Phenological development, viability, and visual tree assessment of *Pinus sibirica* du tour beyond the Arctic circle

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Abstract

The study was performed on the Kola Peninsula and aimed to assess the impact of climatic factors on *Pinus sibirica's* phenological development beyond the Arctic Circle in particular. Eight phenological parameters were analyzed, including vegetative bud swelling and breaking, initiation and cessation of annual linear shoot growth, full lignification of shoots, cessation of needle elongation and maturation, duration of linear lateral shoot growth, and needle growth period. Additionally, correlations between the onset of phenophases and temperature parameters, including average monthly and ten-day temperatures, the dates of the stable transition through the thresholds of 0, 5, and 10°C, sums of active temperatures above 0, 5, and 10°C for phenological phases and periods, monthly and ten-day sums of active temperatures, and monthly and ten-day cumulative sums of active temperatures starting from April, were investigated. Viability assessment involved evaluating the degree of annual shoot lignification, winter hardiness, habitus preservation, shoot-forming capacity, vertical shoot growth, generative reproduction, and reproduction in cultivation. Tree health categories were established based on examinations of root, butt, trunk, crown base, primary branches, and crown for indications of hollows, cracks, decay and fungal fruiting bodies, damage, wounds, weak forks, and dead branches. The onset dates of the phenophases occurring in the beginning of the vegetation period and full shoot lignification correlated with the dates of transition through the thresholds of 0 and 5°C. In contrast, the onset dates of the phenophases occurring in the middle of the vegetation period and duration of phenological periods correlated with accumulated temperatures above 0 and 5°C. The date of transition through 10°C and its associated parameters yielded uninformative results. The onset dates of all phenophases exhibit negative correlations with the following parameters: (1) average temperatures in April and May, (2) the sums of active temperatures (SATs) exceeding 0 and 5°C in May, (3) cumulative SATs above the thresholds of 0 and 5°C from April to May and June, and (4) cumulative ten-day SATs above the thresholds of 0 and 5°C before the onset of a phenophase. *Pinus sibirica* at Polar-Alpine Botanical Garden-Institute (PABGI) exhibited winter hardiness, maintained species-typical life form, and reached the generative stage of development. They were categorized as healthy or weakened. Visual inspection revealed no restrictions to root system growth. They displayed monocormic, unimucronate or bimucronate forms, with dense crowns and well-developed apical and lateral shoots. Some instances of reduced lateral shoot growth and V-shaped trunk forks were observed. Recommendations for regular monitoring, sanitary pruning and other agrotechnical measures have been formulated for the investigated tree individuals.

Received July 17, 2025, *accepted* October 21, 2025.
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Acknowledgements: The study was carried out within the framework of the research theme "Comprehensive analysis of methods for assessing decorativeness and their applicability to woody plants of the Extreme North (based on the collection of introduced woody plants of the Polar-Alpine Botanical Garden and Institute of the Federal Research Centre "Kola Science Centre" of the Russian Academy of Science)", No. state registration 1021071612833–7–1.6.11.

Key words: Siberian pine, phenology, temperature, tree health categories, visual tree assessment

DOI: 10.5817/CPR2025-2-18

Introduction

Siberian pine (*Pinus sibirica*), a wind-pollinated monoecious tree, has a vast range spanning over 5 million km^2. It holds significant importance as a forest genetic resource and plays a crucial role as an ecosystem engineer within highly productive forest communities of Russia's boreal zone (Zhuk and Goroshkevich 2018). The species is believed to be not native to the Kola Peninsula (*see* Appendix).

Non-native coniferous species are believed to have been first cultivated on the Kola Peninsula by monks in the 16th–17th centuries, although no records have survived to confirm this (Kazakov 1993). The earliest documented sightings of young Siberian pine trees date to the early 1910s, with mature specimens discovered in the 1920s (Isaeva et al. 2023). By the late 1920s, Siberian pine cultivation had begun in the forestry units of the Kola Peninsula (Isaeva et al. 2023). In 1931, the Polar-Alpine Botanical Garden-Institute (PABGI) was established, becoming the center for research on plant introduction in the Kola Subarctic region. Therefore, the introduction of Siberian pine to PABGI began in the 1930s.

Phenological monitoring of woody plants in botanical gardens and arboretums provides continuous and objective information about plant health. Given the close relationship between phenology and climate dynamics, phenological observations are essential in understanding how plants respond to climate change (Primack and Miller-Rushing 2009, Rafferty et al. 2013, Panchen et al. 2015, Primack et al. 2021, Rosbakh et al. 2021).

As noted by D'Antraccoli et al. (2023), climate change presents a significant challenge to tree conservation efforts, subjecting specimens to increasingly stressful environmental conditions. Elevated temperatures and drought have been identified as primary stressors contributing to tree mortality (Seidl et al. 2017). Given their long lifespans and limited dispersal capabilities, trees are particularly susceptible to rapid climate shifts (Oleson et al. 2011). Botanical gardens are ideal settings for studying the long-term impact of recently changing climatic factors on plants.

Climatic conditions, particularly air temperature, are believed to influence the seasonal development of plants, and various indicators are used to assess this effect (Rich et al. 2008, Harrington et al. 2016, Montgomery et al. 2020, North et al. 2022). Common indicators include average temperatures, dates of a stable transition across specific temperature thresholds, and heat accumulation indices (McMaster and Wilhelm 1997, Lazareva 2013[2], Kryza et al. 2015, Kishchenko 2021, Rosbakh et al. 2021).

Trees in botanical gardens exhibit diverse characteristics and may display structural flaws. Introduced trees, not native to the region, are particularly susceptible to adverse environmental conditions compared to indigenous species. Emergency trees have specific characteristics (*i.e.*, defects). Tree defects encompass trunk, crown, and root quality deviations resulting from various biotic or abiotic factors compromising tree health and increasing disease risk (Avdeev 2014, Albers 2018).

These defects encompass damage and diseases that weaken trunk, root, or branch strength, leading to architectural abnormalities such as trunk leans, V-shaped stem forks, or the formation of inner bark, large water shoots, *etc*. (Ermohin et al. 2015). However, not all defects jeopardize tree stability or indicate an increased risk of falling. Identifying defects is crucial for assessing a tree's structural integrity. Currently, visual and instrumental methods exist for assessing tree health, and these methods are continuously advancing (Anosov 2015, Ermohin et al. 2015, Palchikov and Anciferov 2016, Kornienko and Prikhodko 2018, Anciferov 2020).

Material and Methods

The object of study

The study focused on Siberian pine (*Pinus sibirica* Du Tour) introduced to the Kola Peninsula in PABGI. Their characteristics are presented in Table 1.

We examined the characteristics of 8 specimens of *Pinus sibirica* in the tree and shrub collection at PABGI, analyzing their phenological development, winter hardiness (Bulygin 1974), and viability following Lapin and Sidneva (1973) methodology (Table 2 and Table 3).

