gubina 1986) has demonstrated conclusively that the peculiarities of the development of various plant species are due to their unequal demands when it comes to environmental factors. Thus, by determining the tolerance range of the main phenophases to environmental factors, we can characterise the adaptation of each species to a given set of habitat conditions.

When analysing the environmental state at the beginning of the phenophases, a very strong year-by-year variability in relative humidity, precipitation, and total solar radiation was found, which indicates an absence of the desired connections. However, the air temperature regime at the onset of the regular phenophase during the study period remained quite stable, only slightly differing between the different plant species.

From our findings, we can conclude that vegetative bud swelling in different *Fraxinus* species begins at rather close average daily air temperature values of between +7.9 and +10.7 °C and that vegetative bud bursting in all the species occurs at almost the same temperature (+10.3 to +10.7 °C).

Initiation and termination of shoot linear growth, shoot corking, leaf segregation on shoots, completion of shoot growth and leaf coloration are all phases which began at almost the same air temperature in all the species.

F. pennsylvanica and *F. excelsior* exhibited leaf shedding at the highest temperature of the species studied (+4.5 to +4.6 °C), with *F. americana* shedding at an air temperature of +1.6 °C.

Moreover, *F. americana* was found to be less sensitive to air temperature in the phase of reproductive bud segregation, which occurred at +9.5 °C. In the studied species, the phenophases of reproductive bud bursting and budding began at almost the same temperature regime (with a difference of no more than 2 °C).

It can be concluded that the beginning and end of blossoming, fruit inception and their ripening in all the species also occur at the same air temperature. The fruit ripening phase begins at the lowest temperature in *F. pennsylvanica* (+8.7 °C), while in *F. americana* the corresponding phase begins at +12.1 °C. Fruit dropping in the studied species takes place when the air temperature decreases to 0 to +1.5 °C.

During the present study an appropriate analysis was carried out to determine the direction, form, and strength of the correlation between environmental factors and the phenophase onset dates. It was found that the direction and strength of the correlation between the phenophase periods and environmental factor dynamics can vary significantly depending on the species, the phenophase and the factor itself.

The study results show that the correlation is straightforward and reliable in most cases. While it can be both positive and negative in direction, its strength can vary over a very wide range, depending on the plant species and phenophase. Thus, in all the studied species, a negative correlation was revealed between the dynamics of air temperature and the dates of shoot growth termination (r = –0.5 to –0.6), the achievement of a mature size (r = –0.8) and ripening (r = –0.8 to –0.9) of fruit and a positive correlation between the dynamics of air temperature and the start date of blossoming (r = +0.5 to +0.6).

A correlation between the phenophase periods and relative air humidity dynamics was only observed in a small number of cases. Thus, for *F. americana*, this correlation was established with the 'fruit growth to ripe size' phenophase (r = +0.7); for *F. pennsylvanica*, the correlation was established with the 'complete shoot corking' phenophase (r = +0.7).

A weak and often unreliable correlation was established between the dates of the studied phenophases and the dynamics of precipitation (r = –0.1 to + 0.3).

It was found that the dynamics of solar radiation negatively correlates with the termination of shoot growth (r = -0.6 to –0.7), fruit growth to ripe size (r = –0.9) fruit ripening (r = –0.7 to –0.8) and leaf colouring (r = –0.3 to –0.7).

When assessing the prospects of the introduced species, the following indicators were taken into account: winter hardiness, habit maintenance, shoot-forming ability, regularity of shoot growth, generative development ability, as well as the possibility of artificial vegetative propagation and decorative effect.

Table 4 demonstrates that all the studied species are highly promising (78–100 points). For all indicators except one, the studied species are identical. Increased winter hardiness puts *F. excelsior* in first place in terms of degree of introduction potential. Similar conclusions regarding this species were previously drawn by M. A. Koltsova (Koltsova 1986), E. N. Kulakova (Kulakova 2017), V. L. Meshkova, and V. L. Borisova (Meshkova and Borisova 2017).

Table 4. Assessment of the introduction potentials of *Fraxinus* species, points

Species	Shoots lignification	Winter hardiness	Habit maintenance	Shoot-forming ability	Height gain	Ability to generative development	The possibility of reproduction in culture	Total prospect assessment
Fraxinus excelsior	20	25	10	5	5	25	10	100
F. americana	20	5	10	3	5	25	10	78
F. pennsylvanica	20	5	10	3	5	25	10	78

Conclusion

For the first time, the seasonal dynamics of the growth and development of the species of the genus *Fraxinus* in the taiga zone was studied. Data including the dates of the beginning, culmination, end, and duration of the phenological phases were obtained. The present study showed that shoot and leaf growth in the studied *Fraxinus* species began in late May-early June, while differences in the initiation of growth between species did not exceed 1–5 days. The cessation of shoot and leaf growth in the studied *Fraxinus* species occurred in July and varied by up to 10 days. *F. pennsylvanica* was found to have the largest shoot sizes, which was most likely a result of a high maximum intensity during growth periods compared with other species.

The dates of the onset and culmination of the growth of shoots and leaves are determined primarily by air temperature, with a year-by-year variability of 3–7 days. Moderate and weak relationships were identified that connect the growth rate of shoots and leaves in the studied species to the dynamics of temperature and humidity, as well as to atmospheric precipitation and solar radiation factors.

The present study found that the phenophase dates showed little variation across all *Fraxinus* species studied. Air temperature had the most significant impact on the dates of *Fraxinus* phenophases when compared with other environmental factors. The direction and strength of this correlation is determined by the type of plant and the features of the phenophase itself. There was a generally weak and negative correlation between phenophase periods; this was also true of the dynamics of air humidity and precipitation. Termination of shoot growth, fruit development and leaf bloom phenophases negatively correlated with the dynamics of total solar radiation.

In conclusion, all the studied *Fraxinus* species show a high degree of introduction potential and can be successfully used for gardening and landscaping purposes in the middle taiga subzone.

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