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Variability in Growth Patterns and Tree-Ring Formation of East European Scots Pine (*Pinus sylvestris* L.) Provenances to Changing Climatic Conditions in Lithuania

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Abstract: An increase in the mean monthly temperature in July and a lack of precipitation during the vegetation period will cause an increase in the frequency and severity of droughts during the vegetation period in Lithuania. Thus, the aim of this study was to assess the growth response to climate change of East European pine provenances in Lithuania. The research was performed based on a long-term pine provenance experiment that was established in 1975 in Lithuania. The results showed that central populations demonstrated the same or better survival and growth results compared with western populations that also included local Lithuanian provenances. Even though southern populations were characterized by the same productivity, their low survival rate suggests a negative introduction effect. Analysis of temporal variation in climate sensitivity showed a higher resistance of central and southern Scots pine provenances to the negative climatic changes, compared to the western provenances. Provenances from the central, southern and especially western locations demonstrated an increasing statistically significant negative effect of monthly temperatures in July. Additionally, provenances from western locations were more sensitive to precipitation amounts, water balance and droughts in June and July. Considering that central and southern provenances demonstrated the consistent effect of growth tolerance, the incorporation of the genetic material from the southern part of European Russia and Ukraine into local breeding programs of Scots pine might amplify positive effects of the transfer. Moreover, knowledge gaps remain regarding the growth performance of Scots pine provenances that originated from central or western European regions. Thus, Scots pine origins from Poland and the northeastern part of Germany should be included in Lithuanian provenance experiments.

Keywords: *Pinus sylvestris*; productivity; seasonal effects; climate sensitivity; droughts

Citation: Linkevičius, E.; Kliučius, A.; Šidlauskas, G.; Augustaitis, A. Variability in Growth Patterns and Tree-Ring Formation of East European Scots Pine (*Pinus sylvestris* L.) Provenances to Changing Climatic Conditions in Lithuania. *Forests* **2022**, *13*, 743. https://doi.org/10.3390/f13050743

Academic Editor: Adele Muscolo

Received: 9 April 2022
Accepted: 4 May 2022
Published: 11 May 2022

1. Introduction

Forests are likely to be increasingly exposed to extreme events such as the increased risk of fire and drought and the spread of pests and diseases that will have negative changes in productivity of various tree species [1]. Increasing air temperature and changing precipitation regimes, including changes in snowfall and the timing, amount and interannual variability of rainfall, are a result of climate change [2].

A significant warming process was observed across Europe between 1960 and 2017 [3]. It is expected that the annual average land temperature over Europe will increase in a range of 1.4 °C to 4.2 °C, and, depending on the scenario of greenhouse gas emissions, the strongest warming is projected across northeastern Europe and Scandinavia in winter and southern Europe in summer [3].

It is well known climate change that not only differs across bioclimatic zones in Europe but also in changes in soil temperature [4].

According to Rivas-Martinez et al. [5], the southern part of Lithuania is on the northern edge of the temperate continental zone and the northern part of Lithuania belongs to hemiboreal zone close to the southern edge of the boreal zone.

Lindner et al. [6] concluded that in the southern parts of the boreal zone, drought events are the main constraint on forest growth and productivity. They also stated that in the temperate continental zone, the mean annual precipitation is expected to increase by up to 10%, mainly in winter, while summer precipitation is projected to decline by as much as 10%. Weigel et al. [7,8] argued that climate change in winter is equally important since the growth of marginal populations in cold areas becomes increasingly sensitive to winter cold (February temperature) and less sensitive to summer water availability (June precipitation). Therefore, drought and precipitation during summertime as well as increased temperatures during the wintertime [9] will be very important factors defining tree growth in Lithuania.

Scots pine (*Pinus sylvestris* L.) is the most widely distributed conifer species in the world, and natural forests or plantations are found in all EU member states [10]. Scots pine is adapted to sub-Atlantic and continental climates in central and eastern Europe, Scandinavia and Asia [11].

Scots pine is of considerable importance as a timber-producing species, particularly in Nordic [10] and Eastern European countries. It is also a very important tree species in Lithuania, covers over 33% of forestland and comprises approximately 30% of the annual harvest [12]. However, growth conditions will become less suitable for conifer tree species such as Norway spruce and Scots pine due to increased temperature induced by climate change up to the end of the 21st century [13].

Climate warming will reduce the growth and survival of Scots pine in southern and central Europe by enhancing heat and moisture stress; however, in the far north, climate change might limit extreme cold stress and result in enhanced survival and growth of Scots pine [14–16]. However, even under the same climatic conditions, temporal differences in the climate–growth relationship among Scots pines were recorded by Misi et al. [17], indicating the phenotypical plasticity of this tree species.

In recent years, climate anomalies in Europe have induced severe episodes of drought, which have affected the growth and even survival of Scots pine [14,15].

For example, drought in 2018, accompanied by sustained low soil moisture conditions and again higher than average temperature and low precipitation in spring/summer 2019, resulted in severe growth reductions in many tree species [18], as a consequence of extensive stem dehydration and depletion of carbohydrate reserves, which will compromise tree growth and survival in coming years [19].

Thus, in uncertain climatic environments, intraspecific differences in tolerance and resilience to drought episodes of Scots pine have become an increasingly important topic. The wide distribution of this species implies a broad range of local climates (cold winters in northern Fennoscandia, Mediterranean climate in southern Spain, wet oceanic climate in Scotland or dry continental climate in central Europe and Asia), making this species a valuable study system to evaluate local responses to climate change [20]. Adaptive plasticity and genotypic variability inherent to Scots pine are the two main processes by which trees can either be selected or can acclimate to changing conditions [21]. The local adaptation processes as well as phenotypic plasticity of tree species could be monitored in the common gardens [22].

The results of the Polish Scots pine provenance experiment covering the central European distribution area of this species showed that, under a spatially uniform but temporally heterogeneous climate, Scots pine provenances manifest temporal variations in growth related to the hydrological conditions of the previous and current spring [23].

The results of the Latvian Scots pine provenance experiment showed greater tolerance to drought events in provenances originating from warmer and drier conditions, indicating adaptation to water deficit and having a high potential to sustain the productivity of Latvian stands in the future [24]. Estimated responses in Latvia suggested phenotypical adaptability limits of the eastern Baltic populations of Scots pine in the longer term, supporting the necessity of climate-smart management for the sustainability of forests in the region in the future [25].

Experimental research concerning the growth of trees in pine provenances in Lithuania is relatively scarce. Most studies have focused on the assessment of adaptation, resistance and productivity of pine populations, mainly by analyzing the survival, diameter and height increments, standing volume accumulation or stem properties [26–28].

Recent dendrochronological studies of Scots pine in Lithuania revealed that the main factor influencing the increased growth of predominantly healthy trees observed since the beginning of the 1980s was the air temperature of the winter period from December to April and of the growing season from May to August; the effect of precipitation was more relevant during the vegetation period [29]. Specifically, more precipitation during February, June and July together with a higher temperature in November and March resulted in a higher basal area increment in pines [30].

However, these findings were clarified by using data from traditional Lithuanian forests. Thus, the gap of knowledge regarding the variation in climate sensitivity of Scots pine origins from various European regions remains. We hypothesize that with the incorporation of the genetic material into Lithuanian Scots pine origins, it would be possible to increase their adaptation to climate change.

Thus, the aim of this study was to assess the growth response to climate change of East European pine provenances in Lithuania. Accordingly, the following tasks were conducted: (a) to estimate the mean yield values in tested pine provenances regarding their location, (b) to evaluate temporal variation in climate sensitivity and (c) the effect of droughts to tree-ring formation for Scots pine provenances, and (d) to clarify the most important monthly climatic variables for tree-ring formation.

2. Materials and Methods

2.1. Establishment of the Experiment

From 1974 to 1976, a series of Scots pine provenance experiments were established across the former USSR [31,32]. The field test of the Prokazin series with 48 provenances from the former Soviet Union was established in 1975 in the Jūrė forest district (54°47′, 23°35′) in central Lithuania (Figure 1). The seeds were collected in natural, phenotypically superior stands. Furthermore, seeds were transported to Lithuania and planted in a bare root nursery. After one year of growth in the nursery, bare-rooted seedlings were transported to the Jūrė provenance test plantation. Soil was completely plowed in the autumn, and the seedlings were planted in spring by using a row planting system. The complete list of investigated pine provenances with their place of origin is presented in Table 1 and Figure 1.

Table 1. The geographic data and locations of pine provenances.

