RESEARCH PAPER

DYNAMICS OF SEASONAL CHANGES IN INTRODUCED PLANTS IN EASTERN TRANSBAIKALIA

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ABSTRACT. The article presents a comparative analysis of the seasonal development of introduced plants in the weather conditions of Eastern Transbaikalia for the growing periods from 2014 to 2019. The results presented are taken from 6-year phenological observations conducted in the arboretum of the Institute of Natural Resources, Ecology and Cryology SB RAS. We constructed the phenological spectra of the studied objects by year. We studied the main phenological indicators of vegetation the East Asian forest-steppe and Manchurian-Daurian preboreal species. We analyzed the meteorological data: the mean daily air temperatures and precipitation for the months of the growing season (2014–2019), and the sum of active temperatures and precipitation for this period.

The data on the dynamics of the development of shrubby plant species in conditions of Eastern Transbaikalia for 2014–2019 indicate that plants respond adaptively to changes in weather conditions. Hereditary and physiological characteristics showed that the introduced plants are characterized as cold-resistant and drought-resistant. *Corylus heterophylla* and *Armeniaca sibirica* are most sensitive to temperature extremes in spring, in contrast to Euonymus maackii, which were stable. Low above-zero air temperatures in spring and a large amount of precipitation encourage plants to pass the development stages (phenophases) faster than in dry and warm weather (*Corylus heterophylla, Armeniaca sibirica*). At the same time, low temperatures (frosts) in spring with a wet period at the time of flowering negatively affect the further fruit formation in Corylus heterophylla individuals. Rainy or cloudy days reduce the color intensity of the autumn leaves, and cool, dry, and sunny weather contributes to the autumn color scheme. *Armeniaca sibirica* and *Corylus heterophylla* are variable in terms of the onset of the main phenophases; individuals of the Euonymus maackii species have minimal individual variability. The longest growing seasons on the phenological spectrum were registered in 2014 and 2018–2019 (in *Corylus heterophylla* individuals – 190 days), which contributes to the accumulation of more phytomass. The shortest growing season was registered in 2015 (*Armeniaca sibirica* – 150 days).

KEYWORDS: Eastern Transbaikalia, arboretum, plants, phenological spectrum, weather conditions.

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INTRODUCTION

Researchers around the world study the dependence of plant development on environmental conditions and regional climatic parameters. It is believed that temperature, precipitation, and extreme weather conditions affect phenological patterns by changing flowering and fruiting seasons. Phenological and reproductive shifts of plants due to climate change can have an important impact on population dynamics (Wolfe et al. 2005; Ruml et al. 2011; Nagy et al. 2013; Nikolaeva 2015; Nurul et al. 2016; Reyes-Fox et al. 2014, 2016; Garcia-Cervigon et al. 2018; Yusong et al. 2018; Minin et al. 2018). In recent years, much has been said about climate warming. Some authors believe that "…rather than warming, we should discuss climate mitigation, an upward trend in monthly precipitation, decrease in the mean monthly temperatures in the warm months (from May to September), and increase in the mean monthly temperatures from October to April…" (Minin 2000; Gustokashina and Maksyutova 2006). "…Phenology links the course of seasonal changes in the life of the plant and animal kingdoms to specific meteorological data and inadequate weather conditions…", the authors argue (Merzlenko 2006, Kozlovsky et al. 2014). Model plots for long-term phenological observations make it possible to establish the relationship between shifts in the beginning of the growing season of plants and the temperature regimes in the previous months (Menzel et al. 2006; Golov et al. 2009; Mirjana et al. 2011; Ovchinnikova et al. 2011).

Observations of the dynamics of the seasonal development of shrubby plant species under influence of regional weather conditions of Eastern Transbaikalia were conducted in the arboretum of the Institute of Natural Resources, Ecology, and Cryology of the SB RAS (INREK SB RAS).

The purpose of this work is to analyze the dynamics of seasonal changes in shrub species of introduced plants for the growing seasons of 2014–2019 in weather conditions of Eastern Transbaikalia.

