Growth of needles and shoots for thirteen species of the *Pinaceae* family: a case study in the Central Black-Soil region

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Abstract. The growth features of needles and shoots for 13 species of coniferous woody plants from the pine family have been revealed in Voronezh region (Russia). Eleven species are representatives of the main genera of the *Pinoid* clade. The factors affecting vegetation have been identified according to the results of phenological observation and length measurements. *Pinus sylvestris* showed the largest annual shoots growth, *Picea abies* and *Picea pungens* – smallest. The longest needles have trees of genus *Pinus* (for example: *P. flexilis* – 7.7 cm, *P. pallasiana* – 7.0 cm). The most important factor for the beginning of the vegetation is the air temperature in April, threshold temperature (triggering the growth processes) is +2…+ 4°C. The species having late beginning and late ending of growth (*Pinus sylvestris*, *Pinus flexilis*, *P. strobus*) are less hardy than the earlier growth species. All the studied species are in good sanitary condition. They enter the phases of pollen dispersion and seed-bearing, are fully adapted to the Central Black Soil region. All of them can be introduced into the range of plants for landscaping and reforestation of the region and the regions having close climatic conditions.

1. Introduction

The success of the plants introduction is closely related to their adaptation, which is based on the breadth of certain features variation [1], i.e. the adaptation of their functions and structures to new environmental conditions. Some species are successfully integrated into a new biosystem, while others are defeated. The question of factors contribution in the most effective invasion of the species remains to be open [1]. The introduction of woody plants contributes to an increase in the biodiversity of cities, the appearance of species with higher biological productivity, new decorative qualities which are not typical for the region of introduction [2].

The *Pinaceae* family occupies a dominant position among coniferous plants, both in the number of species and in distribution in the Northern hemisphere [3]. Species of this family are predominant photosynthetic woody species in boreal forests [4]. Trees will be able to make a significant variety in the dendroflora of cities, increasing their decorative, as well as having phytoncide and anti-asthmatic properties [5]. They improve the quality of the environment.

The *Pinaceae* family consists of 11 genera and is divided into 2 clades [3], which differ in the features of the transcriptome: *Pinoid* (*Cathaya, Larix, Picea, Pinus and Pseudotsuga*) and *Abietoid* (*Abies, Cedrus, Keteleeria, Nothotsuga, Pseudolarix and Tsuga*).

Trees of different ecological and geographical origin have various biological features and adaptive reactions associated with the natural conditions of their origin. The ecological reactions of introduced
species depend on many factors: the origin of the species (hereditary genetic component), the place of origin of seeds or seedlings, and the presence of symbiont organisms (bacteria, fungi-mycorrhizal agents which are peculiar to the species [6], the structure and physiology of tissues. The course of adaptation processes is most clearly expressed in the parameters of plant growth during the growing season. It is necessary to know the features of the growth of all organs to understand the growth of the tree as a whole in a changing environment [7].

The growth of vegetative organs, the presence of pollen dispersion and seed-bearing are the total results of the interaction of the introduced plant with the factors of the new environment.

Historically, arboretums have been the place of the highest concentration of introduced species and an excellent platform for studying species characteristics due to their invasion. Arboretum of Voronezh State University of Forestry and Technologies named after G.F. Morozov is a natural monument and contains a collection of woody forest-forming species and ornamental shrubs, among which a special place is occupied by representatives of the Pinaceae family. Trees belonging to the Pinoid clade: p. Larix, p. Picea, p. Pinus, p. Pseudotsuga grows in a small area. These species are the objects of our study.

The aim of the research is to reveal the growth characteristics of tree species from the Pinoid clade of the Pinaceae family (Pine) introduced in the Central Black Earth region.

2. Methods and Materials
The studies carried out on 13 species of woody Pinaceae: Abies nephrolepis (Trautv) Maxim (Khinghan Fir), Abies sibirica Ledeb. (Siberian Fir), Larix sibirica Ledeb (Siberian Larch), Picea abies (L.) Karet (Norway Spruce), Picea glauca(Moench) Voss (White Spruce), Picea pungens "Glauc" Engelm (Blue Spruce), Picea jezoensis ajanensis (Linde. Et Lord) Fisch (Dark-bark Spruce), Pinus flexilis James (Limber Pine), Pinus pallasiana D. Don, Pinus peuce Griseb. (Macedonian Pine), Pinus silvestrus L. (Scots Pine), Pinus strobus L. (Eastern White Pine), Pseudotsuga menziesii (Mirb) Franco (Douglas-fir). All the studied species except Abies nephrolepis (Trautv) Maxim, Abies sibirica Ledeb. belong to the Pinoid clade according to their systematic position. The age of the trees varied from 17 to 24 years. All the trees were in good sanitary condition, annually bear fruit, so their successful adapted to the conditions of the Central Black Soil.