Prov	Country	Region	Location	LAT	LON	*N*, ha	S, %	*H*, m	*D*, m	V, m^3 ha
43	RUS [1]	Moscow	Eastern	55°32′	38°57′	1555	35.3	14.3	14.4	187.7
45	RUS	Gorky [2]	Eastern	56°40′	43°28′	1331	30.3	15.0	15.5	194.8
46	RUS	Gorky	Eastern	54°56′	43°50′	1268	28.8	15.1	16.4	206.1
47	RUS	Kostroma	Eastern	58°22′	44°44′	1447	32.9	13.7	15.0	181.6
48	RUS	Kostroma	Eastern	58°00′	42°00′	1517	34.5	12.6	13.4	143.6
50	RUS	Ryazan	Eastern	54°40′	39°45′	1424	32.4	14.1	14.6	173.5
54	RUS	Tambov	Eastern	53°12′	41°20′	1261	28.7	14.3	15.2	170.3
57	RUS	Penza	Eastern	53°50′	46°00′	847	19.3	14.8	16.9	142.8
59	RUS	Ulyanovsk	Eastern	54°14′	49°35′	732	16.6	15.3	18.1	144.4
65	RUS	Tarty	Eastern	56°00′	48°00′	1018	23.1	15.7	16.8	179.1
67	RUS	Udmurtia	Eastern	57°30′	54°00′	546	12.4	14.3	17.0	89.8
68	RUS	Tver	Eastern	58°49′	50°06′	1023	23.3	13.0	14.7	118.7
69	RUS	Baskiria	Eastern	55°30′	54°40′	635	14.4	13.6	17.0	99.8
66A	RUS	Tver	Eastern	55°40′	51°26′	715	16.3	13.5	17.6	119.9
C-44	RUS	Vladimir	Eastern	56°21′	41°15′	1204	27.4	13.9	14.7	147.3

Table 1. *Cont.*

Prov	Country	Region	Location	LAT	LON	*N*, ha	S, %	*H*, m	*D*, m	V, m^3 ha
21	RUS	Pskov	Central	56°23′	30°31′	1137	25.8	14.9	15.2	157.5
38	RUS	Sumsk	Central	52°01′	34°00′	900	20.5	16.1	17.6	178.2
41	RUS	Smolensk	Central	54°00′	33°00′	1202	27.3	16.9	17.9	254.7
51	RUS	Bryansk	Central	53°00′	34°00′	1234	28.0	14.5	15.2	169.2
52	RUS	Orlov	Central	53°00′	36°00′	1678	38.1	15.7	16.2	275.5
55	RUS	Voronez	Central	51°38′	39°28′	982	22.3	16.0	17.5	190.2
49_1	RUS	Kaluga	Central	54°25′	36°16′	1053	23.9	15.1	15.9	160.5
49_2	RUS	Kaluga	Central	54°25′	36°16′	1348	30.6	16.2	16.6	239.9
4	RUS	Archangelsk	Northern	62°54′	40°24′	771	17.5	11.6	13.3	66.1
9	RUS	Vologda	Northern	60°00′	43°00′	1057	24.0	13.6	14.9	131.3
15	RUS	Karelia	Northern	61°40′	33°40′	1148	26.1	13.3	14.7	135.0
16	RUS	Karelia	Northern	61°50′	30°28′	953	21.7	12.1	13.9	94.3
19	RUS	Leningrad	Northern	60°00′	30°25′	1684	38.3	14.9	14.4	213.8
23	RUS	Novgrod	Northern	58°15′	33°28′	1288	29.3	14.5	14.8	165.9
42	RUS	Kalinin	Northern	57°45′	36°40′	1139	25.9	14.8	16.0	174.3
C-17	RUS	Karelia	Northern	61°40′	36°33′	1080	24.5	11.9	12.7	89.5
29	BLR	Gomel	Southern	52°14′	31°43′	1117	25.4	16.6	17.0	211.4
39	RUS	Cerkasy	Southern	49°37′	32°00′	996	22.6	14.9	17.5	182.2
33	UKR	Rovno	Southern	51°32′	26°36′	953	21.7	15.8	17.7	186.1
36	UKR	Lvov	Southern	48°07′	24°00′	860	19.5	16.6	19.2	204.2
37	UKR	Kijev	Southern	50°10′	31°20′	908	20.6	16.5	18.9	209.4
28	BLR	Vitebsk	Western	56°00′	29°20′	1210	27.5	14.8	15.1	165.3
30	BLR	Gardin	Western	53°25′	25°15′	1012	23.0	16.2	18.0	208.2
24	EST	Elva	Western	58°10′	26°28′	979	22.3	15.6	17.0	175.6
25	LVA	Jaunjelgava	Western	56°27′	25°10′	1006	22.9	15.6	16.7	175.1
1	LTU	Kazlų rūda	Western	54°45′	23°35′	1713	38.9	16.2	15.1	253.4
2	LTU	Kazlų rūda	Western	54°45′	23°35′	1218	27.7	16.1	15.9	200.2
26	LTU	Prienai	Western	54°42′	23°58′	1256	28.5	15.2	15.8	192.1
M1	LTU	Mažeikiai	Western	56°46′	22°40′	1055	24.0	15.1	16.8	178.9
M2	LTU	Mažeikiai	Western	56°46′	22°40′	1376	31.3	15.2	15.9	211.9
M3	LTU	Mažeikiai	Western	56°46′	22°40′	1261	28.7	15.0	15.6	185.0
22	RUS	Pskov	Western	57°50′	28°26′	1351	30.7	16.4	15.3	208.7
27	RUS	Magilov	Western	53°18′	28°40′	1208	27.5	16.5	16.1	205.9

[1] Country codes are based on the International Organization for Standardization (ISO 3166-1 alpha-3) code. [2] Provenances, marked in bold, were selected to analyze the impact of monthly meteorological parameters on stem radial growth. The following column abbreviations were used: Prov—number of Scots pine provenances, LAT—altitude, LON—longitude, *N*—number of trees per hectare, S—survival rate, *H*—mean height, *D*—mean diameter, V—volume of growing trees.

The Jūrė common garden was designed in large nonreplicated provenance plots with ca. 100–200 trees per provenance. Approximately 4400 seedlings per hectare were planted in each trial area with a spacing of 1.5 × 1.5 m [20]. No thinning was performed during the time of investigation. However, in the last inventory that was performed in 2013, the number of recorded trees was much lower due to self-thinning.

The experimental site is a *Vaccinio myrtilli-Pinetum* forest type with moderately dry and comparatively fertile oligotrophic mineral soils—Haplic Arenosol [33].

To characterize the climatic conditions that affect the growth of trees from pine provenances in their native places, we used data for the 1970–2000 period, provided by the WorldClim 2—Global Climate Data website (https://www.worldclim.org/data/worldclim21.html [34], accessed on 1 April 2020) using ArcMap 10.8.1 software. The mean annual temperature in places of origin of analyzed Scots pine provenances varied from 0 to 10 °C (Figure 1a) and annual precipitation changed from 400 to 1000 mm per year (Figure 1b).

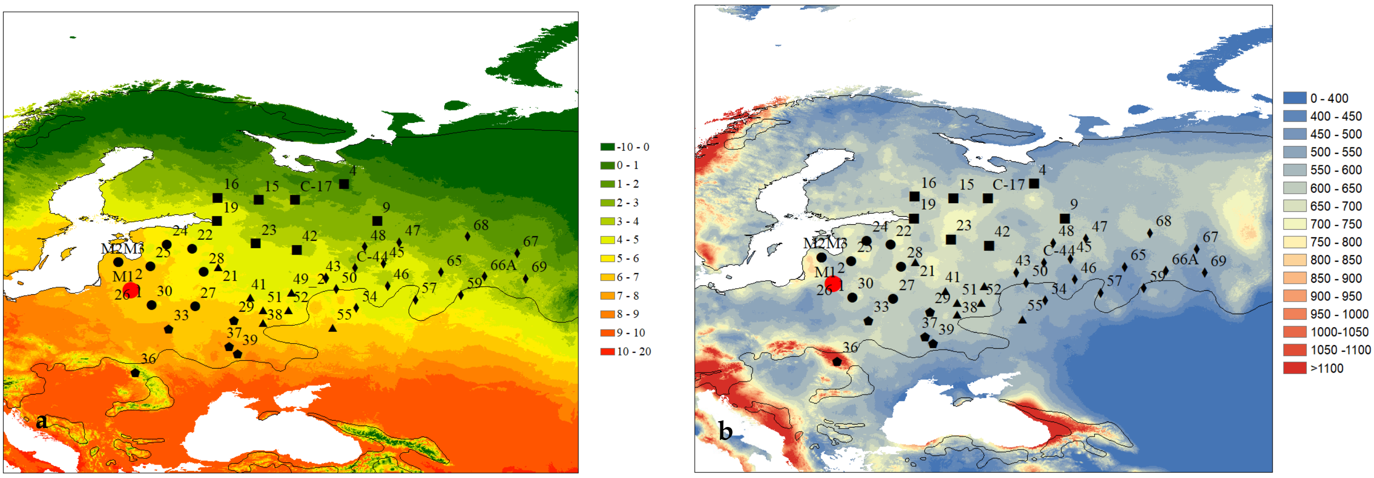

Figure 1. Location of study area (red circle) and places of origin of analyzed provenances (colored triangles). Colors of the maps show: (**a**) mean annual temperature and (**b**) annual precipitation for 1970–2000 period. Climatic maps were provided by WorldClim 2—Global Climate Data website (https://www.worldclim.org/data/worldclim21.html, accessed on 25 April 2022 [34]). The shapes of symbol indicate Scots pine provenances from: diamonds—eastern, triangles—central, squares—northern, pentagons—southern, and circles—western locations that were created by using principal component analysis. The black line indicates distribution range of Scots pine (shapefiles taken from Caudullo et al. [35]).

2.2. Climatic Trends during 1975 to 2013 in the Kaunas Region

The climate data at the site of the experiment in Lithuania from 1975 to 2013 were obtained from the Kaunas region meteorology station, located 25 km from the field test area shown in Figures 2 and 3.