Tree №	Origin of parent material	Height, m / diameter, cm	RDS
1	1950s, sn, Siberia (Russia)	8.4 / 20.5	Pol. irreg. / seeds irreg
2		7.6 / 18.5	Pol. irreg. / seeds irreg
3		9.6 / 26	Pol. irreg. / seeds irreg
4	1982, sn, Khanty-Mansiysk, Western Siberia (Russia)	9 / 23.5	Pol. irreg. / seeds irreg
5		6.8 / 17	Pol. irreg. / seeds irreg
6	1984, sn, Republic of Tuva, Eastern Siberia (Russia)	9.4 / 29	Pol. irreg. / no seeds
7	Unknown	7.6 / 24	Pol. irreg. / seeds irreg
8	1951, sc, Moscow (Russia)	9.8 / 23.5	Pol. irreg. / no seeds

Table 1. Objects of study. Origin of parent material: 1982 and so on. – the year of sowing seeds, sc – seeds of cultural origin, sn – seeds of natural origin; RDS – reproductive development score: pol. irreg. / seeds irreg. – pollination is irregular / seed production is irregular, pol. irreg. / no seeds – pollination is irregular / no seed production. Trunk diameter was measured at a height of 1.3 m from the ground level.

Climate characteristics in the area of investigation

The Polar–Alpine Botanical Garden and Institute (PABGI) is located 120 km north of the Arctic Circle on the Kola Peninsula (67° 38′ N and 33° 37′ E) (*see* Fig. 1). The PABGI has amassed extensive observational data on introduced woody plants, and comprehensive information on the composition of its woody plant collection has been reported in numerous publications (Goncharova et al. 2020).

In the study area, the average monthly temperature in January remains consistently above −13°C, while July temperatures range from +10 to +14°C. Frost can occur from August onwards, persisting until late May or June, resulting in a frost-free period lasting 50–70 days. Precipitation peaks during summer and autumn, with minimal rainfall in spring. The annual average precipitation is 500–600 mm. The stable snow cover persists for 180–200 days with a height of 60–80 cm. The daily temperature transits through the +5°C threshold by May 31st. The growing season lasts 90–120 days in the study area (Semko 1982).

Fig. 1. Location of the Polar-Alpine Botanical Garden and Institute named after Nikolai A. Avrorin. *Maps data*: Google Earth, 2024. – Polar-Alpine Botanical Garden and Institute (67°38′ N, 33°37′ E).

Phenological and meteorological data

Phenological observations were conducted two times per week during the growing seasons (from May to October) from 2015 to 2023 according to Elagin (1961), Borodina (1965), Bulygin (1979), and Aleksandrova et al. (1975). A phenophase was considered to have occurred when 50% of the organs of 50% of the plants exhibited it. To analyze phenological development, we focused on specific parameters presented in Table 4.

Air temperature (at 1.8 m above ground) was recorded every hour using a weather station installed at the PABGI experimental site (67°58′ N, 38°30′ E). Then, the average daily temperature was calculated, serving as the basis for deriving other meteorological indicators (Table 5). Beginning in April (a stable transition through a 0°C threshold occurs in the first half of April), each month was divided into three ten-day periods.

Parameter	Parameter value	Points
Degree of lignification of an annual shoot	fully lignified	20
	75% lignified	15
	50% lignified	10
	25% lignified	5
	not lignified	1
Winter hardiness	no frost damage	25
	up to 50% frost damage of an annual shoot	20
	50–100% frost damage of an annual shoot	15
	frost damage of shoots older than 1 year	10
	frost damage of a plant up to the height of snow cover	5
	frost damage of a plant up to ground level	3
	completely freezes out	1
Preservation of habitus	preserved	10
	restored	5
	not restored	1
Shoot-forming capacity	high	5
	medium	3
	low	1
Height growth	annual growth	5
	non-annual growth	2
Generative reproduction	seeds ripen regularly	25
	seeds ripen irregularly*	23
	a plant blooms but does not bear fruit	15
	does not bloom	1
Reproduction in cultivation	self-seeding	10
	artificial sowing of local seeds	7
	natural vegetative reproduction	5
	vegetative reproduction	3
	sourcing seeds or plants from other regions	1

Table 2. Parameters of viability assessment. *Note*: * – The criterion was introduced by the authors of the article and is not part of the original methodology.

To analyze the influence of climate on seasonal development, sums of active temperatures were used. Sum of active temperature is a sum of average daily temperatures exceeding specific threshold temperatures (0, 5, and 10°C) accumulated for some period.

$$\text{SAT} = \sum_{1}^{n} T_{active}$$

where n – duration of the chosen period, T_{active} – average daily temperature > threshold temperature (0, 5 or 10°C).

For phenophases, SAT is a sum of average daily temperatures above chosen threshold temperatures (0, 5, and 10°C) accumulated from the date of a stable transition through these thresholds to a certain phenodate.

$$\text{SAT} = \sum_{D_{threshold}}^{D_{phenophase}} T_{active}$$

where $D_{threshold}$ – date of the stable transition through the thresholds of 0, 5, and 10°C, $D_{phenophase}$ – onset date of a phenophase, T_{active} – average daily temperature > threshold temperature (0, 5 or 10°C).

Consequently, a comprehensive phenological and meteorological database from 2015 to 2023 was established. Data processing was performed utilizing descriptive statistical methods in Excel, and interpretation followed guidelines outlined by Ivchenko and Medvedev (2017), Bavrina (2020), Bavrina and Borisov (2021), and Petri and Sabin (2021). Data distribution type was assessed using the Shapiro–Wilk test in the Past 4.16c program (Hammer 2022). Spearman's rank-order correlation analysis, performed in the Statistica 13 program, was utilized to explore the relationship between phenological and temperature parameters. We evaluated the statistical significance ($p \leq 0.05$) and strength of correlation using the Chaddock scale (Chaddock 1925, Bavrina and Borisov 2021), focusing solely on correlations deemed statistically significant and demonstrating moderate ($r_s = 0.5…0.7$), strong ($r_s = 0.7…0.9$), or very strong ($r_s = 0.9…1$) correlations during result interpretation.

Visual tree assessment

During the viability assessment following Lapin and Sidneva (1973) method, we analyzed the parameters presented in Table 2.

Then, the plants were categorized into groups based on their scores (Table 3).

Tree health categories were evaluated following Roloff's (2001) methodology. We used the basic tree risk assessment outlined by Baridon et al. (2014, 2016) and Angwin et al. (2022)[1]. The assessment focused on examining the root zone, butt, trunk, crown base, primary branches, and crown for indications of hollows, cracks, signs of decay and fungal fruiting bodies, damage and wounds, weak forks, and dead branches.