Voronezh located in the European part of Russia (geographical coordinates: 51.660781, 39.200269) in the temperate climate zone. According to the local weather station of Voronezh State Agricultural University, the average annual temperature was +8.0°C, average January temperature -9.5°C, average July - +20°C; the absolute minimum – 36°C (January), absolute maximum +37.5°C (July). The duration of the growing season at higher +10°C was 152 days (from April 29 to September 27). The sum of effective temperatures during the growing season was 2800°C. The frost-free period is 150-155 days. The latest frost was observed on June 3, the earliest - in autumn, September 2. The time of onset of stable snow cover was 30-40 cm. Average annual rainfall was 670 mm. South-West, South-East and South winds prevail in winter; in summer - South-West, West and North-West, bringing drought. Relative humidity in summer was 45-60%, in winter - 75-90%. Meteorological conditions in winter, as well as at the beginning and end of the growing season, determine the results of introduction.

Climate data (air temperature and humidity) were provided by weather station of Voronezh State Agricultural University.

One of the most important indicators of invasive plants adaptability to the new conditions of the growth place can be the rhythm of growth processes [8]. The growth rhythm studied by Molchanov A.A. and Smirnov V.V. method [9] by systematic measurements and phenological observations. The length of shoots and needles measured by ruler every day during they growth. We identified the day of beginning and day of the end of needles and shoot growth by daily measuring they length from the bud ring to its apex in mm growth duration determined as the amount of shoot growth days, Statistical processing of the results by Stadia statistical program was applied to the lengths of apical and lateral shoots, needles.
3. Results and discussion

Climatic indicators of the beginning of the growing season in 2018 were provided by weather station of Voronezh State Agricultural University (weather station #34123 "Voronezh", geographical coordinates 51° 40' N., 39°13' E.). Comparative analysis of the dynamics of air temperature and relative humidity for some days of May and June 2018 are given at figure 1. There are no significant changes (increase and decrease) in the average air temperatures. On June 23, there was a slight increase in temperature to 30°C, while the relative humidity does not exceed 20%. During this time, the amount of precipitation was 0 mm. Thus, the beginning of the growing season had stable temperature, but had precipitation deficit. For many regions of the Northern hemisphere, one of the typical climatic features is long periods of drought, forcing plants to adapt to water scarcity.

![Figure 1](image-url)

**Figure 1.** Dynamics of maximal air temperature(a) and maximal relative humidity (b) in May and June 2018 for Voronezh (geographical coordinates: 51.660781, 39.200269).

According to the results of phenological observations and measurements of the needle and shoot growth, the terms of the beginning and end of growth, length of needles and shoots were determined (table 1, 2).

Buds in pine species in the arboretum of Voronezh State University of Forestry and Technologies begin to swell in the first decade of April. The duration of this phase in the genus *Larix* (larch) species lasts from 4 to 16 days, in the *Picea* (spruce) genus – from 8 to 24, in the *Pinus* (pine) genus – from 6 to 32. *Larix sibirica* and *Picea ajanensis* (Linde. Et Lord) Fisch are the earliest species. The growth of needles in these species begins in the middle and end of April, respectively.

Bud break in species of the *Pinus* (pine) genus occurs in the second decade of May and lasts from 8 to 12 days depending on the species. In 2018, the air temperature in April rose to +14.50°C. Swelling of the buds in all studied species came quite early (compared to previous years). In future, the uniform distribution of heat during the growing season contributes to the rapid completion of phenophases.