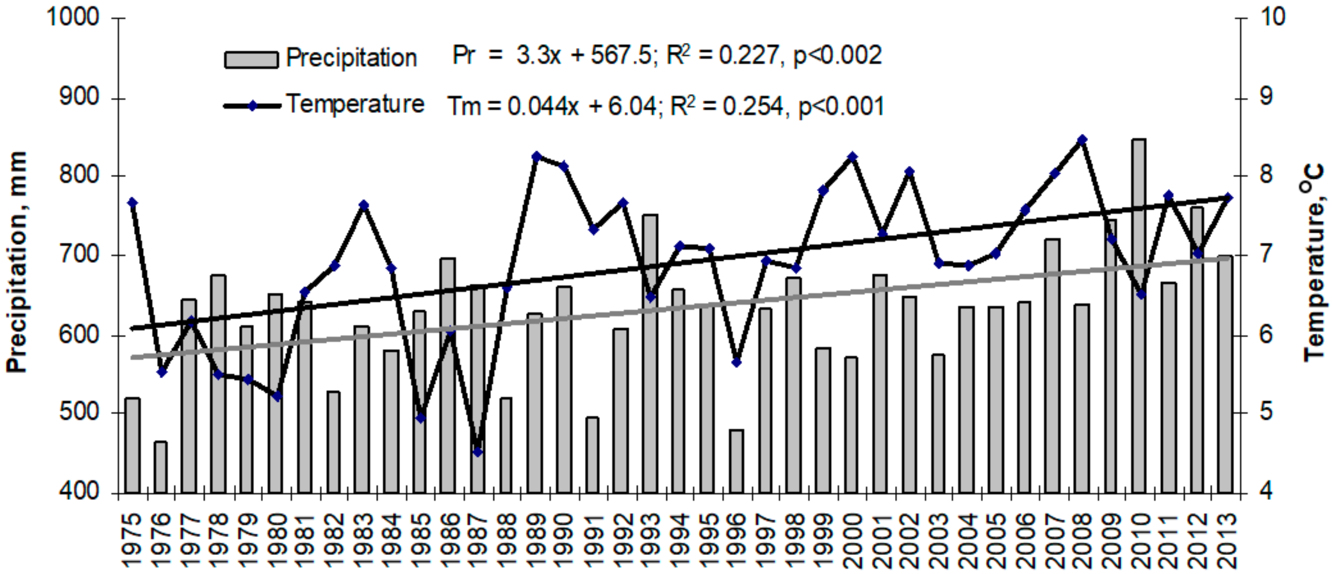

Figure 2. Variation in annual mean daily temperature and mean precipitation sum in the Kaunas region from 1975 to 2013 (data received from the Kaunas region meteorology station).

Figure 2 visualizes the intensity of changes in mean annual temperature and annual precipitation in period from 1975 to 2013. Additionally, linear regression models were used to assess the intensity of interannual changes in monthly meteorological parameters (mean temperature and precipitation) by computing the slope of regression during the considered period (1975–2013) and its significance, *p* (Figure 3). The statistical significance was tested at a confidence level of 95% ($p = 0.05$).

The long-term mean annual temperature fluctuated between +4.6 °C (1987) and +8.5 °C (2008), with an increasing trend of 0.044 °C per year (Figure 2). This increase was statistically significant and was in full agreement with the SES A1 B Project [36]. The annual precipitation amount over the considered period changed from 450 mm in 1976 to 840 mm in 2010, with an increasing trend of 3.3 mm per year.

The most significant trend towards an increase in air temperature ($p < 0.0001$) was detected in July, up to 0.093 °C per year (Figure 3). Additionally, a statistically significant increase in air temperature of more than 0.035 °C per year was detected in February, March, April, June, August, September, November, and December.

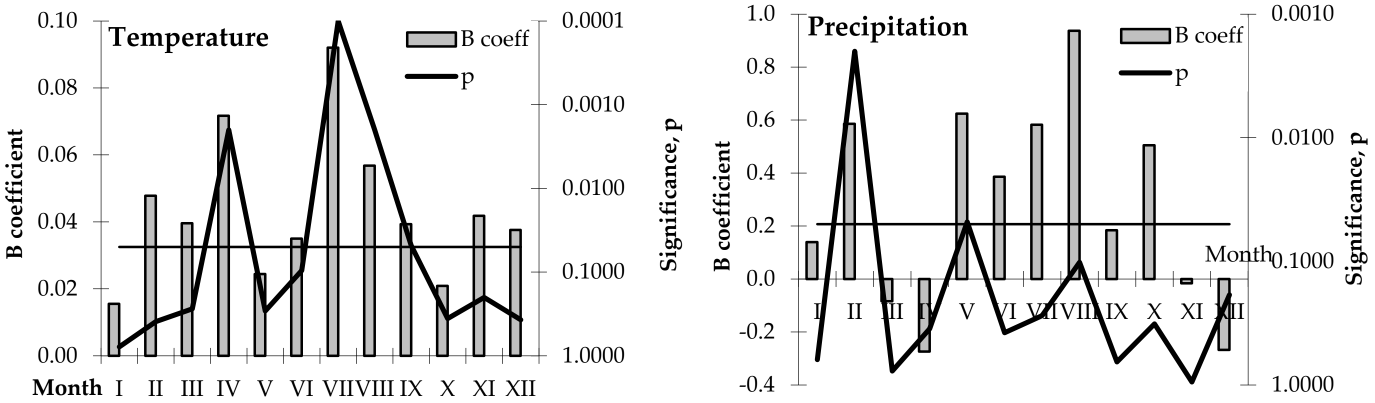

Figure 3. The intensity of changes in monthly meteorological parameters from 1975 to 2013: temperature (**left** figure) and precipitation (**right** figure). Higher B regression slope coefficient values indicate a faster increase in monthly meteorological indicators (data received from the Kaunas region meteorology station). Horizontal lines indicate significant changes at the 0.05 level.

The most significant ($p < 0.01$) trend towards an increase in the amount of precipitation was recorded at the end of winter, i.e., in February, when it was approximately 0.6 mm per year. The precipitation increase in the summertime, i.e., in August, was the highest and was approximately 0.8 mm per year (Figure 3). However, these changes were not significant.

To detect periods with a water deficit, we calculated the standardized precipitation evapotranspiration indices (Figure 4) integrated over three (SPEI3) and six months (SPEI6) as the standardized difference between the monthly precipitation and potential evapotranspiration [37]. The monthly precipitations were obtained from the same Kaunas region meteorology station and the potential evapotranspiration was estimated by using the Thornthwaite [38] method described by Vicente-Serrano et al. [39]. To calculate the potential evapotranspiration, this method has the advantage of only requiring data on the monthly mean temperature. By calculating the standardized evapotranspiration index SPEI 3 and SPEI 6 (Figure 4), we identified the severe drought years 1992, 1994, 1999 and 2006. For this purpose, we used the SPEI cut-off value −1.8.

2.3. Data Collection

Field measurements were carried out in autumn 2013 when the trees were 39 years old. The status of the trees (growing or dead), diameter at breast height (d_{bh}), tree height (h), height to crown base (h_{cb}) and crown width (c_w) were measured. In total, measurements were taken for 9539 trees, representing 48 pine provenances. The d_{bh} for each tree in the sample plot was measured at 1.3 m above the soil level using calipers with a precision of 1 mm. The tree height and height to the crown base were measured with a clinometer. The precision of the clinometer was ±0.5 m. To define the height to the crown base position, the method proposed by Biging and Wensel [40] was applied. To estimate the crown width, the vertical crown projection radius was measured according to the main compass directions—north, east, south and west—and was performed using a tape measure with a precision of ±0.1 m [41].

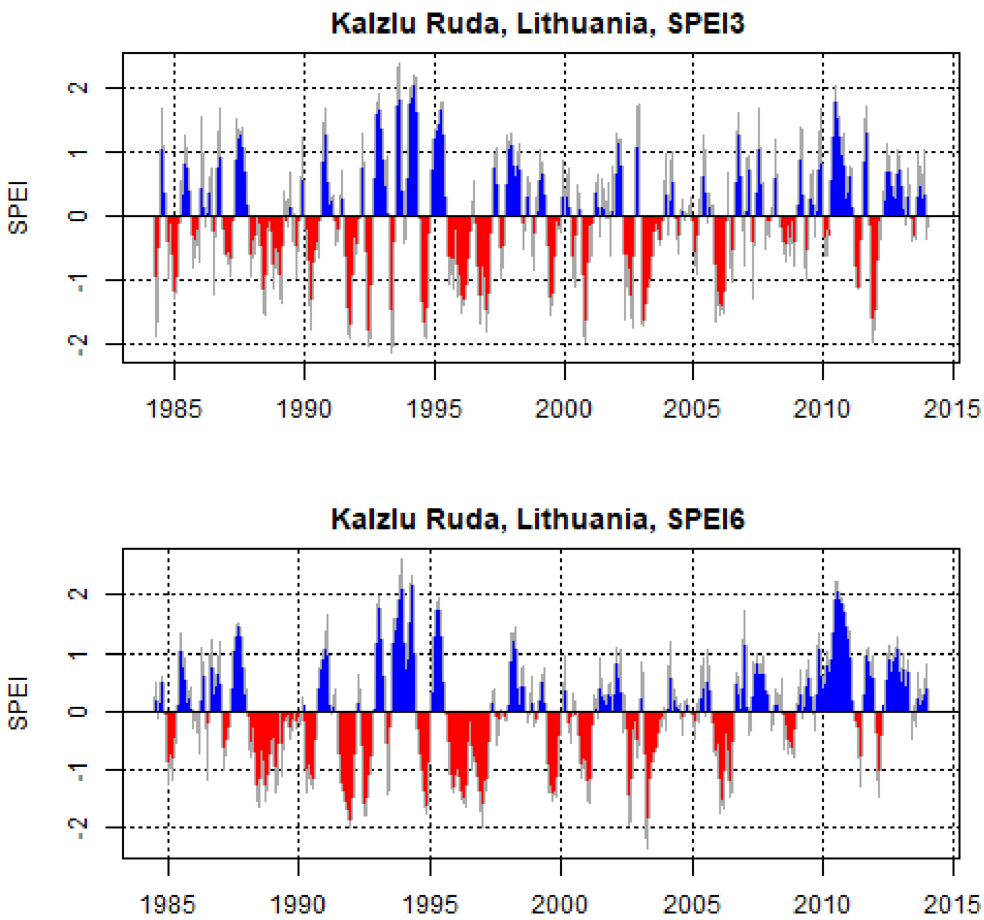

Figure 4. Temporal variations of standardized precipitation evapotranspiration index (SPEI) integrated over three and six months for the 1984–2013 period.

During autumn 2013, increment cores (one core per tree collected from the west-facing direction of the tree) were collected for 22 provenances out of 48 (5 provenances from the eastern location, 4 from the central location, 5 from the western location, 4 from the southern location and 4 from the northern location). Only those provenances in which the mean stand values (survival rate, mean diameter, mean height and volume of growing trees) reacted the most to the effect of latitude and longitude and followed the model trends (lied on the model's line) were selected for the analysis (Figure S1). The methods for the classification of Scots pine provenances into locations are described in Section 2.5.

