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Factors Affecting Radial Increment Dynamics in Lithuanian Populations of Common Juniper (*Juniperus communis* L.)

Rasa Vaitkevičiūtė, Ekaterina Makrickiene and Edgaras Linkevičius *

Agriculture Academy, Faculty of Forest Sciences and Ecology, Vytautas Magnus University, Studentų g.11, Kaunas District, 53361 Akademija, Lithuania; rasa.vaitkeviciute1@vdu.lt (R.V.); ekaterina.makrickiene@vdu.lt (E.M.)

* Correspondence: edgaras.linkevicius@vdu.lt

Abstract: Although common juniper (*Juniperus communis* L.) is a widely spread species and important for the forest biodiversity and economy in many European countries, it remains one of the least studied coniferous species. This research is the first attempt to evaluate the factors affecting the increment of *Juniperus communis* in Lithuanian populations. The aim of this article is to evaluate the patterns of radial increment in *Juniperus communis* and to identify the key factors influencing the increment. We collected stem discs from 160 junipers in 8 stands distributed in the different regions of Lithuania and performed the tree-ring analysis. All studied junipers expressed a pronounced eccentricity of the stem. The results of our study revealed four patterns of *Juniperus communis*' radial increment, which are strongly dependent on the granulometric properties of the soil and hydrologic conditions. The effect of climatic conditions on the *Juniperus communis* increment was strongly dependent on the terrain; however, most of the junipers had a positive reaction to the temperatures in April, July, and August and to the precipitation in February.

Keywords: increment patterns; sexual dimorphism; annual rings; eccentricity

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Citation: Vaitkevičiūtė, R.; Makrickiene, E.; Linkevičius, E. Factors Affecting Radial Increment Dynamics in Lithuanian Populations of Common Juniper (*Juniperus communis* L.). *Appl. Sci.* **2024**, *14*, 3536. https://doi.org/10.3390/app14083536

Academic Editor: John Dodson

Received: 26 February 2024
Revised: 9 April 2024
Accepted: 18 April 2024
Published: 22 April 2024

1. Introduction

Common juniper (*Juniperus communis* L.) is the most widespread species of the Juniper genus [1]. *Juniperus communis* is a typical species of dry and infertile forest soils. In most parts of its wide distribution area, this species is an important element of the ecosystems. Moreover, in many countries, *Juniperus communis* is important due to its industrial application for medical purposes, culinary uses, decorative purposes, and the production of aromatic substances [2–5]. *Juniperus communis* is an important plant for recreational aims [6]. This species produces a big amount of etheric oils [1,7], which are used in traditional medicine [8] and for culinary aims [9]. The wood of *Juniperus communis* is used for small kitchen utensils [10]. However, *Juniperus communis* remains one of the least studied coniferous species, with the episodic studies mostly in southern Europe [11,12], the British Isles [13], and some regions of Russia [14–16]. Lithuanian researchers evaluated the possibility to use *Juniperus communis* as an indicator for biological monitoring [17].

Despite the ecological plasticity of *Juniperus communis* [11,13], in many European countries, researchers observe the decline in its populations [18,19]. Among the threatened populations are those in the Czech Republic [20], some regions of England and Ireland [21,22], the Netherlands, and Belgium [23]. The decline and recovery of *Juniperus communis* are influenced by the wide range of biotic, abiotic, and anthropogenic factors, such as land use changes, climate change, and increased pressure by forest management [13,18,19,22–25]). In Lithuanian populations, only 15 to 34% of *Juniperus communis* individuals can be evaluated as healthy [25–27]. Moreover, due to the changing light and temperature regimes, natural long-term juniper communities became rarer in the forest stands [15]. Only the detailed region-based studies on the main environmental factors having an influence on *Juniperus communis*' stability and condition can help to save the juniper communities.

Juniperus communis: This research is the first attempt to evaluate the factors affecting the increment of *Juniperus communis* in Lithuanian populations. The aim of this article is to evaluate the patterns of radial increment in *Juniperus communis* and to identify the key factors influencing the increment. Our hypotheses are that (a) the climatic variables, especially the mean monthly temperatures and monthly precipitations, have a direct impact on *Juniperus communis* populations; and (b) the mean annual radial increment of the female junipers is smaller than that of the male ones.

2. Materials and Methods

2.1. Sample Stands

Our research was performed in eight stands, distributed in the north-west, north-east, and south-east parts of Lithuania, where junipers are naturally widely spread (Figure 1).