The phase of isolation of needles occurs in the genus *Pinus* (pine) species in the second half of May. It coincides with the most intense growth of shoots. In the genus *Larix* (larch) species growth of needles begins on short shoots. Needles reach normal sizes (24-28 mm) by May 10-12. After that, the buds on some shortened shoots begin to grow and form elongated shoots. The growth of needles on such shoots ends in early June. In *Picea glauca* (Moench) Voss - spruce gray - needles reaches normal size by May 21 (and in 2017 in spruce - in the first half of June).

There is the most intense growth of needles in the *Pinus* (pine) genus in this period, which ends in the second decade of July, *Pinus strobus* L. - July 7, *Pinus flexilis* James - July 30.

According to our observations, the formation of a wintering bud in pine species occurs in the first decade of June, while in the spruce species it was in early June. It is interesting to note the presence of
secondary vegetation in conifers. In 2018, it was observed only in individual specimens, while 2016 and 2017 it was observed in all the species. The process of lignification of the shoots and the formation of the hibernating bud of the most studied species is completed before the onset of autumn cold. This indicates a fairly high importance.

Table 1. The period of needle growth and its length for different pine species.

| Species                        | Growth, day of month | Needles length, cm in the later period of the growing (September), min…max |
|-------------------------------|----------------------|--------------------------------------------------------------------------|
|                               | Beginning…end of earliest growth | Beginning…end of latest growth |                                         |
| Abies nephrolepis (Trautv) Maxim | 3.05…25.05          | 11.05…12.06                 | 1.5±0.04                                   | 1.0…2.5                                      |
| Abies nephrolepis (Trautv) Maxim | 3.05…11.05          | 25.05…12.06                 | 1.5±0.04                                   | 1.0…2.5                                      |
| Abies sibirica Ledeb.          | 6.05…14.05          | 25.05…12.06                 | 2.1±0.05                                   | 1.5…3.5                                      |
| Larix sibirica Ledeb.          | 16.04…9.05          | 10.05…19.05                 | 2.4±0.03                                   | 1.3…4.5                                      |
| Picea abies (L.) Karet         | 7.05…27.05          | 2.06…10.06                  | 1.3±0.01                                   | 1.0…2.5                                      |
| Picea glauca (Moench) Voss     | 1.05…10.05          | 15.05…21.05                 | 1.3±0.02                                   | 0.8…1.8                                       |
| Picea pungens “Glauc” Engelm   | 16.05…30.05         | 4.06…17.06                  | 1.9±0.30                                   | 2.0…3.0                                       |
| Picea ajanensis (Linde. Et Gord) Fisch | 30.04…4.05          | 22.05…27.05                 | 1.3±0.01                                   | 1.2…2.0                                       |
| Pinus flexilis James          | 22.05…31.05         | 28.07…30.07                 | 7.7±0.05                                   | 3.0…7.5                                       |
| Pinus pallasiana D.Don        | 12.05…25.05         | 5.07…20.07                  | 7.0±0.07                                   | 8.0…18.0                                      |
| Pinus peuce Griseb.           | 15.05…27.05         | 25.06…12.07                 | 5.8±0.04                                   | 7.0…10.0                                      |
| Pinus sylvestris L.           | 13.05…27.05         | 13.07…21.07                 | 5.2±0.05                                   | 4.0…7.0                                      |
| Pinus strobus L.              | 16.05…30.05         | 20.06…7.07                  | 4.8±0.01                                   | 5.0…10.0                                      |
| Pseudotsuga menziesii (Mirb) Franco | 4.05…20.05          | 26.05…1.06                  | 2.0±0.04                                   | 1.5…3.5                                      |

In the artificial conditions of the arboretum, located in the urban area, pollen dispersion and seed-bearing in the studied species of pine occurs much earlier than in natural habitats. So in the conditions of the Voronezh State University of Forestry and Technologies arboretum (North American species (white spruce, (blue form) enter the phase of pollen release and seed-bearing at the age of 7-12 years for the first time (whereas in natural conditions, depending on the species, it takes place at the age of 20 and more years). Pollen release of both forms lasts from 3-4 days to 7-11 days. In Scots pine, pollen release begins on May 7 and lasts 6-7 days. Limber pine (Pinus flexilis James) has the latest pollen release. The timing of the onset of mass pollen release depends not only on the characteristics of the species, but also on achieving the optimum temperature.