The provenances that were selected for this study are marked in bold in Table 1. To estimate the provenance effect on the radial increment, for preselected provenances, 15 diameter cores at a breast height of 1.3 m were collected, and tree-ring widths were estimated for the sample trees with an accuracy of 0.01 mm. The sample was formed by representative, well-growing trees, which were not suppressed by competition (excluding the "wolf" trees); their crowns were directly illuminated by sunlight, and they did not have visible damage from biotic or abiotic factors. In total, diameter core samples were collected from 330 trees. To avoid tremendous damage to the trees, one sample per tree was selected. The precise yearly tree-ring widths were estimated with LINTAB [42].

2.4. Estimation of the Mean Growth and Yield Values

The following yield parameters were calculated for each pine provenance in trial: survival rate (S), mean diameter (*D*), mean height (*H*) and volume of growing trees (V). *D* was estimated by using Equation (1) as a quadratic mean diameter of all growing trees [43].

$$D = \sqrt{\frac{\sum_{i=1}^{N} {d_{bh}}^2}{N}} \quad (1)$$

where D is the quadratic mean diameter in cm; d_{bh} is the tree diameter at breast height in cm; and N is the number of trees per plot. The stand height for each provenance that represents relationships between the tree diameter and height at the time of inventory was developed by using the Michailoff [44] formula (Equation (2)). H was estimated by using Equation (3). Regression coefficients a_0 and a_1 that were taken from Equation (2). The mean height to the crown base (H_{cb}) was estimated similar to H by substituting h_{cb} values instead of h values in Equation (2).

$$h = 1.3 + e^{\left(\frac{a_0}{d_{bh}} + a_1\right)} \quad (2)$$

$$H = 1.3 + e^{\left(\frac{a_0}{D} + a_1\right)} \quad (3)$$

where h is tree height in m, d_{bh} is the tree diameter at breast height in cm, H is the mean stand height in m, and D is the quadratic mean diameter in cm.

The volume of each tree was estimated by multiplying its basal area, height and form factor. Form factors were estimated by using Equation (4) [45]. V (m^3/ha) was calculated by summing the volumes of all trees growing in the trial plot and then dividing this by the size of the plot.

$$f_s = 0.41097 + \frac{0.47997}{h} + \frac{1.02196}{d_{bh}} + \frac{0.12880}{d_{bh} \cdot h} - \frac{2.84120}{{d_{bh}}^2} + \frac{6.3796}{{d_{bh}}^2 \cdot h} \quad (4)$$

where f_s is the form factor, h is the height of the tree in m, and d_{bh} is the tree diameter at breast height in cm.

Finally, the mean summarized results for S, *D*, *H* and V regarding eastern, central, western, southern and northern locations are presented in box and whisker plots. The nonparametric Kruskal–Wallis method was used to check whether the differences between the locations were statistically significant ($p < 0.05$).

2.5. Classification of Scots Pine Provenances

The bioclimatic distance between provenance origins and the experimental site was determined by using principal component analysis (PCA). The climate data for the trial site as well as for the locations representing the 48 analyzed Scots pine provenances were extracted from WorldClim 2 at a spatial resolution of 30 s, [34]. The values of the climatic variables were then extracted by using ArcMap 10.8.1 software. Out of 19 bioclimatic parameters taken from Fick and Hijmans [34], we selected 7 variables, leaving those with the highest contributions to the first principal component PC1 and the second principal component PC2, by removing highly correlated variables ($r > 0.7$ or $r < -0.7$) [46].

Based on the PCA analysis results, all Scots pine provenances were classified to five clusters or locations: eastern, central, northern, southern and western. The experimental site represented the western location.

2.6. Standardization and Chronology Building Methods

The synchronization of individual tree-ring-width series for each provenance was performed by using visual comparison of the ring-width graphs [47]. Additionally, a statistical check was performed by calculating gleichläufigkeit or the coefficient of coherence [48,49]; the mean sensitivity (MS), which indicated a general climate sensitivity of growth; as well as the rbar total (r_{bt}), which shows the mean of all the correlations between different cores [50–52]. The expressed population signals (EPS), a measure of the quality of the common growth signal within a population [51]; and the mean inter-series correlation and first-order autocorrelation (AR1), an indicator of the effects of the previous year's conditions upon the current year's growth, were calculated to characterize raw, individual tree-ring-width series. The calculation of chronology statistics was performed in R [53] by using the "dplR" package 1.7.2 [54]. Since 1992, 1994, 1999 and 2006 were characterized by severe droughts during the vegetation period (SPEI < -1.8), we used these years to synchronize the tree-ring-width series within each Scots pine provenance. Analysis of pointer years was performed by using pointRes package pointRes [55] implemented in R [53] software. Only the year 1992 was identified as a pointer year (Mean Crropper value < -1.5. The Mean Crropper values for 1994 and 2006 were lower than -1 but did not reach significant levels.

The standardization of the tree-ring-width series for each Scots pine provenance and elimination of the age trend was performed by calculating the mean tree-ring-width indices RWI. For this purpose, we used the "dplR" [54] package and its function "detrend" together with the "Spline" method, implemented in R [53] software 4.2.0.

2.7. Analysis of Temporal Variation in Climate Sensitivity

To investigate the climate sensitivity of Scots pine provenances, the mean monthly temperature, monthly precipitation and standardized precipitation evapotranspiration index integrated over six months (SPEI 6), starting from October of previous year and ending with September of the current year, were used and related to the indexed mean tree-ring-width series RWI.

The temporal variation in climate sensitivity analysis of Scots pine provenances, grouped to the clusters or locations, was implemented by using moving correlations in windows of 12 years. The analysis was implemented by using the "treeclim" [56] package implemented in R [53] software.

2.8. Drought Impact Analysis

The severe drought years 1992, 1994, 1999 and 2006 were identified by calculating the standardized evapotranspiration index SPEI 3 and SPEI 6 (Figure 4). Superposed epoch analysis (SEA) was used to test the significance of the tree growth response to drought years. For this purpose, we used the "dplR" [54] package and its function "SEA" implemented in R [53] software 4.2.0.

2.9. The Importance of Monthly Climatic Variables for Tree Ring Formation

To clarify the most influential climatic variables (mean temperature and precipitation amounts October of previous year and ending with September of the current year) on tree-ring formation, we used a general classification and regression tree module implemented in the program STATISTICA 10. It is important to note that we applied the same preselected list of pine provenances (Table 1, marked in bold). The analysis was performed separately regarding the location of origin of pine provenances.

Classification and regression trees determine a set of if–then logical (split) conditions that permit the accurate prediction or classification of cases by applying methods that are nonparametric and nonlinear [57]

This tool also estimates the importance of each predictor variable by summing the decrease (delta) in node impurity (delta (I) for classification) or the resubstitution estimate (for regression trees delta(R)) over all nodes in the tree and expresses these sums relative to the largest sum found over all predictors or the most important variable [58]. Thus, each climatic variable obtains a value from 0 (least important) to 1 (most important).

3. Results

3.1. Grouping of Scots Pine Provenances Based on Bioclimatic Analysis

The principal component analysis (PCA) that included 7 bioclimatic variables out of 19 bioclimatic parameters taken from Fick and Hijmans [34], representing the 40 origin sites as well as the provenance trial site in Kazlų Rūda, explained a total of 66.8% of the overall variance (Table 2 and Figure 5). In detail, the first principal component (PC 1) explained 44.9% and the second (PC 2) accounted for 21.9%. PC 1 positively correlated (0.220 < r < 0.479) with Bio_2, Bio_4 and Bio_ 10 and negatively correlated (−0.30 < r < −0.446) with Bio_1, Bio_9, Bio_12 and Bio_17. PC 2 was positively correlated (0.029 < r < 0.277) with Bio_4, Bio_12 and Bio_17 and negatively correlated (−0.123 < r < −0.636) with Bio_1, Bio_2, Bio_9 and Bio_10.

Table 2. The eigenvector values between climatic variables and the first two major components, with eigenvalues and the explained variation.

Bioclimatic Variables	Abbreviation	PC 1	PC 2
Annual Mean Temperature	Bio_1	−0.300	−0.550
Mean Diurnal Range (Mean of monthly (max temp-min temp))	Bio_2	0.321	−0.123
Temperature Seasonality (standard deviation ×100)	Bio_4	0.479	0.029
Mean Temperature of Driest Quarter	Bio_9	−0.334	−0.339
Mean Temperature of Warmest Quarter	Bio_10	0.220	−0.636
Annual Precipitation	Bio_12	−0.426	0.277
Precipitation Seasonality (Coefficient of Variation)	Bio_15		
Precipitation of Driest Quarter	Bio_17	−0.446	0.104
Eigenvalue		3.59	1.75
Variance explained		44.9	21.9