N	Group	Score (pts)
1	Quite viable	91–100
2	Viable	76–90
3	Less viable	61–75
4	The least viable	41–60
5	Non-viable	21–40
6	Absolutely unsuitable	5–20

Table 3. Plant viability groups according to Lapin and Sidneva's (1973) method.

Abbreviation	Parameter
Onset date	
Vb1	vegetative bud swelling
Vb2	vegetative bud breaking
Gs1	initiation of annual linear shoot growth
Gs2	cessation of annual linear shoot growth
Lig2	full lignification of shoots
L3	cessation of needle elongation and maturation
Duration	
PGS	linear lateral shoot growth period
PGN	needle growth period

Table 4. Phenological parameters. The methodology used designated the date of vegetative bud swelling (Vb1) as the start of shoot growth (Gs1), while the period of needle growth began with bud breaking (Vb2).

Dates of the stable transition through the thresholds of 0, 5, and 10°C (D0, D5, D10)	The first day of the period during which the sum of positive deviations from the corresponding temperature threshold exceeds the sum of negative deviations in any subsequent period with negative deviations.
SAT of a phenophase	Sum of active temperatures accumulated from the date of stable transition through the chosen thresholds to a certain phenodate
SAT of a phenoperiod	Sum of active temperatures accumulated for the phenological period
Average monthly temperature	Sum of average daily temperatures for the month divided by the number of days in this month
Average ten-day temperatures	Sum of average daily temperatures for the ten-day period divided by 10
Monthly SAT	Sum of active temperatures for the month
Ten-day SAT	Sum of active temperatures for 10 (11) days
Monthly cumulative SAT	Sum of active temperatures beginning with April (as the date of the stable transition through a threshold 0 °C occurs in the first half of April) until the end of the month
Ten-day cumulative SAT	Sum of active temperatures beginning with the first ten-day period in April (as the date of the stable transition through a threshold 0°C occurs in the first half of April) until the end of the ten-day period

Table 5. Meteorological parameters used in the paper.

Results

Phenological development

The vegetative phenological development rhythm of Siberian pine at the PABGI experimental site is outlined in Table 6. Each phenological parameter corresponds to a specific accumulation of active temperatures above different temperature thresholds (0, 5, and 10°C).

The timing of the onset of all phenophases demonstrates a positive correlation with each other: a shift in one phenodate leads to a corresponding shift in other phenodates in the same direction (Fig. 2). However, such a relationship was not observed between the date of the end of annual linear shoot growth and the full lignification of shoots.

The dates of the stable transition through the thresholds of 0, 5, and 10°C are important agrometeorological parameters. Correlation analysis revealed that the onset of the period of vegetation, phenophases of the beginning of the vegetation period (bud swelling and breaking, beginning of shoot growth), and full lignification positively correlate with the dates of transition through 0 and 5°C (Table 7). However, in local climate, the transition through 10°C occurs relatively late, potentially after certain stages of vegetative development have already passed. Nevertheless, no significant relationship was observed between the date of transition through 10°C and the phenological parameters.

Parameter	Vb1, Gs1	Vb2	Gs2	L3	Lig2	PGS	PGN
Date/ Duration, days	29.V ± 9.0	8.VI ± 8.7	2.VII ± 8.6	26.VII ± 12.6	22.VIII ± 14.4	34.9 ± 7.1	48.0 ± 7.2
SAT(0), °C	204.9 ± 53.9	301.3 ± 50.2	596.7 ± 77.9	952.3 ± 87.7	1 306.2 ± 155.6	410.3 ± 69.9	636.4 ± 117.6
SAT(5), °C	134.8 ± 55.7	227.1 ± 56.2	519.4 ± 88.3	871.9 ± 89.2	1 228.2 ± 150.5	401.9 ± 68.9	644.5 ±108.7
SAT(10), °C	×	×	282.6 ± 99.9	628.0 ± 141.5	908.6 ± 183.9	307.0 ± 75.6	554.8 ± 149.7

Table 6. Seasonal development rhythm of *Pinus sibirica*. *Note*: Vb1 – vegetative bud swelling, Vb2 – vegetative bud breaking, Gs1 – initiation of annual linear shoot growth, Gs2 – cessation of annual linear shoot growth, Lig2 – full lignification of shoots, L3 – cessation of needle elongation and maturation, PGS – linear lateral shoot growth period, PGN – needle growth period. The data in the cells is presented as follows: Mean±SD (standard deviation). SAT(0), SAT(5), SAT(10) – sums of active temperatures above 0, 5, 10°C correspondingly. Vb1, Gs1 and Vb2 transpire quite often earlier than D10, so we excluded SAT(10) for them.

Parameter	Vb1, Gs1	Vb2	Gs2	L3	Lig2	PGS	PGN
D0	**0.66**	**0.62**	**0.46**	**0.49**	**0.69**	**-0.39**	0.10
D5	**0.65**	**0.62**	**0.34**	**0.49**	**0.74**	**-0.50**	0.10
D10	×	×	0.07	0.18	-0.22	0.15	0.05
SAT(0)	**0.38**	0.30	**0.66**	**0.47**	**0.59**	**0.78**	**0.53**
SAT(5)	0.13	0.15	**0.58**	**0.50**	**0.53**	**0.71**	**0.53**
SAT(10)	×	×	**0.51**	0.20	**0.51**	0.06	0.29

Table 7. Correlations between phenological and temperature parameters. *Note*: Vb1 – vegetative bud swelling, Vb2 – vegetative bud breaking, Gs1 – initiation of annual linear shoot growth, Gs2 – cessation of annual linear shoot growth, Lig2 – full lignification of shoots, L3 – cessation of needle elongation and maturation, PGS – linear lateral shoot growth period, PGN – needle growth period. D0, D5, D10 – dates of the stable transition of average daily temperatures through the thresholds of 0, 5, 10°C correspondingly; SAT(0), SAT(5), SAT(10) – sums of active temperatures above 0, 5, 10°C correspondingly. For phenological periods, SAT is the sum of active temperatures accumulated over this period. Significant ($p \leq 0.05$) correlation coefficients are highlighted in **bold**. Vb1, Gs1 and Vb2 transpire quite often earlier than D10, so we excluded them from the analysis.

Additionally, the SATs exceeding a threshold temperature can affect the timing of phenophase onset and the duration of phenological periods. The onset dates of the phenophases in the middle of the vegetation period demonstrate positive correlation with SATs: end of annual linear shoot growth and full lignification of shoots correlates with SATs above 0, 5 and 10°C, although, end of needle elongation and maturation correlates only with SAT above 5°C. The duration of phenological periods demonstrate positive correlations with SATs above 0 and 5°C.