The duration of the phase of bud swelling was twice as long as in previous years, so the pollen dispersion was moved to a later date and began at a temperature of +110 C and lasted 7 days. In conifers, especially the Pinus genus, as in most gymnosperms, the time interval between pollination and fertilization is large and lasts up to 13 months. Pollination and fertilization can occur during the vegetation period for spruce, fir, larch, and Douglas fir.

In the conditions of the arboretum of Voronezh State University of Forestry and Technologies (Russia, Voronezh region) arboretum in pine species, the fall of 3-4-year-old needles begins in August.
and continues until the spring of the next year, but the mass fall of needles occurs in October and the first decade of November. The needles length of the majority of our introduced species reaches the normal (home) size (table 2). This indicates the adaptability of the introducents to the new conditions of existence (figure 2).

Figure 2. Length of needle.

We have established that, the beginning of coniferous needles growth is observed from mid-April to mid-May in Voronezh. We observed a difference in needle length at the end of growth among the species studied. The genus Pinus have the longest needles among other species clade Pinoid. In Pinus flexilis, the growth of needles begins much later than in some representatives of this genus, but the length of the needles reaches eight centimeters. Other conifers do not have such high rates in the length of the needles.

The study of annual growth rhythm is of great importance for assessing the degree of adaptation of pine trees to new conditions of existence. As our studies have shown, the length of growth of lateral shoots in trees aged 17-24 years (table 3) depends primarily on the species.

The largest average 4 years increase in the height of the annual shoot is observed for Siberian larch (46.6±2.5 cm), the smallest – for Picea jezoensis ajanensis (11.3±2.2 cm). The results of annual growth dynamics observations of lateral shoots in coniferous trees of 5 species (table 3/figure 3) have showed that the intensity of growth varies during the growing season. It is seen from the data of the table that the growth of lateral shoots in spruce, Pseudotsuga menziesii, Siberian fir and Scots pine begins in the second decade of April.

Analyzing the dynamics of growth of side annual shoots of some species for some days in May and June 2018, we see that this feature is individual for each species. In Pinus sylvestris, which is a common native species for the Central Black Soil zone, the peak of growth (increase up to 22 mm) falls at the very beginning of the vegetation on May 19 and gradually decreases. Further increase is reduced, most likely, this is due to the formation of early wood in Pinus sylvestris in May.

The smallest and uniform amplitude increase is observed in Pseudotsuga mensiesii. A small peak is seen on June 9. Abies sibirica has a peak on June 23. For the species of spruce (Picea abies, Picea pungens “Glaucac”), two peaks of growth are seen: at the beginning of May and end of June. Given the highest growth activity, we can assume the increasing need of plants for optimum temperatures and rainfall during these periods of growth maximum.
Earlier it was shown that reaction of plants to the new environmental conditions is manifested in their rhythm of growth and development [10]. Different types of reactions to the environment changes are seen in varying degrees. They depend on the geographical location and history of the formation of these organisms. Changes in the environment are both natural and random according to Lapin [11].

**Table 2.** The dynamics of growth (time) lateral annual shoots of some pine species in arboretum of Voronezh State University of Forestry and Technologies (Russia, Voronezh region).

| Species                  | Beginning of the growth, day of month | Length of shoots on May 12, cm (annual growth rate for 2017) | Increment of shoots, mm (in 2018) |
|--------------------------|--------------------------------------|-------------------------------------------------------------|----------------------------------|
|                          |                                      | May 19 | May 26 | June 2  | June 9  | June 16 | June 23 |
| *Picea abies*            | 15.04                                | 11.1±2.2 | 9.9±0.7 | 2.0 | 1.4 | 4.3 | 5.0 |
| *Picea pungens* «Glauca» | 12.04                                | 6.0±0.5  | 10.1±2.2 | 2.1 | 1.9 | 7.1 | 10.0 |
| *Abies sibirica*         | 11.04                                | 0.8±0.2  | 1.5±0.3  | 1.4 | 2.5 | 5.8 | 2.8 |
| *Pinus sylvestris*       | 11.04                                | 21.4±2.7 | 2.0±0.9  | 0.9 | 3.2 | 3.6 | 2.4 |
| *Pseudotsuga menziesii*  | 17.04                                | 1.1±0.4  | 1.0±0.1  | 2.1 | 1.6 | 1.4 | 1.3 |

![Figure 3](image-url)  