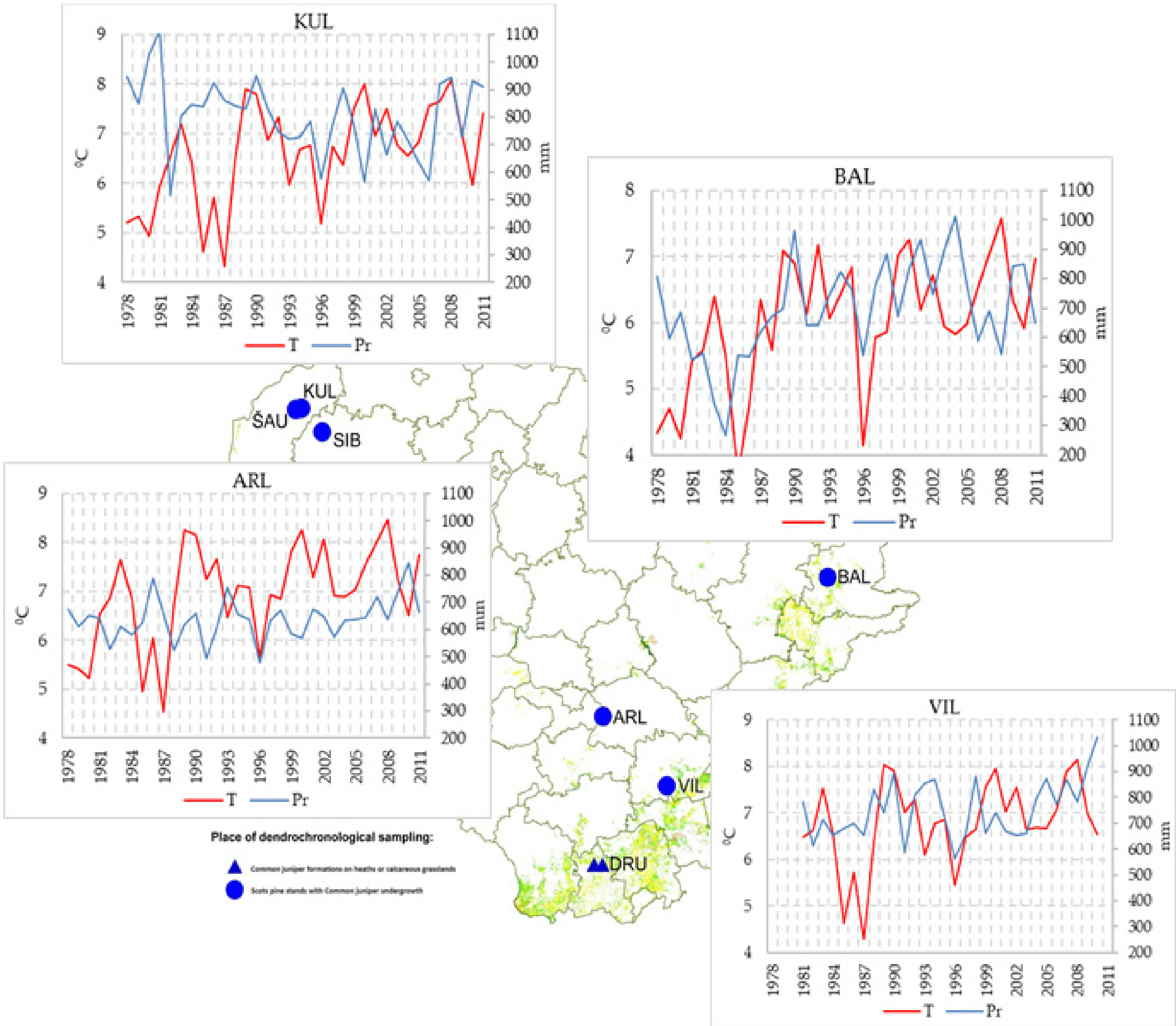

Figure 1. Distribution of the study sites, mean annual temperature (T), and annual precipitation (Pr) for 1976–2011 period in Arlaviškės (ARL), Baluošas (BAL), Kulaliai (KUL), Vilkokšnis (VIL) research objects. Meteorological data were received from Lithuanian hydrometeorology service. Places of dendrochronological sampling: *Juniperus communis* formations on heaths or calcareous grasslands (blue triangles), Scots pine stands with *Juniperus communis*' undergrowth (blue circles).