Furthermore, we analyzed the correlations of phenological parameters with other temperature parameters, including average monthly and ten-day temperatures, monthly and ten-day SATs, and monthly and ten-day cumulative SATs starting from April (as the date of the stable transition through a threshold 0°C occurs in the first half of April).

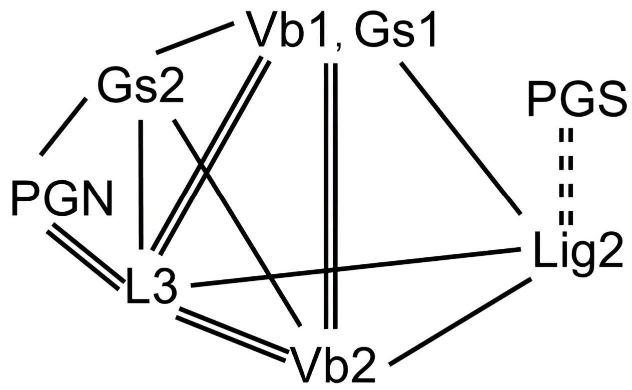

Fig. 2. Correlations between phenological parameters of *Pinus sibirica*. Correlations are indicated by lines: solid line – positive correlation, dotted line – negative correlation, single line – moderate correlation, double line – strong correlation.

Please refer to Table A1 and Table A2 in the Supplementary material for more detailed information. The average temperatures in April and May (approximately one or two months before bud swelling and breaking) exhibit negative correlations with the dates of all the phenophases. Besides, the SATs exceeding 0 and 5°C in May, and the cumulative SATs above 0 and 5°C beginning with April to May and to June (on average, the first month of the period of vegetation) also demonstrate negative correlations with the dates of onset of all the phenophases. Additionally, the cumulative SATs above 0 and 5°C before the phenophase onset beginning with cumulative SATs of the second ten-day period of May also demonstrate negative relationships with all the phenodates.

Viability assessment

Trees 1–7 were classified as viable (Table 8). They preserved their characteristic life form (habitus). Their annual shoots were found fully lignified along their entire length. The tissues of shoots were not damaged by frost. They demonstrated a high shoot-forming capacity and annual height growth. Seeds of trees 1–5 and 7 ripened irregularly. Tree 6 did not produce seeds. Therefore, seeds from other regions must be sourced for reproduction in cultivation.

Tree 8 was identified as less viable than the 1–7 group. It preserved its habitus. Its annual shoots fully lignified along its entire length. The tissues of shoots were not damaged by frost. However, it showed a low shoot-forming capacity and irregular shoot growth. The tree did not produce seeds. Therefore, they must be sourced from other regions for reproduction in cultivation.

The results of the basic tree risk assessment are presented in Fig. 3 and Table 9.

All the examined trees grow solitary and only trees 1–3 grow in a row at a distance of 4–4.7 m from each other. They are partially protected from wind exposure. The areas where the trees may potentially fall are not actively used because the trees are located within the boundaries of the PABGI collection area.

Tree №	Shoot lig.	WH	Habitus	ShFC	ShG	Gener. dev.	Repr.	Score	Viab. gr.
1	20	25	10	5	5	23	1	89	2
2	20	25	10	5	5	23	1	89	2
3	20	25	10	5	5	23	1	89	2
4	20	25	10	5	5	23	1	89	2
5	20	25	10	5	5	23	1	89	2
6	20	25	10	5	5	15	1	81	2
7	20	25	10	5	5	23	1	89	2
8	20	25	10	1	2	15	1	74	3

Table 8. A viability assessment of introduced *P. sibirica* trees. Lig shoots – degree of shoot lignification, points (pts); WH – winter hardiness, pts; Habitus – growth form preservation, pts; ShFC – shoot-forming capacity; ShG – height growth, pts; Gener. dev. – ability to generative development; repr. – methods of reproduction in cultivation; score – a sum of points; viab. gr. – a viability group.

The examined Siberian pines are monocormic, unimucronate, and bimucronate. Their crowns were symmetrical, fully developed, and dense, with the exception of tree 8, which had a sparse crown. Typically, the lowest living branches were located approximately 50 cm above the ground, except of tree 8. Tree 6 had hanging dead primary branches that were broken by snow, while tree 8 exhibits dead primary branches. Tree 2 has dry branches in the lower third of its crown. The trunks are generally upright, except for a curvature at a height of 2.5 m observed in tree 8. No water shoots or "tobacco branches" (broken, decayed branches with a brown color that easily crumble into powder) were observed on the trunks. Traces of resin bleeding were absent only on the trunks of trees 3 and 7. Resin bleeding was noted in the lower third of the trunk in trees 1, 4, 5, and 8; at the base of the crown in trees 6 and 8; and near weak forks in trees 2 and 4. Evidence of a hollow in the butt zone was found only in tree 8.

According to Roloff's (2001) assessment of tree health categories, trees 1–4 and 7 were classified as healthy, showing no signs of weakening. Their crowns were fully developed in accordance with their age, and growing conditions. Both apical and lateral shoots exhibited vigorous and uniform growth. These trees are considered to be in good to very good condition. Trees 5 and 6 are classified as weakened, exhibiting slightly reduced shoot growth and shorter lateral shoots relative to apical ones. Their crowns showed some minors gaps, and their overall condition was considered average. Tree 8 was rated as severely weakened, characterized by a sparse crown with dry branches, low shoot-forming capacity, and the presence of a hollow. Its overall status was assessed as weak.

Figure 3. Examined *P. sibirica* trees in the PABGI collection. *Photo*: Oxana Goncharova, Olesya Zotova: **A.** Tree 3. A crown; **B.** Tree 4. A crack and resin bleeding; **C.** Tree 6. The hanging dead primary branches, damaged by snow; **D.** Tree 8. A sparse crown, dry primary branches.