**Figure 3.** Growth increase of lateral shoots of some pine species (in 2018).

It was also shown that *Pinaceae* has an increased number of osmoprotector proteins in the dehydrin family in comparison with other woody species. It explains the high drought resistance in spruce and other pine species, which contributes to high adaptability in spatially and temporarily changing environments [12]. Adams H. D. and Collins A. D. [13] investigated the effects of natural drought and heat treatment on the growth of shoots and needles in *Pinus edulis*. There is a decrease in the growth of shoots by more than 39% with prolonged drought, high temperature and artificial heat treatment. There is also a negative impact of high temperature on the appearance of needles on the primary axial shoots, which is manifested in the delay in the needles’ flowering for 19-57 days. The needles flowered less on the secondary axial branches. The needles did not appear with the simultaneous effects of drought and heat.
It is interesting to note that the amount of growth is influenced by a set of climatic factors, both the current growing season and the previous one. So the *Pinus koraiensis* coniferous trees [14] showed the age-dependence for response to the climatic changes. Young trees with the diameter 10-20 cm at breast height are more sensitive to changes in the average minimum temperature of the current vegetation period and meteorological factors of the previous year. Adult trees (diameter > 40 cm) were more sensitive to changes in the average temperature and the average relative humidity of the current growing season.

Terms of the beginning of shoot and needle growth vary depending on weather conditions in the same species in different years [15]. Seasonal rhythm of growth of the local species and types of exotic species from the areas with similar climatic conditions is more stable than in the species, introduce from the places with warmer climates. Our data have shown that the value of seasonal growth of shoots in different years is associated with temperature, humidity during the growth of shoots. The nature of growth also depends on their position in the crown of the tree. The lower trunk has shorter period of seasonal growth and small seasonal growth.

Schiestl-Alto, Makela [7] showed that the process leading to the beginning of growth is a long-term continuum in which it is necessary to take into account the temperature for the previous months. For Scots pine, they found that low temperatures (below +5°C) are sufficient to trigger growth. In our experiments *Larix sibirica* started growth undoes lowest temperature. The threshold temperature (triggering the growth processes) is from +2 to +4°C.

For the *Pinus sylvestris* species Schiestl-Alto, Makela [7] found that the elongation of the needle begins simultaneously with the lengthening of the shoot. According to many authors [15, 16] the length of needles is an indicator of compliance or non-compliance of new environmental conditions of biological features of introducers.

4. Conclusion
In this paper, for the first time in Central Russia, we characterized the phenological and morphological characteristics of introduced species of the Pinoid clade. In particular, it is shown that the growth activity of shoots in the studied species is different. The maximum of shoots growth in may is typical for *Pinus sylvestris*. Two maximums are typical for genus *Picea*. Growth without peaks is typical for *Pseudotsuga mensiesii*. Beginning and end of needles and shoot growth vary depending on the weather conditions of the growing season in the same species in different years. The growth of *Pinus flexilis* needles begins much later than in some members of clade Pinoid, but the length of the needles reaches eight centimeters. Other conifers do not have such high rates in the length of the needles. In the artificial conditions of the arboretum, located in the urban area, pollen dispersion and seed-bearing in the studied species of pine occurs much earlier than in natural habitats.

The influence of geographical origin on the seasonal rhythm of needles and shoot growth has already been smoothed for adult introducers, the period of adaptation of which is already decades. Most of the studied species are included in one Pinoid clade of the Pinopsidae family and are similar in many parameters that determine the functioning of the whole organism. The timing of vegetation and needles and shoot growth are the individual characteristics of the species, and not for all clade species.

The greatest increase in the height of the annual shoot in an average of 4 years is observed in Siberian larch (46.6±2.5 cm) the smallest – in spruce Ayan (11.3±2.2 cm). The value of seasonal growth of shoots depends on the temperature and humidity during growth. In some species, it is more dependent on air temperature, in others - on humidity. Terms of the beginning and end of needles and shoot growth in different species can be an indicator of their winter hardiness. The species having late beginning and late ending of growth are less hardy than the species which have earlier growth.

All the studied species are adapted to the conditions of the Central Black Earth region (temperate zone) and can be introduced into the range of plants for landscaping and reforestation of the region and regions having close climatic conditions.
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