Additionally, Figure 1 visualizes the intensity of changes in the mean annual temperature (T) and annual precipitation (Pr) in the period from 1976 to 2011 in the analyzed regions of Lithuania. The lowest Ts, ranging from 4.3 to 8.2 °C, were recorded in the south-eastern region of Lithuania where the Vilkokšnis (VIL) research object is located. Conversely, the highest mean annual temperatures were estimated in the north-western region at the location of the Kulaliai (KUL) research object, fluctuating from 5 to 8.7 °C during the same period. The highest amounts of precipitation were recorded in the north-western region as well, ranging from 515 to 1116 mm in the period from 1976 to 2011. Conversely, the least amounts of annual precipitation were recorded in the central part of Lithuania at the location of the Arlaviškės (ARL) research object, fluctuating from 479 to 847 mm during the analyzed period. These differences result from the increasing effect of the continental climate from the western part, which is affected by the Baltic Sea, towards the north-eastern part of the country.

The stands belong to the two types of natural communities: two Scots pine (*Pinus Sylvestris* L.) stands with extensive *Juniperus communis* undergrowth and six *Juniperus communis* formations on heaths or calcareous grasslands (Natura 2000 habitat type 5130). Chosen stands cover a wide range of soil conditions (Table 1). All the studied communities formed naturally and are unmanaged, with the only exception in Arlaviškes, where the *Juniperus communis* formation emerged due to grazing and is regularly mown by the personnel of the regional park to keep this formation in its non-typical habitat.

Table 1. Study sites, their coordinates, and soil properties.

Region	Latitude	Longitude	Altitude	Stand Type	Area, ha	Soil Conditions	Number of Sampled Individuals	Abbreviation
Siberija	56°2′0.63″ N	21°49′11.11″ E	145	Pure	1.2	Pachiterri-Fibric Histosol	10	SIB
Kulaliai	56°7′44.95″ N	21°38′14.63″ E	63	Pure	6.6	Orthieutric Gleysol	20	KUL
Šaukliai	56°7′34.95″ N	21°35′27.44″ E	51	Pure	79	Orthieutric Gleysol	40	ŠAU
Baluošas	55°23′59.27″ N	26°3′17.39″ E	144	Pure	4.4	Areni-Mollic Gleysol	20	BAL
Arlaviškes	54°48′49.87″ N	24°10′46.68″ E	83	Pure	2.6	Bathihypogleyi-Epicalcaric Cambisols	10	ARL
Vilkokšnis	54°29′59.56″ N	24°42′29.33″ E	140	Pure	3.5	Epicalcaric Cambisol, (top of the slope) Skeleti-Rendzic Leptosol (bottom of the slope)	20	VIL
Druskininkai	54°9′34.07″ N	24°17′0.37″ E	123	Scots pine undergrowth	3.1	Bathihypogleyi-Eutri-Haplic Arenosols	20	DRU
Druskininkai	54°9′52.53″ N	24°18′2.85″ E	117	Scots pine undergrowth	3.7	Bathihypogleyi-Eutri-Haplic Arenosols	20	DRU

The granulometric properties of the soils were evaluated during the field work. The soil profiles were dug in every sample plot. In case of the even sample plot conditions, we dug one soil profile per plot. In case of uneven conditions (e.g., slope), we dug 3 soil profiles per sample plot to represent all soil conditions. To classify the soils, we used the Buivydaitė et al. [28] classification system based on the FAO-UNESCO Soil Classification System [29,30].

2.2. Tree-Ring Sampling and Measurements

For our research, we chose 20 typical junipers from every stand. We chose the healthy, undamaged junipers of I–II Kraft [31] classes with the average diameter and height for the given stand. The choice of the sample junipers was determined by the scope of growth conditions, exposition of the slope, and representation of Lithuanian natural climatic regions. The chosen junipers widely represented the whole scope of the above-listed conditions.

In the initial phase of our research, we took the annual ring samples with the increment borer at breast height (1.3 m). The primary analysis showed that due to the often missing (sometimes more than 10 per sample) or double annual rings, it was impossible to synchronize the increment data; thus, these samples could not be used for future analysis. That made us choose another way of research: the sample junipers were cut, and the stem discs were taken from their root collar and at the heights of 0.5 and 1.3 m. This method let us synchronize the annual rings and determine if the annual rings were forming in the bottom part of the stem despite unfavorable conditions [32]. The cutting of junipers for the scientific aims was officially allowed by the local forest management and environmental authorities. In total, we sampled 480 stem discs from 160 junipers; however, the discs (63) from 21 junipers were later excluded from the further analysis due to the non-synchronic rings.