Tree №	Condition of a crown	Condition of a trunk	Condition of roots and a butt	Tree health category
1	*Crown*: fully developed, dense. *Needles*: glossy green, in isolated cases: chlorosis. *Annual shoot growth*: normal.	A monocormic tree. Traces of old resin bleeding in the lower third of the trunk.	*Root and butt zone:* no defects.	0
2	*Crown*: fully developed, 1/3 – dry branches. *Needles*: glossy green, in isolated cases: chlorosis. *Annual shoot growth*: normal.	A monocormic tree. Traces of old resin bleeding in the lower third of a trunk. Recent resin bleeding at the fork.	*Root and butt zone:* no defects.	0
3	*Crown*: fully developed, dense. *Needles*: glossy green, in isolated cases: chlorosis. *Annual shoot growth:* normal.	A monocormic tree. No signs of trunk damage were found.	*Root and butt zone:* no defects.	0
4	*Crown*: fully developed, dense. *Needles*: glossy green, in isolated cases: chlorosis. *Annual shoot growth*: normal.	A monocormic tree. A sizeable crack with traces of resin bleeding on the trunk. A week fork. Minor traces of old resin bleeding. Minor bark cracks and resin bleeding on the trunk at the base of the crown.	*Root and butt zone:* no defects.	0
5	*Crown*: fully developed, dense. *Needles*: glossy green, in isolated cases: chlorosis. *Annual shoot growth*: normal. Minor damage and cracks on the *primary shoots*. *Lowest living branches in the crown:* at a height of 66 cm from the ground.	A monocormic tree. A minor crack with traces of resin bleeding in the lower third of the trunk.	*Root and butt zone:* no defects.	1
6	*Crown*: fully developed, dense, 2 hanging primary branches in the upper half (a snow break). *Lowest living branches in the crown:* at a height of 42.5 cm from the ground.	A monocormic tree. A minor crack with traces of resin bleeding on the trunk. A weak fork.	*Root and butt zone:* no defects.	1
7	*Crown:* fully developed, dense. *Needles:* glossy green, in isolated cases: chlorosis. *Annual shoot growth:* normal. *Lowest living branches in the crown:* at a height of 50 cm from the ground.	A monocormic tree. A weak fork.	*Root and butt zone:* no defects.	0
8	*Crown:* significantly sparse, dry branches, weak stem forks, resin bleeding on the primary branches. *Needles:* chlorosis. *Annual shoot growth:* shortened. *Lowest living branches in the crown:* at a height of 148 cm from the ground.	A monocormic tree. A healed crack in the lower third of the trunk. Traces of old and recent resin bleeding on the trunk, weak resin bleeding at the base of the crown. A curvature of the trunk at a height of 2.5 m.	*Root and butt zone:* no defects. A hollow in the butt zone.	2

Table 9. Results of *Pinus sibirica* tree examination for tree health categories according to Roloff (2001).

No environmental risk factors affecting the trees were identified because they are cultivated within the confines of the botanical garden. However, structural defects associated with tree risk were observed in trees 4, 6, and 8. Tree 4 has bark cracks near a weak fork accompanied by resin bleeding, while tree 6 exhibits hanging primary branches. Tree 8 shows resin bleeding on the trunk and primary branches, weak forks on the primary branches, dry branches in the crown, and a hollow in the butt zone. Despite these structural defects, they were assessed as not posing an immediate danger at the time of the study. The most affected areas were the crown and primary shoots. Notably, in urban environments, these same zones also tend to exhibit the highest number of defects (Goncharova and Zotova 2023).

We recommend inspecting the trees for structural defects every two years in order to evaluate general trend in viability of individual trees. Dry branches in the crowns of trees 2, 5, and 8 should be pruned. For tree 6, removal of the hanging primary branches is advised. Additionally, tree 8 requires further treatment for the hollow. Tree removal is not considered necessary at this time.

Discussion and Concluding remarks

The following conclusions based on our investigation of phenological development, viability assessment, and tree risk assessment of *Pinus sibirica* could be made: (1) The phenological rhythm observed in Siberian pine introduced to PABGI aligns well with the environmental conditions. (2) Vegetative growth begins in the first half of June, and by the end of August, annual shoots fully lignify, indicating the plants' acclimation for relatively early approaching winter period.

Patterns identified for *Pinus sibirica* Du Tour under the conditions of the Kola Peninsula include the following:

(1) All phenodates exhibit positive interdependence, except for a lack of correlation between the dates of cessation of annual linear shoot growth and full lignification of shoots.

(2) The onset dates of the phenophases occurring in the beginning of the vegetation period (vegetative bud swelling and breaking, beginning of annual linear shoot growth) and full lignification of shoots display positive correlations with the dates of the transition through the thresholds of 0 and 5°C. Conversely, the onset dates of the phenophases occurring in the middle of the vegetation period demonstrate positive correlation with SATs: end of annual linear shoot growth and full lignification of shoots correlates with SATs above 0, 5 and 10°C, and additionally, end of needle elongation and maturation correlates with SAT above 5°C. The duration of phenological periods positively correlated with SATs above 0 and 5°C.

(3) The dates of all phenophases exhibited negative correlations with certain parameters, including the average temperatures in April and May (approximately one to two months before bud swelling and breaking), the sums of active temperatures exceeding 0 and 5°C in May, cumulative SATs above the thresholds of 0 and 5°C beginning with April to May and to June (typically the first month of the period of vegetation), and cumulative ten-day SATs above the thresholds of 0 and 5°C before the onset of a phenophase beginning with cumulative SATs of the second ten-day period of May.

Consequently, parameters associated with the stable transition dates through the thresholds of 0 and 5°C exert the greatest influence on the vegetative phenological development of *Pinus sibirica* on the Kola Peninsula. Other factors also play a role in shaping phenological development.

The viability assessment of Siberian pine indicates that the trees exhibit winter hardiness, maintain the characteristic life form of the species, and demonstrate a high shoot-forming capacity and annual vertical growth. They have reached a generative stage of development. Overall, the examined trees belong to the viable and less viable categories.

The introduced Siberian pines in the PABGI collection were found healthy or weakened. Because the trees are grown in the collection sites, the soil cover remains undisturbed, and there are no restrictions on the development of their root systems. In some cases, a reduction of the growth of lateral shoots compared to apical ones may be observed. Some trunks may feature V-shaped forks, while one tree was found to have a hollow in the butt zone. Additionally, traces of resin bleeding were detected, potentially indicating underlying disturbances that warrant further instrumental examination to assess the impact of diseases or pathogens on tree stability.

The approach employed, integrating the analysis of seasonal development, viability, and tree fall risk, is promising for conducting a comprehensive and repetitive assessment of the condition of Siberian pine during their introduction to the Arctic zone of Russia.

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Appendix

Native range of *Pinus sibirica*

In the north, the distribution boundary of *P. sibirica* extends to the Arctic Circle. To the south, isolated habitats in the Mongolian Altai, the South-Eastern Khangai and the South-Western Khentei mark the southern border of its range. Eastward expansion is impeded by cold permafrost soils and a sharply continental climate. In the Baikal region, Transbaikalia, and the south of Yakutia, *P. sibirica* shares a habitat with *Pinus pumila* (Pall.) Regel, a related species of five-needle pines. In the west, the range of *P. sibirica* is limited by the distribution of *Picea abies*, which is more competitive in the Eastern European climate. *Picea abies* overshadows *P. sibirica* and does not allow it to get to the top layer and form a generative generation. In the mountainous regions of Southern Siberia, *P. sibirica* is distributed from the dark coniferous taiga zone to the subalpine zone, forming the altitudinal tree line and exhibiting potential for dwarf forms. The widespread distribution of *P. sibirica* underscores its high ecological valency and biospheric value (Petrova et al. 2014).