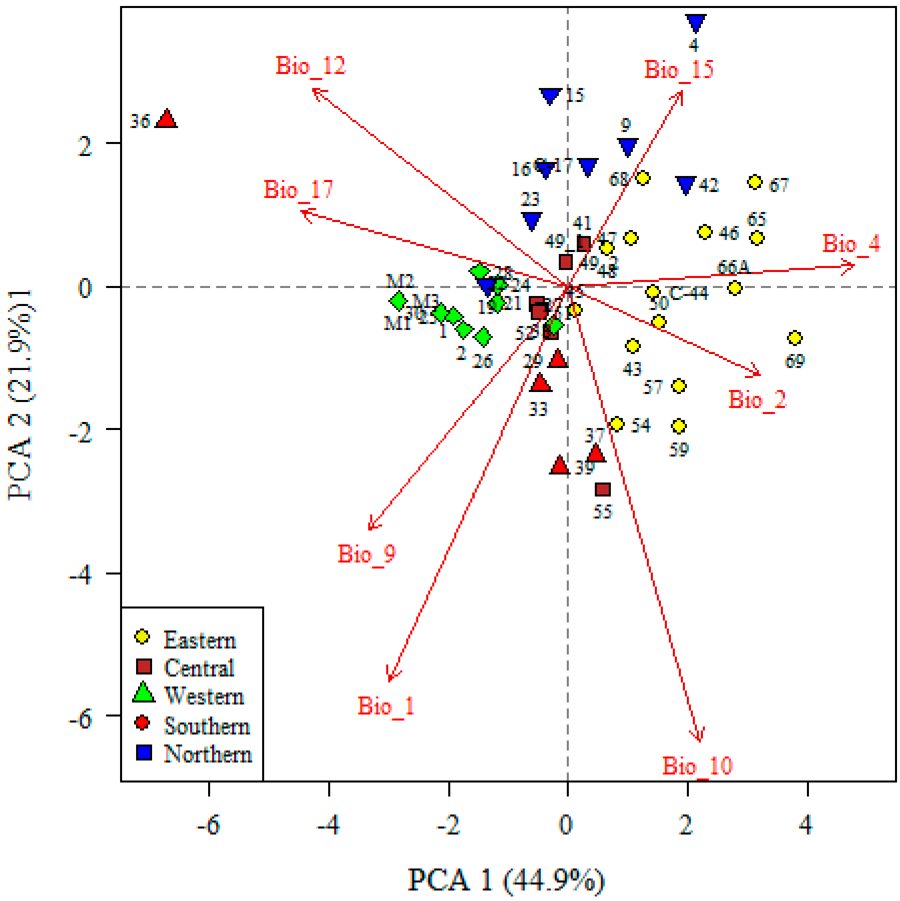

Figure 5. Climate-related variability between Scots pine provenances regarding their places of origin, based on bioclimatic indexes.

Based on the PCA analysis, five clusters of Scots pine provenances were distinguished. The clustering of provenances was determined visually, according to their locations on the PCA biplot.

The first cluster, which represented the eastern location (Table 1, Figures 1 and 5), was formed by 43, 45, 46, 47, 48, 50, 54, 57, 59, 65, 67, 68, 69, 66A and C-44 provenances. This cluster was mainly influenced by bioclimatic variables Bio_4 and Bio_2. The second cluster, which represented the central location, was formed by 21, 38, 41, 51, 52, 55, 49_1 and 49_2 provenances. Since it was settled on the cross of PC 1 and PC 2, no more remarkable influence of bioclimatic variables was detected. An additional cluster was separated, which represented the northern location and was formed by 4, 9, 15, 16, 19, 23, 42 and C-17 provenances. This cluster was mainly under the influence of Bio_12 and Bio_15. Accordingly, the fourth cluster was separated representing the southern location and was formed by 29 39, 33, 36 and 37 provenances. Bio_1 and _Bio_10 representing temperatures had the highest influence for this cluster. Since the bioclimate of provenance 36 was distinguished not only by very high annual mean temperatures (about 10 °C, Figure 1) but also very high mean annual precipitation (about 1000 mm) per year, its location on the PC1 and PC 2 axis remarkably deviated from the main cluster, offering an additional cluster that was not formed due to a lack of provenances with the same bioclimate.

The last cluster, representing the western location, was formed by 1, 2, 22, 24, 25, 26, 27, 28, 30, M1, M2 and M3 provenances.

This cluster was characterized by the negative influence of Bio_9 and positive influence of Bio_17, indicating the importance of the mean temperature and precipitation of the driest quarter for this cluster.

3.2. Mean Survival and Yield Trends

In the analyzed experiment, the provenances from the western region had the highest mean survival, 27.7% (Figure 6a). Lower survival was recorded for the provenances from central, eastern and northern locations (27.1, 25.0 and 25.9%, respectively). The lowest survival, 22%, was estimated for the southern provenances. Individually, the highest survival rate, 38.9%, was recorded for the local Lithuanian 1 (Kazlų rūda, W (western location)) provenance.

We found that provenances from the southern location possessed the highest mean diameter, 18.6 cm (Table 1 and Figure 6b). In contrast, the northern provenances possessed the lowest mean diameter, 14.3 cm. The mean diameter for the remaining provenances, representing eastern, central and western locations, varied by approximately 16 cm. The Lithuanian M1 (Mažeikiai, W) provenance, which had the best results compared with other Lithuanian provenances, had a mean diameter of 16.8 cm

The southern provenances also had the highest mean height, 16.1 m (Table 1 and Figure 6c). Slightly lower results were recorded for western and central provenances, approximately 15.7 m. Provenances from the eastern and northern locations were characterized by remarkably lower mean heights that reached only 14.2 and 13.64 m. The highest mean height in trees from Lithuanian provenances was measured in trees from provenance 1 (Kazlų Rūda, W), 16.2 m.

The last yield value analyzed was the mean volume of growing trees from pine provenances in regard to their location (Table 1 and Figure 6d). The highest volume of growing trees was estimated for provenances that are in the central location with 203 m^3/ha. Slightly lower volumes of growing trees were estimated for provenances that represent southern and western locations: 199 and 197 m^3/ha, respectively. Provenances in northern locations accumulated very low volumes, compared with the other locations, only 148 m^3/ha. The least performing Lithuanian M1 (Mažeikiai, W) provenance accumulated 178.9 m^3/ha.

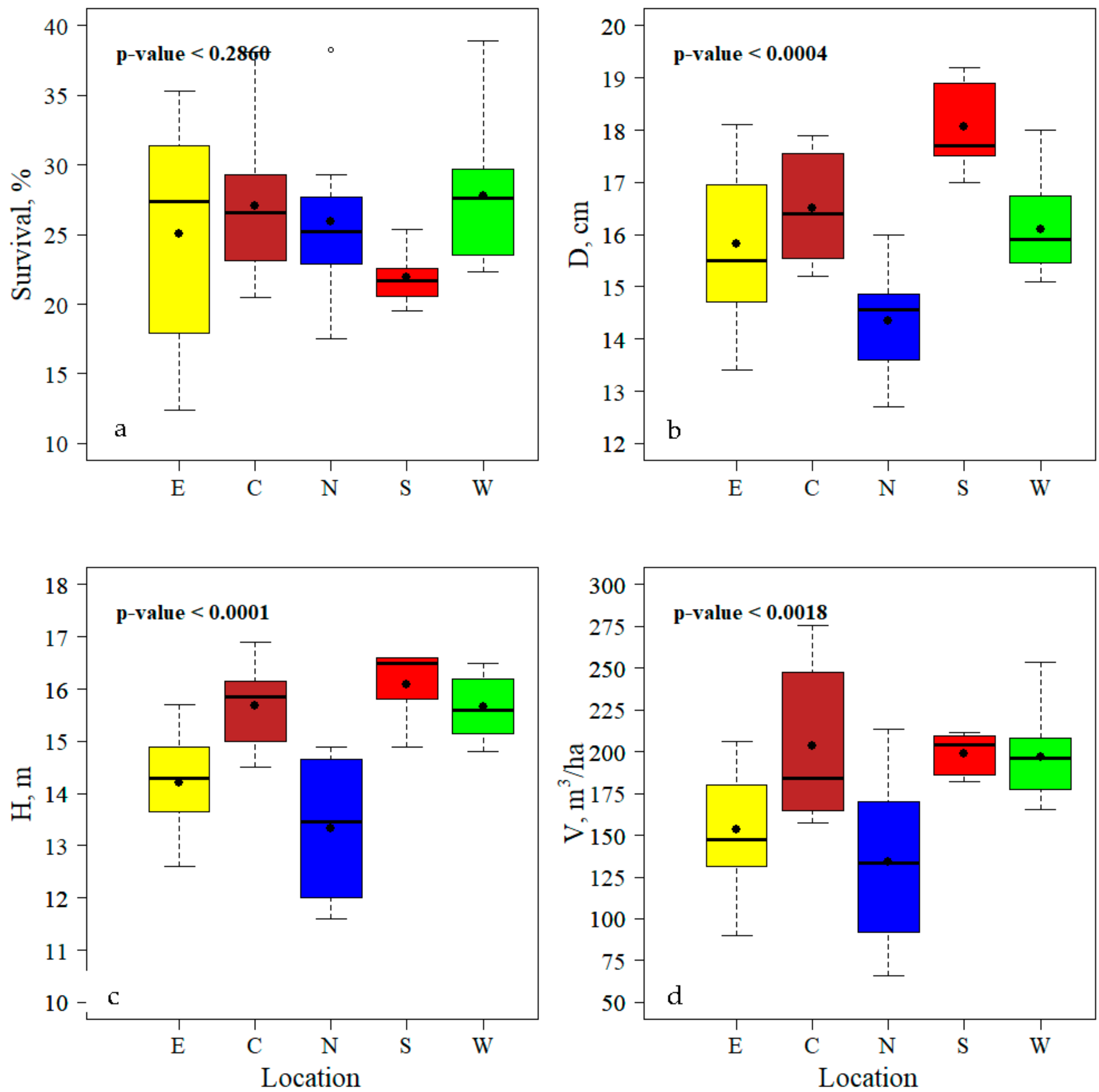

Figure 6. The mean growth and yield values (**a**) survival rate, (**b**) quadratic mean diameter, (**c**) mean height and (**d**) volume of growing trees per hectare of Scots pine (*Pinus sylvestris*) provenances, grouped by their eastern (E), central (C), northern (N), southern (S) and western (W) locations.