MATERIALS AND METHODS

Study area

The arboretum where the research was conducted belongs to the Trans-Baikal mountain-forest region and is located in a zone of severe natural and climatic conditions: uneven distribution of precipitation in the annual cycle (annual precipitation is 310–340 mm, of which only 20–40 mm falls in May and June and up to 230 mm falls in August – September); large temperature fluctuations throughout the year and the growing season (the mean annual air temperature is –2.7 °C, the daytime air temperature ranges from –15–20 °C to +10–+15 °C in March – April and from -10–15 °C to +15–+20 °C in September – October; late spring (May – June) and early autumn (August – September) frosts (the frost-free period is 65–75 days) and low relative humidity in spring (15–25% in April – June). The soil of this site is sod mountain-taiga permafrost. Ground water is located at a depth of up to 3 m. Humidification is mainly atmospheric. In general, the soils in the vicinity of the arboretum are characterized by freezing in winter to a great depth (3–3.5 m) and slow thawing in spring and summer (Bobrinev and Pak 2011). The territory of the arboretum is planted on three sides with protective forest strips of scots pine with a blown structure, which creates a special microclimate for the site. Figure 1 shows the site where the research was conducted.

The main phenological parameters were studied in introduced East Asian forest-steppe species: *Armeniaca sibirica* Lam. and *Euonymus maackii* Rupr., and Manchurian-Daurian preboreal species – *Corylus heterophylla* Fisch. ex Trautv. These species are listed as flora objects in the Red Book of the Trans-Baikal Territory (Decree of 2018). The studied objects were brought to the arboretum in the late 1980s from different botanical and geographical areas and planted.

The natural habitat of *Armeniaca sibirica* was noted in Northern, Eastern and Southeastern Mongolia, and in China (in the basin of the Suangri river, in the spurs of the Qinling ridge). In Russia, it grows in the Republic of Buryatia and the Primorsky Territory as well as in the southern and southeastern regions of the Trans-Baikal Territory. *Armeniaca sibirica* grows on the southern macroslopes of ridges at an altitude of 600–900 m above sea level, on mountain chestnut powdery-calcareous soils. It is extremely winter-hardy, drought-resistant, photophilous, undemanding to soil and moisture (Bobrinev et al. 2016; Koropachinsky and Vstovskaya 2012; Red Data Book of the Trans-Baikal Territory 2017).

Euonymus maackii is common on the Korean Peninsula, in Manzhuria andin the south of the Russian Far East. In the Trans-Baikal Territory, it is found in the southeast of the region – in the basin of the Argun riverin the Nerchinsk-Zavodskoy region. *Euonymus maackii* grows on the southern rocky slopes, in light forests, along rocky river banks. It is photophilous, frost-resistant, undemanding to soil, and moderately moisture-loving. It does not tolerate stagnant waterlogging and upper shading, especially in youth (Bobrinev et al. 2016; Koropachinsky and Vstovskaya 2012; Red Data Book of the Trans-Baikal Territory 2017).

Corylus heterophylla is commonin northeastern China, Korea, and Japan. It is also common in the south of the Far East – in Primorye and Amur region. In Siberia, it was recorded only in the Trans-Baikal Territory. *Corylus heterophylla* grows on the south dry mountain slopes, in the open spaces and on the edges of the forest. It is frost-resistant, shade-tolerant, low-demanding for soil moisture, demanding for soil fertility (Bobrinev et al. 2016; Koropachinsky and Vstovskaya 2012; Red Data Book of the Trans-Baikal Territory 2017).

Growth and development of shrubs were studied according to the methods of phenological observations. From the moment of the most obvious phenophase of "bud swelling" (April – May), the beginning of the growing season in plants was considered; the end of the observations was the phase of "end of leaf fall" (September – October) (Methodology of the study of forest ecosystems 2013; Arestova and Arestova 2017). The main meteorological parameters (air temperature, precipitation) were obtained from a portable mini-meteorological station (Davis Vantage Pro_2, USA) located next to the arboretum. Phenological spectra, graphs, and histograms were constructed using Microsoft Excel 7.0.

Fig. 1. Location of the INREK SB RAS arboretum

RESULTS AND DISCUSSION

The sequence and duration of the phenological stages of the seasonal development of each plant are presented in the color graphic form – the phenospectrum (Fig. 2).

When conducting observations in the arboretum for the growing season from 2014 to 2019 (April – October), we analyzed individual phenological variability of the studied objects in dynamics. The sensitivity of plants to the weather conditions of the region varies throughout the seasonal development.

The diagram (Fig. 3) shows an estimate of the weather data of the mean daily air temperature and precipitation for the months of the growing season (2014 – 2019) in the study area.