The stem discs were dried for a month at room temperature, and then polished with a belt sander. After such preparation, the stem discs were measured using the MBS–9 microscope, with an accuracy of 0.05 mm. Due to the eccentricity of the juniper stem discs, the annual rings were measured in all 4 cardinal directions (N, E, S, W). For the further analysis, we used the average increment for every stem slice.

As the comparison of the mean annual increment can only be conducted using synchronous tree rings, the data from all the stem discs of every sampled juniper were synchronized between themselves using the following formula, applied in the MS Excel software (Office 365):

$$P_r = \frac{n^+}{n-1} \tag{1}$$

where P_r is the similarity rate, n^+ is the number of concurrent rings, and n is the total number of compared tree rings.

Regarding the recommendations for other coniferous species, tree-ring dynamics with similarity rates lower than 0.5 were considered non-synchronic, those between 0.51 and 0.6—weakly synchronic, between 0.61 and 0.7—moderately synchronic, between 0.71 and 0.8—highly synchronic, and those higher than 0.8—very synchronic [33]. Junipers with the non-synchronic chronologies were excluded from the further analysis.

The rings of the remaining samples were cross-dated using the software Tsap-Win professional 4.89, which determines the cross-dating index (cdi). For our research, the threshold cdi value was >20 at α = 0.001 [34]. During the procedure, the missing or double rings were determined.

For every juniper, we determined the pattern of radial increment using the method of the 5-year moving average with the 1-year step, based on the relatively small age of the junipers, previously made similarity analysis, and the methods used for other coniferous species [35].

For the evaluation of the climate effect on the radial increment of junipers, we used the long-term data on temperatures and precipitation from the meteorological stations situated close to the research objects (Table 2). Regarding the measured junipers' age, we used the data for the period from 1893 to 2011.

We used the data for the hydrologic year (from September to August) because this is the period affecting the formation of the annual rings [36]. The data consisted of monthly temperature and precipitation averages. For this analysis, we used the increment data, standardized using the TSAP-Win software. The detrending procedure was applied to the chronology of all samples. After that, the indexation procedure was applied.

Table 2. Meteorological stations and their distances to the study sites.

Research Object	Meteorological Station	Distance to the Study Sites, km
Siberija	Telšiai	27.4
Kulaliai	Skuodas	16.4
Šaukliai	Skuodas	15.4
Baluošas	Vaišnoriškė	3.4
Arlaviškės	Kaunas	18
Vilkokšnis	Varėna	31.9

3. Results

3.1. Eccentricity of the Juniper Stems

The age of the measured individuals varied from 12 to 82 years in a pure juniper stand and from 31 to 118 years in the forest. There was a big variation in the radial increment between the individuals, depending on soil properties. The current annual increment in different years varied from 0.01 mm on poor soils to 4.39 mm on fertile soils.

We noticed a variation in the mean annual increment of *Juniperus communis* depending on the cardinal direction. In most cases, the biggest mean annual increment could be noticed in the northern and eastern directions, with the only exception in the Vilkokšniai pure juniper stand, where the biggest mean annual increment was in the southern direction. An unevenly spread by cardinal directions mean annual increment resulted in the eccentricity of juniper stems (Figure 2).