3.3. Radial Growth Chronologies

Chronology statistics of Scots pine provenances were evaluated and presented in Table 3. Gleichläufigkeit values varied from 0.613 to 0.687 and were above a general threshold of 60%. Additionally, the mean sensitivity for all the provenances was higher than 0.2, generally accepted as series that are sensitive enough for climate reconstruction [59]. The average pairwise correlation between series was above desirable value of 0.5 [60] for all provenances. Accordingly, the expressed population signal exceeded the threshold of 0.85, indicating an adequate strength of the common signal in the time series. The mean inter-series correlation varied between 0.423 and 0.659 and the first-order autocorrelation changed between 0.595 and 0.774. While evaluating the chronology statistics of Scots pine provenances, no remarkable trend related to the geographical origins of provenance was detected.

Table 3. Chronology statistics of Scots pine provenances, glk—gleichläufigkeit, MS—mean sensitivity, rbt—the average pairwise correlation between series, EPS—expressed population signal; R—mean inter-series correlation, AR1—first-order autocorrelation.

Provenances	glk	MS	rbt	EPS	R	AR1
1	0.627	0.276	0.746	0.969	0.566	0.721
2	0.644	0.314	0.611	0.901	0.492	0.607
4	0.630	0.296	0.737	0.960	0.423	0.649
9	0.658	0.285	0.648	0.947	0.427	0.705
16	0.632	0.291	0.841	0.984	0.545	0.750
23	0.653	0.257	0.692	0.959	0.453	0.683
27	0.613	0.259	0.684	0.958	0.443	0.724
29	0.614	0.280	0.790	0.977	0.659	0.598
30	0.667	0.260	0.759	0.973	0.587	0.640
36	0.636	0.277	0.817	0.977	0.495	0.774
37	0.687	0.258	0.793	0.977	0.523	0.758
37	0.636	0.291	0.798	0.978	0.536	0.681
41	0.667	0.243	0.788	0.972	0.551	0.725
45	0.647	0.302	0.578	0.936	0.560	0.595
52	0.647	0.280	0.877	0.989	0.463	0.714
54	0.659	0.289	0.751	0.978	0.588	0.713
55	0.665	0.264	0.825	0.983	0.510	0.759
59	0.649	0.276	0.832	0.984	0.541	0.691
66A	0.641	0.286	0.703	0.966	0.521	0.731
67	0.620	0.285	0.759	0.971	0.521	0.668
492	0.660	0.283	0.741	0.968	0.444	0.707
M3	0.646	0.239	0.857	0.982	0.407	0.770

3.4. Temporal Variation in Climate Sensitivity

Climate-growth response of the Scots pine (*Pinus sylvestris*) provenances was different over time. The moving correlation analysis in windows of 12 years, performed separately for each provenance location (easter, central, northern, southern and western) that were formed by using the PCA analysis (Figure 5), confirmed the location–specific temporal response and climatic sensitivity. Provenances showed an increasing trend in the tree ring growth sensitivity to temperature (Figure 7).

The temperatures in September, July, March and February were the most influential climatic variables for the tree ring formation of the Scots pine provenances. More specifically, provenances from the central, southern and especially west locations between 1999 and 2010 demonstrated an increasing statistically significant, negative effect of monthly temperatures in July. Increasing monthly temperatures in September, in the window 1994–2005, had a significant negative effect in eastern and northern provenances. In contrast, increasing monthly temperatures in February and March had a significant positive effect on provenances from eastern, central and northern locations starting from 1994 to 2005 and for provenances from southern and western locations starting from 2000 to 2011.

The moving correlation analysis in windows of 12 years also confirmed the importance of monthly precipitation sums on tree-ring formation between 1984 and 2013. More specifically, precipitation amounts in January, June, August and September were the most influential climatic variables for the tree-ring formation of the Scots pine (*Pinus sylvestris*) provenances (Figure 8).

The precipitation amounts in June had a strong positive statistically significant effect on provenances in all locations in the first 6–10 years of the studied period and a weakened effect at the end of the study period. Accordingly, a statistically significant effect of monthly precipitation amounts in January favored the formation of tree-ring widths starting from 1998 to 2009. This was particularly true for provenances from eastern, central and western locations (Figure 8a,b,e). In this case, precipitation amounts in February compared to January were more important for provenances in the north. In contrast, precipitation amounts in August and September had a negative, statistically significant effect for provenances in all locations between 1995 and 2006. The effect was the highest for provenance from the eastern location and the least from the western location.

To evaluate the drought effect, we used SPEI 6 with a 6-month accumulation period since it represents a seasonal estimate of drought [61]. The effect of the water deficit on the growth of Scots pine provenances varied over the analyzed period (Figure 9).

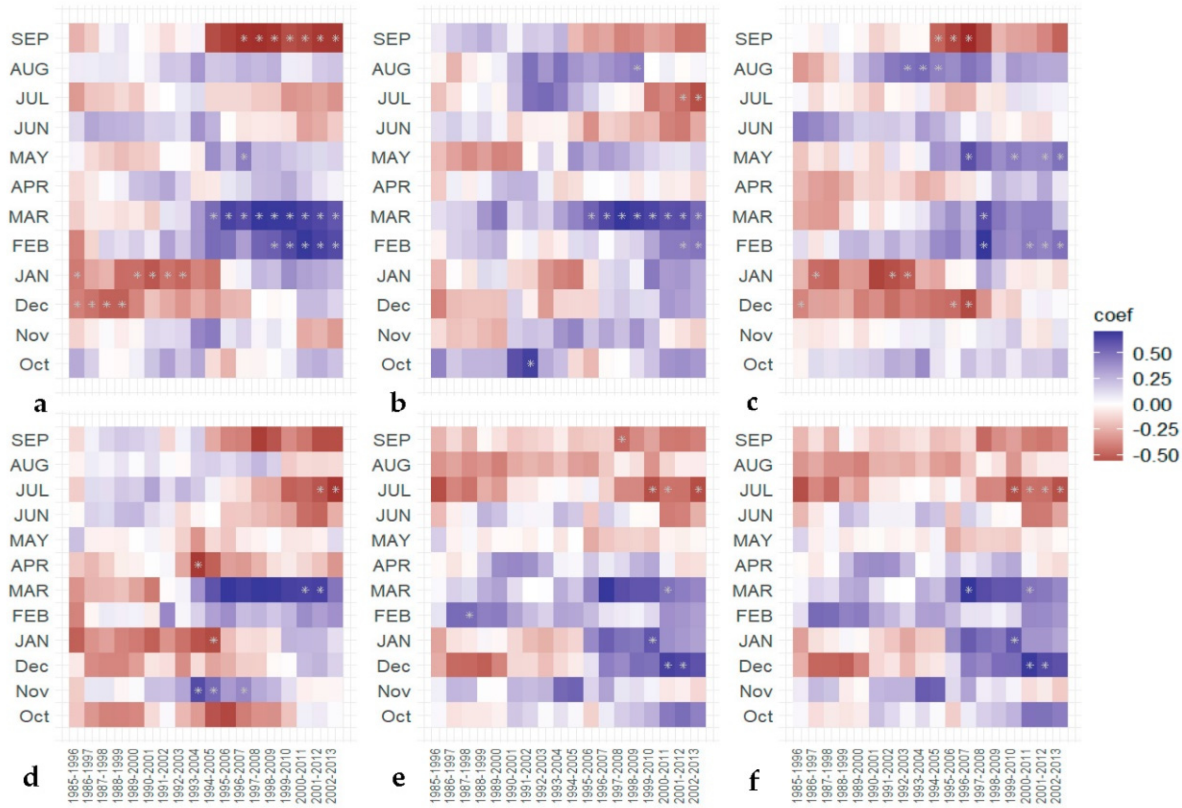

Figure 7. Matrix plots of moving correlation function relating the ring-width index (RWI) of Scots pine (*Pinus sylvestris*) provenances, representing (**a**) eastern, (**b**) central, (**c**) northern, (**d**) southern, (**e**) western locations and (**f**) all provenances, with monthly temperatures, from October in the previous year through September in the current year, over the period 1984–2013. The moving correlation is carried out in windows of 12 years, offset by 1 year. Significant correlations are denoted by asterisks (*).

The negative, statistically significant water-balance effect in January and April was present in the beginning of the analyzed period (first five windows, covering 1985–2000 years) and had the highest impact on provenances from eastern location. However, this effect was weakened and, in some cases, even became positive for provenances from eastern and central locations at the end of the analyzed period (1993–2009).

Contrarily, the water-balance effect in December of the previous year, February, May, June and July had a statistically significant positive effect on the tree-0ring formation for Scots pine provenances from most locations at the beginning to the middle of analyzed period (1985–2004). However, in the coming years, it became negative and, in some cases, even statistically significant, with the highest effect on the Scots pine provenances in the west. In general, the SPEI 6 analysis shows that the water-balance effect on tree-ring formation shifted towards the negative side in the analyzed period, indicating the increasing negative consequences of the droughts.

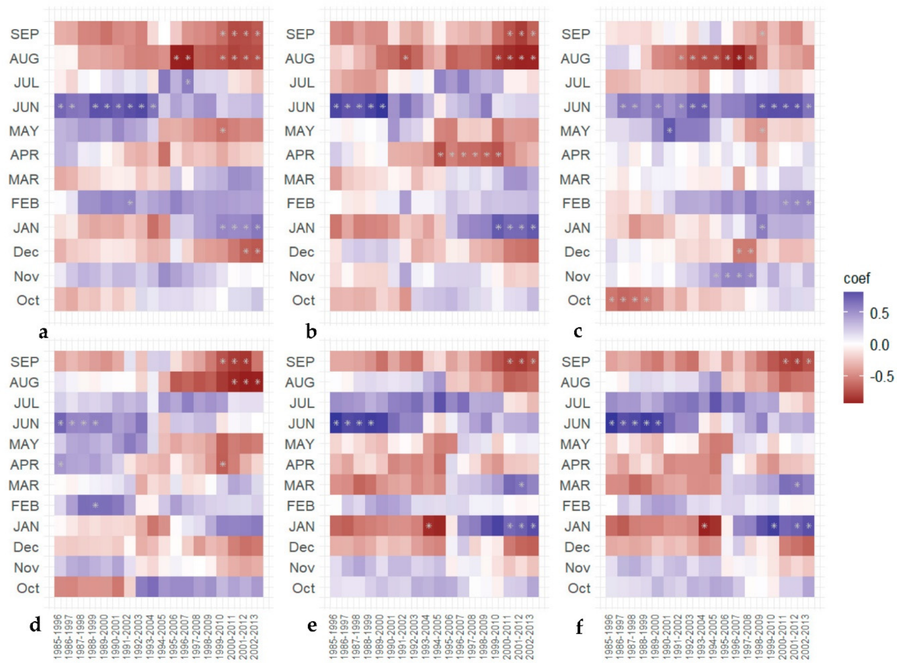

Figure 8. Matrix plots of moving correlation function relating the ring-width index (RWI) of Scots pine (*Pinus sylvestris*) provenances, representing (**a**) eastern, (**b**) central, (**c**) northern, (**d**) southern, (**e**) western locations and (**f**) all provenances, with sums of precipitation, from October in the previous year through September in the current year, over the period 1984–2013. The moving correlation is carried out in windows of 12 years, offset by 1 year. Significant correlations are denoted by asterisks.