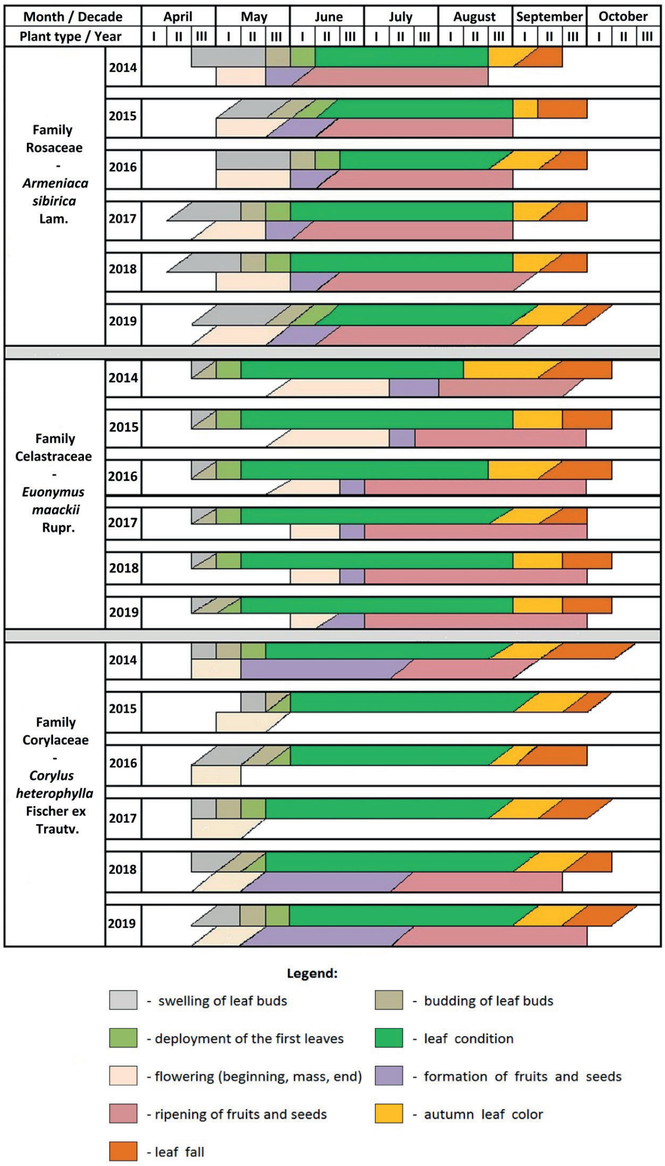

Fig. 2. Phenological spectrum of the growing season of shrubby plant species in the arboretum of INREK SB RAS

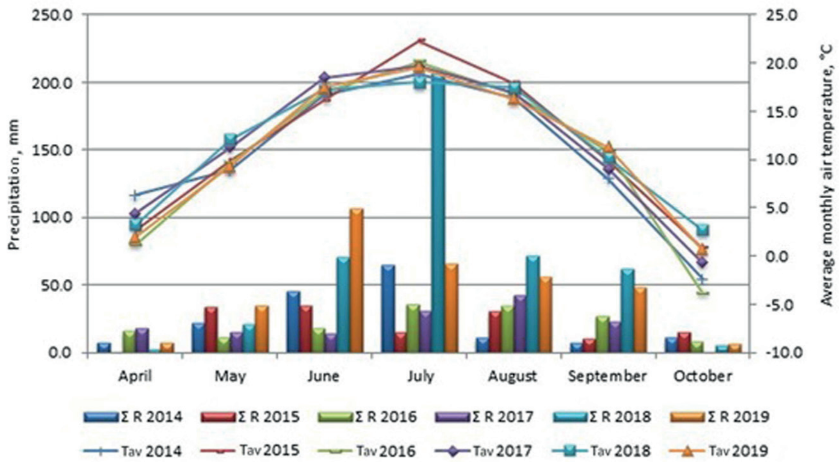

Fig. 3. Weather data by months for the growing season 2014 – 2019: Tav – mean daily temperatures, ° C; Σ R – precipitation, mm

Statistical processing of the main meteorological parameters for the period from 2014 to 2019 showed that the months during the year are characterized by long-term variability. Thus, the highest precipitation variation coefficients recorded within the growing season reached their maximum in mid-summer. The temperature regime showed the greatest variability over the years in April and October and was slightly variable from May to June and from August to September; July was characterized by the greatest instability. It is known that one of the important components of climatic heterogeneity is the high variability of thermal conditions at the beginning and end of the growing season, which determines the different dates of the beginning and end of the growing season and the different time intervals by plants.