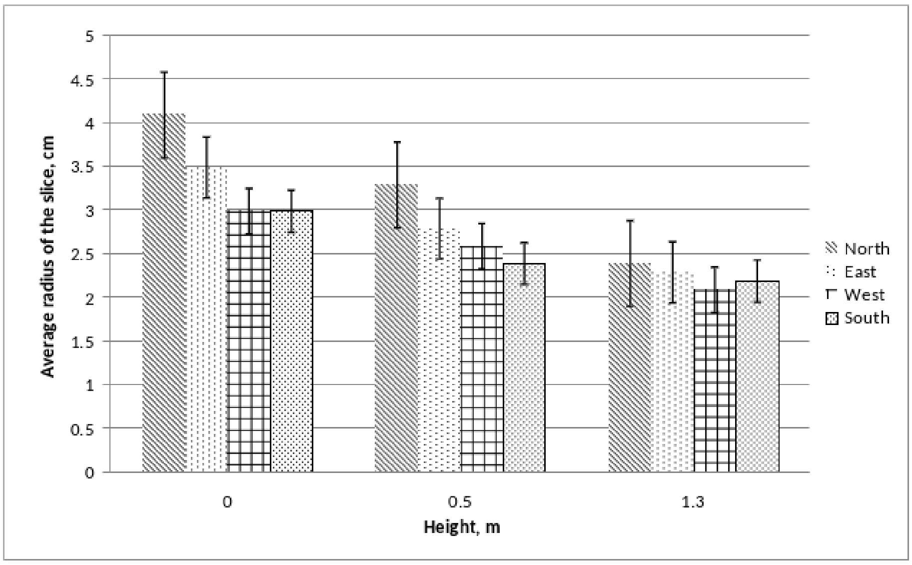

Figure 2. Average radius of juniper stem slices taken from the different height of the stem, distributed by the cardinal directions.

The biggest eccentricity could be noticed at the root collar, where a bigger increment to the north and east could be clearly seen. At the higher points of the stem, this difference is not so strong, and at the height of 1.3 m, it is almost unnoticeable.

3.2. Patterns of Radial Increment

The similarity analysis revealed four patterns of radial increment, which were strongly dependent on the granulometric properties of the soil and hydrologic conditions. The first increment pattern can be characterized by the two expressed repetitions of a certain shape, consisting of an increment rise from minimal in the beginning of growth until maximal growth, and then again a growth decline (Figure 3). This radial increment pattern was typical for the individuals growing on the loamy soils. Such growth could be noticed for 36.5% of all studied individuals.

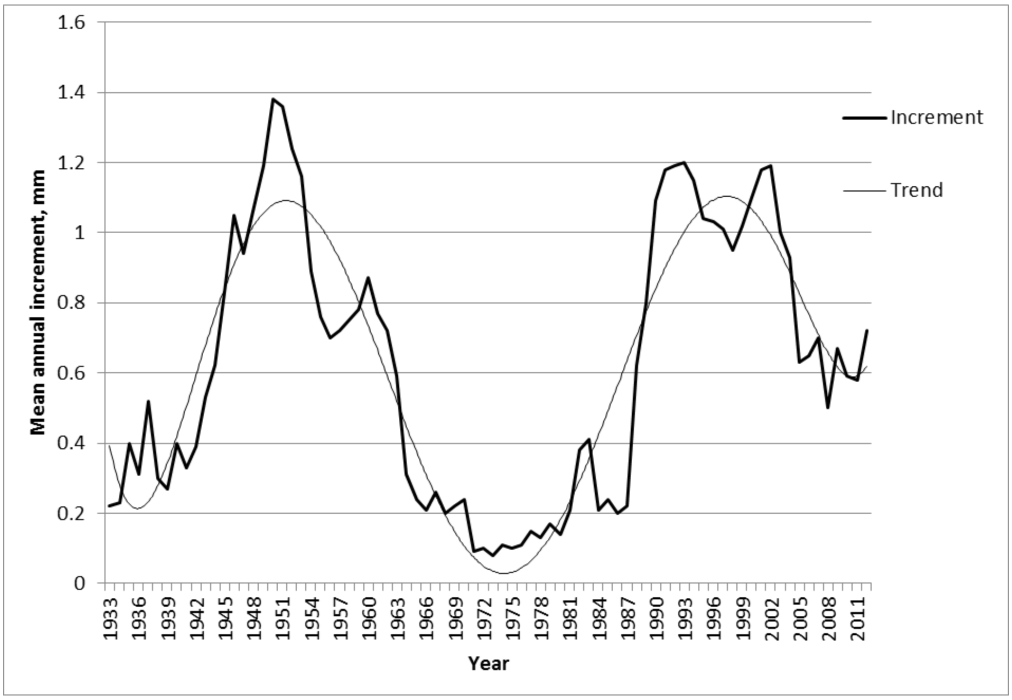

Figure 3. The long-term dynamics of first increment pattern in *Juniperus communis* (n = 57). Thicker line shows the average increment for the individuals of this increment pattern, thinner line shows the trend.

The second increment pattern could be characterized by the even shifts with slight increment increases or declines in certain periods and expressed a decrease in increment in older age (Figure 4). This increment pattern was the most represented from all and could be noticed for 50.5% of all studied individuals. Such growth was typical for the individuals growing on gleysols, where the water in autumn and spring was not deeper than 0.9 m.