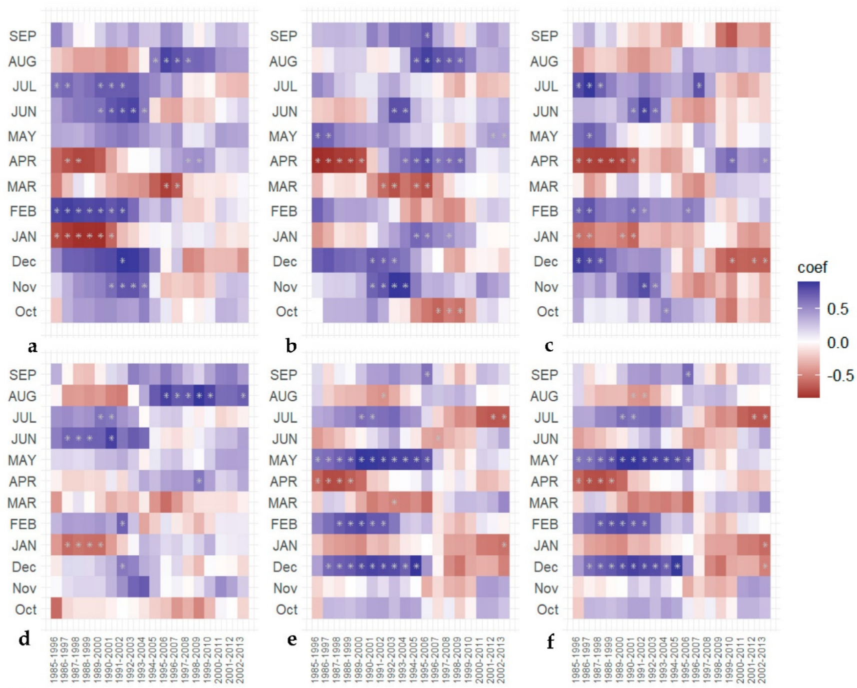

Figure 9. Matrix plots of moving correlation function relating the ring-width index (RWI) of Scots pine (*Pinus sylvestris*) provenances, representing (**a**) eastern, (**b**) central, (**c**) northern, (**d**) southern, (**e**) western locations and (**f**) all provenances, with the standardized precipitation evapotranspiration index integrated over six months (SPEI 6), from October in the previous year through September in the current year, over the period 1984–2013. The moving correlation is carried out in windows of 12 years, offset by 1 year. Significant correlations are denoted by asterisks.

3.5. Drought Impact Analysis

The severe drought years 1992, 1994, 1999 and 2006 were identified by calculating the standardized evapotranspiration index SPEI 3 and SPEI 6. The results of superposed epoch analysis (SEA) based on these years showed a significant reduction in the tree ring formation of Scots pine provenances from eastern, central, northern and western locations. The mentioned reduction for provenances from the southern location was insignificant (Figure 10).

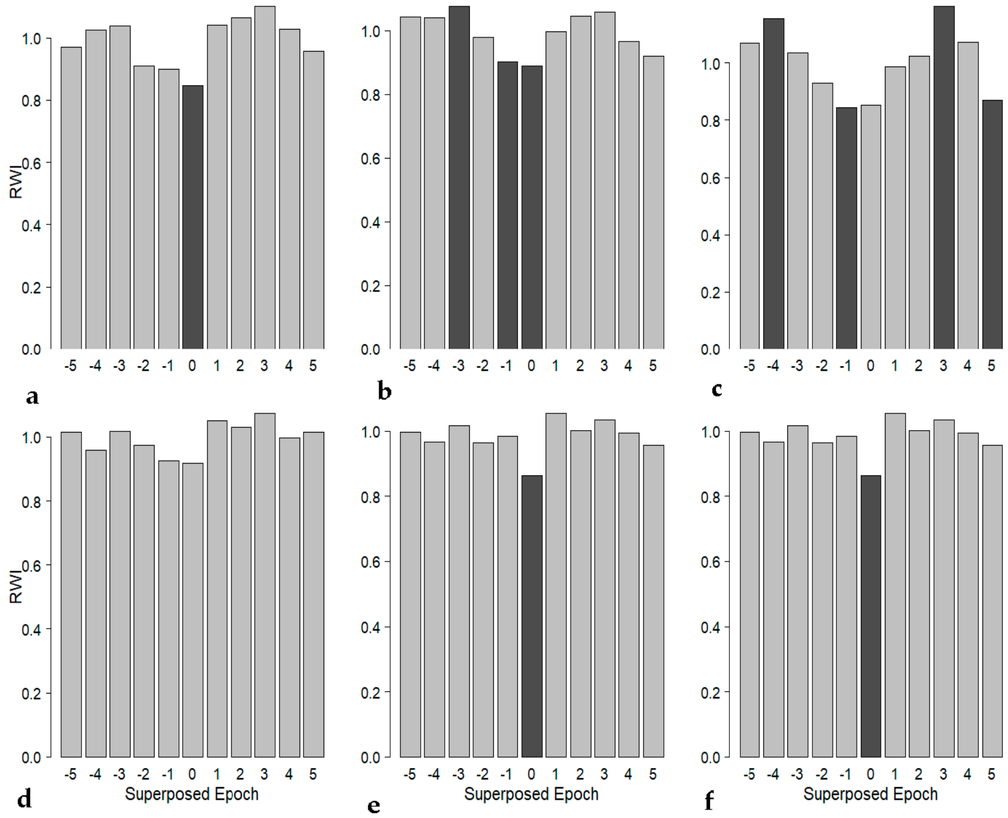

Figure 10. Results of superposed epoch analysis (SEA) showing the significant influence of droughts in 1992, 1994, 1999 and 2006 on Scots pine (*Pinus sylvestris*) provenances, representing (**a**) eastern, (**b**) central, (**c**) northern, (**d**) southern, (**e**) western locations and (**f**) all provenances. In the figure, 0 indicates the event year, −1, −2, and −5 and +1, +2 and +5 show one, two and five years before and following the drought events, respectively. The dark-colored bars indicate a significant growth reduction ($p < 0.05$).

Even though the drought impact and growth reduction for provenances from eastern and western locations was the highest during the impact year, in the following year, the tree-ring formation was fully restored and even higher than before droughts.

The impact of the droughts on the following years was observed only for Scots pine provenances from the northern location, being insignificant for Scots pine provenances from other locations.

3.6. Importance of Monthly Climatic Variables

In this section, we present results that clarify the importance of each climatic variable to tree-ring formation based on the methods used in the classification and regression trees (Figure 11). To clarify the differences, we sorted the climatic variables when all populations were considered (Figure 11).

It was found that precipitation amounts in July, August, June, September of the current year and in December of previous year, as well as mean temperatures in September and in

July of the current year are the most important climatic variables to tree-ring formation. However, the impact of these variables on Scots pines from different locations was different.

The Scots pine provenances from western locations demonstrated sensitivity to precipitation amounts in June and July of the current year and precipitation amounts and mean temperature in December of the previous year. Provenances from the southern location showed the highest reaction to precipitation amounts in July but were not sensitive to precipitation amounts in June of the current year. Contrarily, Scots pine provenances from the eastern location were the most sensitive to precipitation amounts in June but much less sensitive to precipitation amounts in July of the current year. Provenances from the central location were the most sensitive to precipitation amounts in August of the current year. However, precipitation amounts in July and June were important as well by leaving ahead only the mean temperature in October of the previous year and mentioned precipitation amounts in August of the current year.

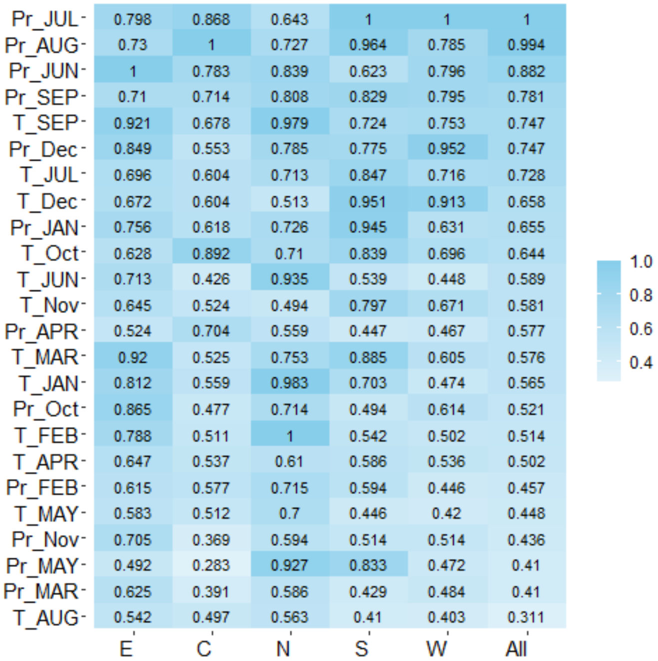

Figure 11. The importance of monthly climatic variables on the ring-width index (RWI) regarding the location of the origin of pine provenances (T indicates monthly temperature and Pr indicates monthly precipitation; all letters in caps indicate months of current year, and lowercase letters indicate months of previous year).