Statistical processing of the data of the main meteorological parameters for the six years of the growing season (2014 – 2019) was performed in accordance with generally accepted methods (Table 1).

We analyzed the sum of the mean daily air temperatures above 10 °C for the period from 2014 to 2019. The highest sum of active temperatures (SAT) was recorded in 2015 and amounted to almost 2,182 °C; the lowest was recorded in 2014 (almost 1,933 °C). The maximum precipitation during the period of active temperatures was observed in 2018 (383.3 mm), the minimum was observed in 2017 (98.8 mm) (Fig. 4).

Earlier, the authors (Obyazov and Noskova 2015; Noskova et al. 2019) analyzed the sum of active air temperatures (above 10°C) over the past decades in the entire Trans-Baikal Territory. According to these works, the SAT, on average, varied from 1,500 °C (in the mountainous taiga northern regions) to 2,300 °C (in the steppe south-eastern regions), which confirms our calculations. The authors note that "...days with air temperatures above 10 °C are usually observed from mid-May to the first decade of September, and on average their number is 110, with the maximum values in the south-east of the region (more than 130 days) and the minimum in the north (less than 90 days)…". Our research objects grow in the central part of the Trans-Baikal Territory and manage to complete the full cycle of their development in an average of 110 days.

An increase in air temperature in the spring period boosts vegetation. An increase in temperature (within the normal range) accelerates growth and decreases phenological intervals, while a decrease (within the normal range), on the contrary, slows down development and increases the phenological intervals (Schnelle 1961; Larcher 1978; Shultz 1981). At the same time, the temperature sufficient for vegetation of any species varies from year to year, depending on other conditions, such as, for example, the winter duration and weather or the endogenous dormancy of the plant (Schultz 1981). Let us consider in more detail the dynamics of seasonal changes in introduced plants by phenophases.

The initial phase of the growing season – "bud swelling" – changed over the years. For individuals of *Corylus heterophylla*, this phase began somewhat earlier in 2014 (in the 3rd decade of April), compared to 2015–2019. The highest air temperature for that April was 6.3 °C, and the total precipitation in April was 7.6 mm, which exceeds the indicators of 2015 and 2018–2019. The temperature in April of 2017 and 2018 was slightly less – 4.4 and 3.3 °C, respectively, and there was less precipitation. Our

Table 1. Statistical processing of mean monthly air temperatures/precipitation for the growing season 2014 – 2019

Statistical indicator	Years of observation					
	2014	2015	2016	2017	2018	2019
Σ	72.8/170.8	79.7/141.7	71.6/151.2	79.2/144.1	81.1/439.4	76.7/326.2
X	10.4/24.4	11.4/20.2	10.2/21.6	11.3/20.7	11.6/62.8	11.0/46.6
min–max	−2.4–18.8/ 7.5–65.3	0.8–22.3/ 0.6–35.2	−3.9–20.1/ 8.4–36.1	−0.7–19.7/ 0.5–42.8	2.7–18.0/ 3.0–206.8	0.7–19.6/ 6.9–106.7
±σ	3.81/5.84	3.99/5.32	3.78/5.49	3.98/5.38	4.03/9.37	3.92/8.70
V, %	36.6/24.0	35.1/26.3	37.0/25.5	35.2/26.0	34.8/14.9	35.7/17.3

Note. Σ – total value; X – arithmetic mean; min-max – minimum and maximum values; ±σ – standard deviation; V – coefficient of variation, %.

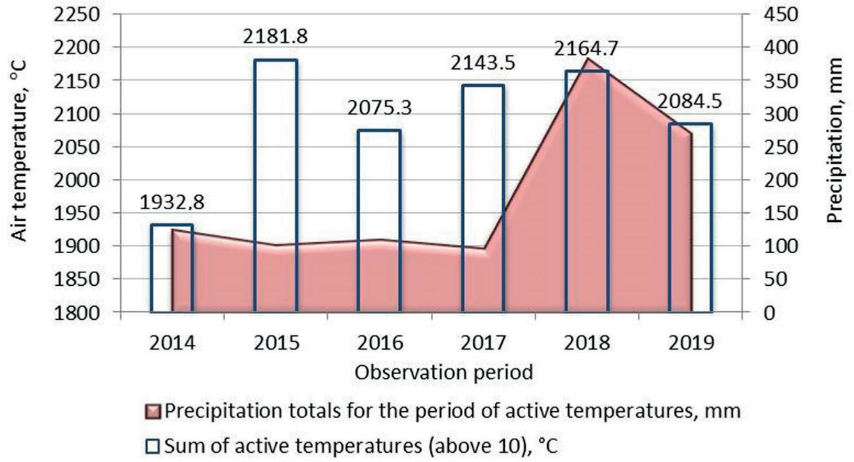

Fig. 4. Meteorological indicators of the growing season from 2014 to 2019: ΣT – sum of active temperatures (above 10), °C; Σ R – sum of precipitation for the period of active temperatures, mm