Supplementary material

Table A1. ► Correlations between phenological and monthly temperature parameters. *Note*: Vb1 – vegetative bud swelling, Vb2 – vegetative bud breaking, Gs1 – initiation of annual linear shoot growth, Gs2 – cessation of annual linear shoot growth, Lig2 – full lignification of shoots, L3 – cessation of needle elongation and maturation, PGS – linear lateral shoot growth period, PGN – needle growth period. t 4, t 5, etc – the average monthly temperature of April, May, etc; t 3(0), t 3(5), t 3(10) – monthly sums of active temperatures above 0, 5, 10°C correspondingly, t 3(S0), t 3(S5), t 3(S10) – monthly cumulative sums of active temperatures above 0, 5, 10°C correspondingly. Significant ($p \leq 0.05$) correlation coefficients are highlighted in **bold**. ✕– the data were excluded from the analysis.

Table A2. ▼ Correlations between phenological and ten-day temperature parameters. *Note*: Vb1 – vegetative bud swelling, Vb2 – vegetative bud breaking, Gs1 – initiation of annual linear shoot growth, Gs2 – cessation of annual linear shoot growth, Lig2 – full lignification of shoots, L3 – cessation of needle elongation and maturation, PGS – linear lateral shoot growth period, PGN – needle growth period. t 31, t 32 , t 33, etc – the average ten-day temperature of the first, second and third ten days of March correspondingly, etc; t 31(0), t 31(5), t 31(10) – ten-day sums of active temperatures above 0, 5, 10°C correspondingly, t 31(S0), t 31(S5), t 31(S10) – ten-day cumulative sums of active temperatures above 0, 5, 10°C correspondingly. Significant ($p \leq 0.05$) correlation coefficients are highlighted in **bold**. ✕– the data were excluded from the analysis.

Parameter	Vb1, Gs1	Vb2	Gs2	L3	Lig2	PGS	PGN
Date/ Duration, days	29.V±9.0	8.VI±8.7	2.VII±8.6	26.VII±12.6	22.VIII±14.4	34.9±7.1	48.0±7.2
Average monthly temperature							
t 3	0.16	0.11	0.20	-0.34	-0.28	0.18	-0.25
t 4	**-0.67**	**-0.52**	**-0.64**	**-0.50**	**-0.51**	0.25	-0.25
t 5	**-0.92**	**-0.85**	**-0.57**	**-0.65**	**-0.80**	**0.54**	-0.22
t 6	-0.11	**-0.37**	**-0.57**	**-0.42**	0.01	-0.29	**-0.40**
t 7	×	×	-0.21	**-0.62**	-0.19	0.16	**-0.50**
t 8	×	×	×	**-0.54**	**-0.59**	×	-0.24
t 9	×	×	×	×	**-0.43**	×	×
Sum of active temperatures above 0°C							
t 3(0)	-0.03	-0.14	-0.30	**-0.65**	-0.27	-0.01	**-0.58**
t 4(0)	**-0.54**	**-0.40**	**-0.71**	-0.23	**-0.36**	0.01	-0.11
t 5(0)	**-0.92**	**-0.86**	**-0.58**	**-0.64**	**-0.81**	**0.54**	-0.21
t 6(0)	-0.11	**-0.37**	**-0.57**	**-0.42**	0.01	-0.29	**-0.40**
t 7(0)	×	×	-0.21	**-0.62**	-0.19	0.16	**-0.50**
t 8(0)	×	×	×	**-0.51**	**-0.62**	×	-0.23
t 9(0)	×	×	×	×	**-0.43**	×	×
Sum of active temperatures above 5°C							
t 4(5)	**-0.38**	-0.31	**-0.67**	-0.33	**-0.40**	-0.04	-0.36
t 5(5)	**-0.90**	**-0.87**	**-0.51**	**-0.74**	**-0.81**	**0.59**	-0.27
t 6(5)	-0.07	-0.33	**-0.54**	**-0.41**	-0.01	-0.29	**-0.40**
t 7(5)	×	×	-0.21	**-0.62**	-0.19	0.16	**-0.50**
t 8(5)	×	×	×	**-0.51**	**-0.62**	×	-0.23
t 9(5)	×	×	×	×	**-0.61**	×	×
Sum of active temperatures above 10°C							
t 4(10)	**-0.56**	**-0.56**	**-0.57**	**-0.65**	**-0.64**	0.28	**-0.56**
t 5(10)	**-0.72**	**-0.76**	-0.24	**-0.73**	**-0.57**	**0.57**	-0.12
t 6(10)	0.07	-0.12	**-0.50**	-0.10	0.27	**-0.48**	-0.22
t 7(10)	×	×	-0.08	**-0.49**	-0.20	0.18	**-0.41**
t 8(10)	×	×	×	**-0.53**	**-0.62**	×	-0.25
t 9(10)	×	×	×	×	**-0.43**	×	×
Cumulative sum of active temperatures above 0°C							
t 4(S0)	**-0.54**	**-0.40**	**-0.71**	-0.23	**-0.36**	0.01	-0.11
t 5(S0)	**-0.92**	**-0.86**	**-0.58**	**-0.64**	**-0.81**	**0.54**	-0.21
t 6(S0)	**-0.84**	**-0.89**	**-0.51**	**-0.82**	**-0.84**	**0.54**	**-0.40**
t 7(S0)	×	×	-0.25	**-0.44**	**-0.53**	**0.35**	-0.16
t 8(S0)	×	×	×	**-0.49**	**-0.62**	×	-0.16
t 9(S0)	×	×	×	×	**-0.68**	×	×
Cumulative sum of active temperatures above 5°C							
t 4(S5)	**-0.38**	-0.31	**-0.67**	-0.33	**-0.40**	-0.04	-0.36
t 5(S5)	**-0.92**	**-0.86**	**-0.58**	**-0.64**	**-0.81**	**0.54**	-0.21
t 6(S5)	**-0.84**	**-0.89**	**-0.51**	**-0.82**	**-0.84**	**0.54**	**-0.40**
t 7(S5)	×	×	-0.22	**-0.45**	**-0.53**	0.32	-0.18
t 8(S5)	×	×	×	**-0.49**	**-0.62**	×	-0.16
t 9(S5)	×	×	×	×	**-0.85**	×	×
Cumulative sum of active temperatures above 10°C							
t 5(S10)	**-0.82**	**-0.86**	**-0.42**	**-0.83**	**-0.69**	**0.56**	-0.30
t 6(S10)	**-0.57**	**-0.76**	**-0.60**	**-0.69**	-0.30	0.15	-0.37
t 7(S10)	×	×	0.02	**-0.39**	**-0.43**	**0.33**	-0.17
t 8(S10)	×	×	×	**-0.38**	**-0.52**	×	-0.15
t 9(S10)	×	×	×	×	**-0.65**	×	×

Table A1.