The reaction of northern Scots pine provenances was very different compared to provenances from other locations. Temperatures in February, January, June and September were the most important climatic variables. The importance of precipitation amounts in June or July was estimated to be only minor.

4. Discussion

4.1. Growth and Survival

Scots pine is a highly adaptable forest tree species that grows under different climatic conditions [62]. However, the productivity and survival of this tree species varies across provenances.

The higher productivity of trees from southern and central provenances compared with those from local Lithuanian provenances indicates the possibility of maintaining or increasing the productivity of Lithuanian forests by using hybridization with trees from these provenances with those from Lithuanian provenances [28]. It is well known that transfer to a warmer site reduces the growth and especially survival in southern populations while increasing the growth and survival in northern populations [14]. Seeds transferred northwards at medium distances show better or the same performance in productivity compared with local seeds [63,64]. In contrast, seeds transferred from northern populations to farther south show poor productivity performance compared with local seeds [65–67].

The higher wood yield in trees from southern provenances may be explained by the transfer effect: when moved northwards, Scots pine ceases active growth later and thus produces more wood [28,68]. These differences in the phenological cycle may also explain the differential response of the radial increment of trees to the variation in temperature and precipitation over time.

To evaluate the performance of the analyzed Scots pine provenances regarding growth and survival, we grouped them into five clusters or groups, based on PCA analysis (Figure 5). Therefore, the assignment of marginal populations to one or another group could give slightly different results. The assessment of adaptability depends on ecologically marginal environments [69]. However, we present individual results of Scots pine provenances in Table 1 as well.

4.2. Monthly Meteorological Changes and Tree Ring Formation

Climate warming has already caused changes in forests, and future changes of such magnitudes would lead to the loss of important functions and services, reduced forest carbon stocks or reduced sequestration capacity [70].

Jacob et al. [71] presented three different annual warming scenarios with regional differences in the range of 1–4.4 °C for RCP 4.5, 3–4.5 °C for A1B and 2.5–5.5 °C for RCP8.5 scenarios from 2071 to 2100. More specifically, in Lithuania, the modest RCP4.5 scenario shows a 2.5 °C increase in temperature and an approximately 15% increase in precipitation. However, according to the RCP8.5 scenario, the increase in temperature should reach approximately 3.5 °C, and the amount of precipitation should increase up to 20%. Annual changes in temperature and precipitation are very important; however, the mean monthly changes are decisive to tree ring formation.

Additionally, we highlight the importance of droughts that can appear at higher frequencies and severities during the vegetation period. For example, in recent decades, the highest increase in monthly temperature was recorded in July, and the highest increase in precipitation was in February, May and August (Figure 3). Considering that the present temperature in July (Figure 7) already has a significantly negative effect on Scots pine annual ring formation, a further increase in the mean temperature and lack of precipitation in July would cause very dry growth conditions and become a major factor, limiting the growth of this tree species in Lithuania.

The described climatic changes and the future perspectives require actions to be taken to decrease the negative consequences to Scots pines. One of possible active measures taken could be the incorporation of genetic material from foreign provenances to the local population to increase the resistance of local pines to climate change. This is a difficult situation, yet some insights are provided by other studies in the region and our findings.

The results of Matisons et al. [25], Harvey et al. [72], and Taeger et al. [73] clearly demonstrate the importance of considering provenance in the discussion about the future adaptability of tree species under climate change. Matisons et al. [74], while analyzing the results of Scots pine provenances in Latvia, concluded that top-performing provenances from northern Poland have great potential in sustaining the productivity of stands within the region in the future.

Taeger et al. [73] focused on two sites of the Scots pine provenance trial IUFRO 1982 in Germany, including Scots pines from provenances in Sweden, Russia, Latvia, Poland, Germany, and France, focusing on their reaction to drought events. By analyzing the resistance, resilience and recovery after droughts, Taeger et al. [73] highlighted the superior performance of trees from the local German provenances. Trees from provenances in France and Poland were ranked above average, whereas those from northern provenances were found to be less suitable.

Matisons et al. [74] presented results from trials that were established in Latvia to compare the performance of local Scots pine provenances with other provenances originating from Germany and Poland. Apart from the absence of sensitivity to the precipitation amount in July, which was opposite for Latvian provenances, the Polish RYT provenance together with the German GUS provenance showed a lower sensitivity of growth to weather conditions and was more resilient to unfavorable weather extremes.

Klisz et al. [23] classified GU (GUS) and RY (RYT) provenances to one cluster, confirming their similarity of their climate origin. Due to these findings, Matisons et al. [74] recommended applying top-performing provenances in commercial forestry or including them in breeding programs to amplify the positive effects of the transfer.

The synthesis of our results, presented in Figures 7–11, would suggest the higher sensitivity of western populations to increased monthly temperatures in July, precipitation amounts in June and July, and the effect of drought years to tree-ring formation compared to provenances from central and southern locations. These findings could be a result of several factors, mainly prolonged vegetation season in the region and wood anatomy of Scots pines. Waszak et al. [75] reported that the growing season of Scots pine has changed in northern Poland with precipitation now starting as early as February–March and extending to June–July. According to Matisons et al. [74], the top-performing provenances when transferred to the north have a longer vegetation period, which makes them less sensitive to weather conditions and more resilient to unfavorable weather extremes.

The importance of wood anatomy is clearly identified by Matisons et al. [20]. The authors highlight the highest phenotypical plasticity of wood anatomy of top-performing southern provenances, due to formed larger tracheids with thinner walls which have been advantageous under a warming climate but have a lower mechanical durability of wood [20].

Furthermore, it is important to highlight that neither the climate nor the climate growth response of Scots pine has been stable in this region during the last decades [75]. For example, previous studies in Lithuania have shown that the temperature of late winter (February), early spring (March and April) and late summer (August) mostly positively affect pine growth rates [9,76]. However, recently, Augustaitis et al. [30] highlighted the importance of precipitation amounts in June and July, which was not the case in earlier studies.

If negative climate change scenarios come true, many tree species, including Scots pines, would face a significant decrease in suitable habitat area [77]. Lithuanian climatic conditions may fall outside the optimum for growing Scots pine.

Additionally, it is important to highlight that the presented study covers only the first 39 years of Scots pine growth, leaving another 62 years until these tree species reach maturity. The inclusion of an additional 62 years of growth could remarkably change the results. Thus, further studies on the analyzed research question will be necessary. Moreover, we acknowledge the limitations of our findings due to the lack of replication in this study.

At this point, it is important to highlight that our study covered only East European Scots pine provenances, leaving aside provenances in Scandinavia and the western or south-western regions of Europe. In future research, German and Polish provenances should be assessed first due to their good performance in Latvian Scots pine provenance experiments.

Finally, we would like to stress that the findings of this study could provide a theoretical background for establishing recommendations for further silvicultural needs in Lithuania.

5. Conclusions

The remarkable increase in the mean annual temperature of 0.044 °C per year, as well as annual precipitation amount of 3.3 mm per year, during recent decades raises the question of whether pines that currently grow in Lithuania will maintain the same growth and productivity rates in the future, especially if climate change continues at the same speed. Additionally, the question remains whether the incorporation of genetic material from foreign provenances would increase the resistance of local pines to climate change.

Central populations demonstrated the same or better survival and growth results compared with western populations that also included local Lithuanian provenances. Even though southern populations were characterized by the same productivity, their low survival rate suggests a negative introduction effect. Accordingly, the introduction of far eastern or far northern populations would lead to decreased standing volumes compared with local populations.

The analysis of temporal variation in climate sensitivity showed a higher resistance of central and southern Scots pine provenances to negative climatic changes, compared to the western provenances.

For example, provenances from the central, southern and especially western locations demonstrated increasing statistically significant negative effects of monthly temperatures in July. Moreover, provenances from the west were more sensitive to precipitation amounts, water balance and droughts in June and July.

Considering that central and southern provenances demonstrated the consistent effect of growth tolerance, the incorporation of the genetic material from the southern part of European Russia and Ukraine into local breeding programs of Scots pine would amplify the positive effects of the transfer by lowering the sensitivity of local populations to climatic conditions and increasing the resilience to unfavorable weather extremes.

However, knowledge gaps remain regarding the growth performance of Scots pine provenances that originated from central or western European regions. Thus, further research should focus on evaluation of Scots pine origins from Poland and the northeastern part of Germany under Lithuanian growth conditions by including them in Lithuanian provenance experiments.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/f13050743/s1, Figure S1. The effect of latitude and longitude on survival and wood yield of Scots pine provenances, data containing yearly mean diameter widths at provenance level from 1984 to 2013.

Author Contributions: Conceptualization, E.L. and A.A.; methodology E.L. and A.A.; validation E.L., A.K. and A.A.; investigation E.L., A.K., G.Š. and A.A.; formal analysis E.L., A.K. and A.A.; data curation E.L., A.K., G.Š. and A.A.; writing—original draft preparation E.L.; writing—review and editing E.L, A.K., G.Š. and A.A.; visualization E.L.; project administration A.A.; funding acquisition A.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by EUROPEAN SOCIAL FUND AGENCY, grant number VP1-3.1-ŠMM-08-K-01-025.

Data Availability Statement: Data used for this study are presented as supplementary material.

Acknowledgments: The authors would like to express their gratitude to Julius Danusevičius and Darius Danusevičius for their great efforts in establishing and managing the experimental plantation analyzed in this study.

Conflicts of Interest: The authors declare no conflict of interest.

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