observations confirm the opinion that warm and dry weather accelerates the development of *Corylus heterophylla*. In 2015–2016 and 2019, these individuals entered the growing season later, at a mean monthly air temperatures of 2.7, 1.2, and 2.0 °C, respectively. For the species *Armeniaca sibirica*, the earliest onset of the growing season was recorded in 2017–2018 (in mid-April), which is one decade earlier than in 2014. In 2019, the growing season began in the third decade of April, as opposed to 2015–2016 (I decade of May). For individuals of *Euonymus maackii*, the onset of this phase remained unchanged from year to year (vegetation begins in the third decade of April and lasts for one decade).

The accompanying phases of **"leaf bud budding"** and **"first leaf budding"** occurred either systematically or in parallel to each other for one week. For example, for individuals of *Corylus heterophylla*, we registered a simultaneous swelling and rapid deployment of the first leaves during the third decade of May 2015, despite the large amount of precipitation and cool weather, compared to other years. In all other years, these two phases occurred one week earlier, successively replacing each other (I–II decade of May). Consequently, cold spring temperatures and humid air accelerate developmental stages of plants. In individuals of *Armeniaca sibirica*, we observed a similar reaction to the weather in 2015–2016 and 2019, including the late opening of leaf buds and their deployment (from late May to mid-June) compared to 2017–2018 (II–III decade of May), with the gradual passage of two phases. The phenospectrum of *Euonymus maackii* samples showed simultaneous swelling of leaf buds, and their flowering was stable from 2014 to 2019 in the third decade of April. However, in 2019, we registered a late consistent opening of the buds (from the 3rd decade of April to the 1st decade of May).

In general, the initial phenological phases of vegetation in the studied species fall on the period from mid-April to the end of May. At this time, there are frequent ground and atmospheric frosts with changes in air temperatures. Based on the data of the graph of meteorological parameters (by month) and the phenospectrum, individuals of *Corylus heterophylla* and *Armeniaca sibirica* were the most sensitive in spring to temperature extremes, in contrast to *Euonymus maackii*, which were stable. The duration of the phenophases was different over the years.

In parallel, the **"onset of flowering"** was recorded in the spring-summer period. It is known that *Armeniaca sibirica* and *Corylus heterophylla* according to the characteristics of phenological development is of the early spring type (generative buds bloom earlier than vegetative ones). The duration of the flowering phase varied: it was within 18–22 days for individuals of *Armeniaca sibirica*; 15–25 days for *Euonymus maackii*; and 10–15 days for *Corylus heterophylla*.

The subsequent phase of **"fruit formation"** follows flowering and occurs in spring or in summer. In individuals of *Armeniaca sibirica*, it was registered in the period from the end of May (2014–2015, 2017, 2019), as well as from the first decade of June (2016, 2018). In individuals of *Corylus heterophylla*, it was registered in the 2nd decade of May (with the exception of 2015–2017, when no fruiting was observed). In individuals of *Euonymus maackii*, it was registered at the end of June (2016–2019) and at the beginning of July (2014–2015). No fruiting in *Corylus heterophylla* can probably be associated with low temperatures (frosts in mid-May) or with a wet period at the time of flowering. It was found that with the highest amount of precipitation and relative air humidity, despite the mean daily air temperature above +10 °C, in individuals of this species, flowering was delayed until a more favorable time. Anemophilic pollen was released from anthers, which cracked under the influence of dry air. In May 2015, when the flowering continued, the highest amount of precipitation was recorded – 34.0 mm. In 2016–2017, the phase came earlier (in April); the amount of precipitation was 16.0 and 17.8 mm, respectively, which exceeded the indicators of this month in other years. In this regard, most likely in these years, the fruits were not formed. However, it is difficult to say unequivocally, since in May 2019, there was also a large amount of precipitation (35.1 mm), with low mean monthly air temperatures (9.3 °C); fruiting in individuals was noted.