Parameter	Vb1, Gs1	Vb2	Gs2	L3	Lig2	PGS	PGN
Date/ Duration, days	29.V±9.0	8.VI±8.7	2.VII±8.6	26.VII±12.6	22.VIII±14.4	34.9±7.1	48.0±7.2
Average ten-day temperature							
t 31	0.07	-0.02	0.14	-0.32	**-0.38**	0.23	-0.26
t 32	**0.41**	**0.41**	**0.44**	0.07	-0.09	0.01	-0.05
t 33	0.06	0.08	**-0.54**	-0.18	0.19	**-0.40**	-0.28
t 41	**-0.71**	**-0.57**	-0.22	**-0.46**	**-0.77**	**0.63**	-0.02
t 42	-0.17	-0.08	**-0.36**	-0.07	0.24	-0.23	0.00
t 43	**-0.40**	-0.27	-0.27	-0.06	**-0.44**	0.23	-0.05
t 51	**-0.49**	**-0.59**	-0.29	**-0.55**	**-0.65**	**0.42**	-0.16
t 52	**-0.82**	**-0.74**	**-0.40**	**-0.50**	**-0.60**	**0.49**	-0.13
t 53	**-0.60**	**-0.72**	-0.30	**-0.61**	**-0.78**	**0.51**	-0.17
t 61	**0.73**	**0.63**	0.10	0.29	**0.77**	**-0.70**	-0.05
t 62	**-0.42**	**-0.60**	**-0.59**	**-0.61**	0.03	-0.02	-0.34
t 63	×	**-0.64**	**-0.33**	**-0.61**	**-0.50**	0.23	**-0.46**
t 71	×	×	**-0.43**	**-0.64**	-0.09	-0.03	**-0.65**
t 72	×	×	-0.10	**-0.50**	**-0.46**	**0.37**	-0.30
t 73	×	×	×	-0.22	-0.22	×	-0.18
t 81	×	×	×	**-0.73**	**-0.66**	×	**-0.41**
t 82	×	×	×	**-0.42**	**-0.51**	×	-0.27
t 83	×	×	×	-0.11	0.17	×	-0.02
t 91	×	×	×	×	-0.19	×	×
t 92	×	×	×	×	**-0.55**	×	×
t 93	×	×	×	×	×	×	×
Sum of active temperatures above 0°C							
t 31(0)	0.22	0.03	0.03	-0.17	0.31	-0.18	-0.04
t 32(0)	0.07	0.04	0.32	-0.31	**-0.51**	0.33	-0.21
t 33(0)	-0.09	-0.22	**-0.56**	**-0.62**	-0.09	-0.18	**-0.64**
t 41(0)	-0.26	-0.26	0.05	-0.25	**-0.55**	**0.42**	-0.09
t 42(0)	-0.29	-0.19	**-0.42**	-0.15	0.02	-0.14	-0.05
t 43(0)	**-0.46**	**-0.39**	**-0.44**	**-0.35**	**-0.50**	0.18	-0.20
t 51(0)	**-0.49**	**-0.59**	-0.29	**-0.55**	**-0.65**	**0.42**	-0.16
t 52(0)	**-0.81**	**-0.73**	**-0.43**	**-0.49**	**-0.61**	**0.48**	-0.13
t 53(0)	**-0.60**	**-0.72**	-0.30	**-0.61**	**-0.78**	**0.51**	-0.17
t 61(0)	**0.73**	**0.63**	0.10	0.29	**0.77**	**-0.70**	-0.05
t 62(0)	**-0.42**	**-0.60**	**-0.59**	**-0.61**	0.03	-0.02	-0.34
t 63(0)	×	**-0.66**	**-0.35**	**-0.61**	**-0.50**	0.25	**-0.45**
t 71(0)	×	×	**-0.47**	**-0.68**	-0.06	-0.06	**-0.67**
t 72(0)	×	×	-0.10	**-0.50**	**-0.46**	**0.37**	-0.30
t 73(0)	×	×	×	-0.22	-0.22	×	-0.18
t 81(0)	×	×	×	**-0.73**	**-0.66**	×	**-0.41**
t 82(0)	×	×	×	**-0.42**	**-0.51**	×	-0.27
t 83(0)	×	×	×	-0.11	0.17	×	-0.02
t 91(0)	×	×	×	×	-0.19	×	×
t 92(0)	×	×	×	×	**-0.55**	×	×
t 93(0)	×	×	×	×	×	×	×
Sum of active temperatures above 5°C							
t 41(5)	×	×	×	×	×	×	×
t 42(5)	-0.20	-0.21	-0.23	-0.23	0.01	-0.08	-0.24
t 43(5)	**-0.46**	**-0.31**	**-0.72**	**-0.39**	-0.14	-0.11	**-0.37**
t 51(5)	**-0.64**	**-0.61**	-0.25	**-0.47**	**-0.79**	**0.57**	-0.08
t 52(5)	**-0.79**	**-0.68**	**-0.43**	**-0.45**	**-0.49**	**0.42**	-0.12
t 53(5)	**-0.60**	**-0.72**	-0.30	**-0.61**	**-0.78**	**0.51**	-0.17