This is followed by the **"ripening of fruits and seeds"** phase. In *Armeniaca sibirica*, maturation lasted from 80 to 100 days; in *Corylus heterophylla*, it lasted up to 110 days; and in Euonymus maackii, it lasted 60 to 100 days. However, some fruits in *Euonymus maackii* did not fall over the winter and were recorded on the branches of the plants the following spring. In 2014 and 2015 fruit maturation was faster in all the studied objects; 2017 and 2018 were the years, in which this phase lasted longer.

One of the final stages of the growing season is the **"autumn leaf color"** phase. In 2014, 2016, and 2017, in all species it began earlier (at the end of August), and later leaf coloring (at the beginning of September) was noted in 2015, 2018, and 2019. In general, by the end of September, the full color of the leaves of all the studied plants was recorded over the years, with a mean monthly air temperature in the range of 8.0–11.3 °C (below-zero values were noted only in 2014, in the third decade of September). The influence of short daylight hours and low above-zero temperatures in autumn contributes to the intensity and variety of the color palette of the leaves (from bright red to purple shades). However, early frosts weaken the bright red color of the foliage. Rainy or cloudy days reduce the color intensity of the autumn leaves, and cool, dry, and sunny weather contributes to the autumn color scheme.

The final phase of the growing season is **"leaf litter"**. The East Asian forest-steppe species complete the growing season in late September – early October. The Manchu-Daurian preboreal species turned out to be the most variable over the years. The years of 2014, 2016, and 2017 were characterized by below-zero mean monthly temperatures in October (–2.4 °C; –3.9 °C; –0.7 °C, respectively). It was during these years that the individuals showed early leaf fall and the end of the growing season.

CONCLUSIONS

The dynamics of seasonal changes in introduced plants under conditions of Eastern Transbaikalia indicates that the East Asian forest-steppe and Manchurian-Daurian preboreal species exhibit phenological plasticity in response to sudden changes in air temperatures and insufficient precipitation in the region (*Armeniaca sibirica, Corylus heterophylla*). All objects under study complete a full cycle of phenorhythms – from lignification of shoots and to leaf fall. The observed small deviations in seasonal development (duration of phenophases) over the years are associated with the weather conditions in the region. At the beginning of the growing season, atmospheric frosts with changes in air temperatures are rather common. *Corylus heterophylla* and *Armeniaca sibirica* are most sensitive to temperature extremes in spring, in contrast to Euonymus maackii, which were stable. Warm and dry weather contributes to the early start of the growing season (*Corylus heterophylla*). Low above-zero air temperatures in spring and a large amount of precipitation encourage plants to pass the development stages faster (phenophases) than in dry and warm weather (*Corylus heterophylla, Armeniaca sibirica*). At the same time, low temperatures (frosts) in spring with a wet period at the time of flowering negatively affect the further fruit formation in *Corylus heterophylla* individuals.

Based on the hereditary and physiological characteristics, it was established that introduced plants are adapted to the conditions of Eastern Transbaikalia and are cold- and drought-resistant. According to the phenological development, the individuals have the following characteristics: early flowering (*Armeniaca sibirica, Corylus heterophylla*) and longer retention of foliage on the branches in the autumn (*Corylus heterophylla*), as well as retention of fruits in winter (*Euonymus maackii, Corylus heterophylla*). The influence of short daylight hours and low above-zero temperatures in autumn contributes to the intensity and variety of the color palette of the leaves (from bright red to purple shades). Rainy or cloudy days reduce the intensity of the color of the autumn leaves, and cool, dry, and sunny weather contributes to the autumn multi-color. Below-zero monthly mean temperatures in October were observed for 2014, 2016–2017 (–2.4 °C; –3.9 °C and –0.7 °C, respectively). It was during these years that the individuals showed early leaf fall and the end of the growing season.

Armeniaca sibirica and *Corylus heterophylla* are variable in terms of the onset of the main phenophases; individuals of the species Euonymus maackii are characterized by minimal individual variability. The longest growing seasons on the phenological spectrum were demonstrated in 2014 and 2018–2019 (in individuals of *Corylus heterophylla*, it was 190 days), which contributes to the accumulation of greater phytomass. The shortest growing season was in 2015 (for *Armeniaca sibirica*, it was 150 days). We assessed the most objectively the resistance of introduced plants under conditions of Eastern Transbaikalia.

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