t 61(5)	**0.73**	**0.63**	0.10	0.29	**0.77**	**-0.70**	-0.05
t 62(5)	**-0.44**	**-0.65**	**-0.50**	**-0.68**	-0.08	0.09	-0.33
t 63(5)	×	**-0.66**	**-0.35**	**-0.61**	**-0.50**	0.25	**-0.45**
t 71(5)	×	×	**-0.47**	**-0.68**	-0.06	-0.06	**-0.67**
t 72(5)	×	×	-0.10	**-0.50**	**-0.46**	**0.37**	-0.30
t 73(5)	×	×	×	-0.22	-0.22	×	-0.18
t 81(5)	×	×	×	**-0.73**	**-0.66**	×	**-0.41**
t 82(5)	×	×	×	**-0.42**	**-0.51**	×	-0.27
t 83(5)	×	×	×	-0.11	0.17	×	-0.02
t 91(5)	×	×	×	×	-0.19	×	×
t 92(5)	×	×	×	×	**-0.55**	×	×
t 93(5)	×	×	×	×	×	×	×
Sum of active temperatures above 10°C							
t 41(10)	×	×	×	×	×	×	×
t 42(10)	×	×	×	×	×	×	×
t 43(10)	**-0.52**	**-0.54**	**-0.45**	**-0.62**	**-0.61**	0.28	**-0.46**
t 51(10)	**-0.51**	**-0.54**	-0.20	**-0.58**	**-0.53**	**0.45**	-0.28
t 52(10)	**-0.72**	**-0.66**	-0.29	**-0.45**	**-0.47**	**0.48**	-0.04
t 53(10)	**-0.45**	**-0.57**	-0.04	**-0.55**	**-0.76**	**0.59**	-0.10
t 61(10)	**0.64**	**0.52**	-0.06	0.23	**0.67**	**-0.71**	-0.17
t 62(10)	**-0.34**	**-0.44**	**-0.63**	-0.27	0.19	-0.20	-0.09
t 63(10)	×	**-0.77**	**-0.41**	**-0.73**	**-0.61**	**0.38**	**-0.47**
t 71(10)	×	×	**-0.47**	**-0.68**	-0.06	-0.06	**-0.67**
t 72(10)	×	×	-0.10	**-0.50**	**-0.46**	**0.37**	-0.30
t 73(10)	×	×	×	-0.23	-0.28	×	-0.16
t 81(10)	×	×	×	**-0.65**	**-0.70**	×	-0.33
t 82(10)	×	×	×	-0.21	**-0.54**	×	-0.11
t 83(10)	×	×	×	0.13	0.04	×	0.20
t 91(10)	×	×	×	×	-0.18	×	×
t 92(10)	×	×	×	×	**-0.36**	×	×
t 93(10)	×	×	×	×	×	×	×
Cumulative sum of active temperatures above 0°C							
t 41(S0)	-0.26	-0.26	0.05	-0.25	**-0.55**	**0.42**	-0.09
t 42(S0)	-0.31	-0.20	-0.26	0.04	-0.22	0.05	0.24
t 43(S0)	**-0.54**	**-0.40**	**-0.71**	-0.23	**-0.36**	0.01	-0.11
t 51(S0)	**-0.66**	**-0.50**	**-0.63**	**-0.51**	**-0.49**	0.26	-0.26
t 52(S0)	**-0.88**	**-0.78**	**-0.64**	**-0.58**	**-0.67**	**0.43**	-0.23
t 53(S0)	**-0.92**	**-0.86**	**-0.58**	**-0.64**	**-0.81**	**0.54**	-0.21
t 61(S0)	**-0.92**	**-0.86**	**-0.58**	**-0.64**	**-0.81**	**0.54**	-0.21
t 62(S0)	**-0.92**	**-0.88**	**-0.64**	**-0.66**	**-0.81**	**0.49**	-0.22
t 63(S0)	×	**-0.89**	**-0.51**	**-0.82**	**-0.84**	**0.54**	**-0.40**
t 71(S0)	×	×	**-0.65**	**-0.76**	**-0.55**	0.32	**-0.48**
t 72(S0)	×	×	**-0.56**	**-0.83**	**-0.66**	**0.43**	**-0.47**
t 73(S0)	×	×	×	**-0.76**	**-0.55**	×	**-0.48**
t 81(S0)	×	×	×	**-0.83**	**-0.66**	×	**-0.47**
t 82(S0)	×	×	×	**-0.83**	**-0.66**	×	**-0.47**
t 83(S0)	×	×	×	**-0.83**	**-0.66**	×	**-0.47**
t 91(S0)	×	×	×	×	**-0.48**	×	×
t 92(S0)	×	×	×	×	**-0.62**	×	×
t 93(S0)	×	×	×	×	×	×	×
Cumulative sum of active temperatures above 5°C							
t 41(S5)	×	×	×	×	×	×	×
t 42(S5)	-0.01	-0.10	0.07	-0.01	-0.27	0.05	0.03
t 43(S5)	**-0.38**	-0.31	**-0.67**	-0.33	**-0.40**	-0.04	-0.36
t 51(S5)	**-0.67**	**-0.51**	**-0.48**	**-0.52**	**-0.64**	**0.40**	-0.21
t 52(S5)	**-0.86**	**-0.71**	**-0.54**	**-0.45**	**-0.75**	**0.50**	-0.14
t 53(S5)	**-0.92**	**-0.86**	**-0.58**	**-0.64**	**-0.81**	**0.54**	-0.21

t 61(S5)	**-0.92**	**-0.86**	**-0.58**	**-0.64**	**-0.81**	**0.54**	-0.21
t 62(S5)	**-0.90**	**-0.87**	**-0.51**	**-0.74**	**-0.81**	**0.59**	-0.27
t 63(S5)	×	**-0.89**	**-0.51**	**-0.82**	**-0.84**	**0.54**	**-0.40**
t 71(S5)	×	×	**-0.57**	**-0.80**	**-0.69**	**0.37**	**-0.48**
t 72(S5)	×	×	**-0.56**	**-0.83**	**-0.66**	**0.43**	**-0.47**
t 73(S5)	×	×	×	**-0.77**	**-0.55**	×	**-0.51**
t 81(S5)	×	×	×	**-0.83**	**-0.66**	×	**-0.47**
t 82(S5)	×	×	×	**-0.83**	**-0.66**	×	**-0.47**
t 83(S5)	×	×	×	**-0.83**	**-0.66**	×	**-0.47**
t 91(S5)	×	×	×	×	**-0.81**	×	×
t 92(S5)	×	×	×	×	**-0.81**	×	×
t 93(S5)	×	×	×	×	×	×	×
Cumulative sum of active temperatures above 10°C							
t 41(S10)	×	×	×	×	×	×	×
t 42(S10)	×	×	×	×	×	×	×
t 43(S10)	**-0.56**	**-0.56**	**-0.57**	**-0.65**	**-0.64**	0.28	**-0.56**
t 51(S10)	**-0.66**	**-0.65**	**-0.45**	**-0.71**	**-0.64**	**0.43**	**-0.47**
t 52(S10)	**-0.83**	**-0.74**	**-0.35**	**-0.49**	**-0.67**	**0.58**	-0.02
t 53(S10)	**-0.82**	**-0.86**	**-0.42**	**-0.83**	**-0.69**	**0.56**	-0.30
t 61(S10)	**-0.68**	**-0.80**	**-0.55**	**-0.88**	**-0.54**	**0.37**	**-0.49**
t 62(S10)	**-0.49**	**-0.68**	**-0.48**	**-0.69**	-0.08	0.15	-0.29
t 63(S10)	×	**-0.76**	**-0.60**	**-0.69**	-0.30	0.15	-0.37
t 71(S10)	×	×	**-0.71**	**-0.78**	-0.32	0.06	**-0.58**
t 72(S10)	×	×	**-0.39**	**-0.74**	**-0.52**	0.28	**-0.56**
t 73(S10)	×	×	×	**-0.72**	**-0.41**	×	**-0.49**
t 81(S10)	×	×	×	**-0.70**	**-0.41**	×	**-0.46**
t 82(S10)	×	×	×	**-0.70**	**-0.63**	×	**-0.49**
t 83(S10)	×	×	×	**-0.69**	**-0.51**	×	**-0.45**
t 91(S10)	×	×	×	×	**-0.56**	×	×
t 92(S10)	×	×	×	×	**-0.56**	×	×
t 93(S10)	×	×	×	×	×	×	×

Table A2.