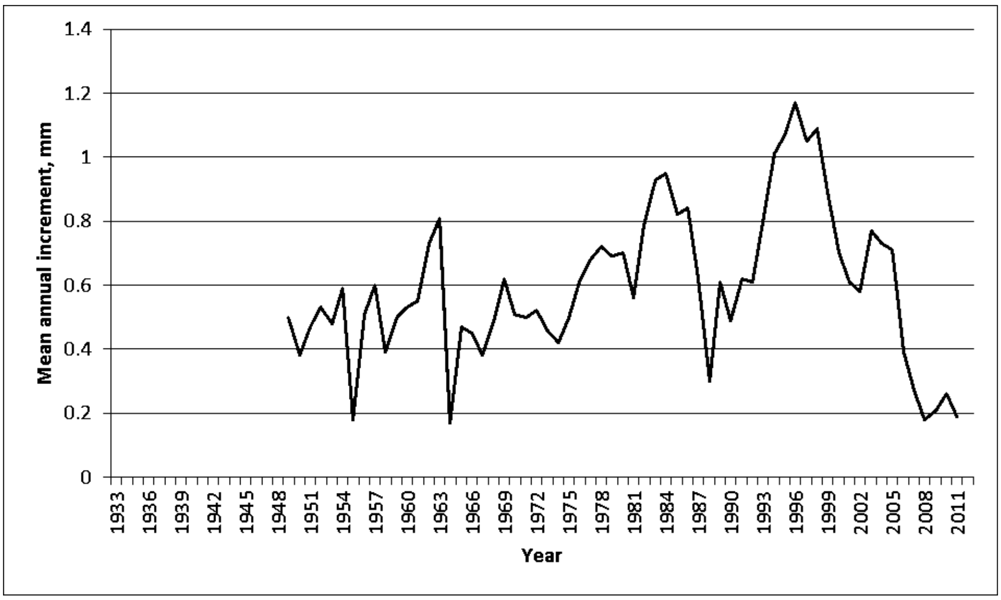

Figure 4. The long-term dynamics of second increment pattern in *Juniperus communis* (n = 79). The black line shows the average increment for the individuals of this increment pattern.

The third increment pattern, when the increment was decreasing in the middle of growth (Figure 5), and the fourth increment pattern, when there was a certain period of intensive growth with the low increments in the beginning and end of growth (Figure 6), were represented by 6.5% of all studied individuals each. Such increment patterns could be mostly noticed on the gleysols and podzolic soils. Moreover, the average radial increments of individuals with the third and fourth increment patterns were usually two times smaller than the individuals with the first and second increment patterns.

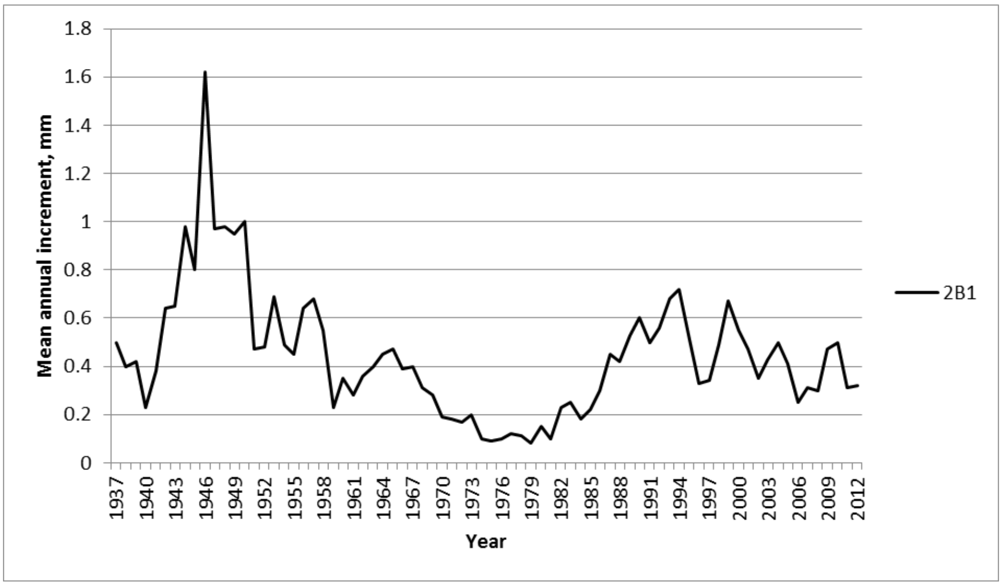

Figure 5. The long-term dynamics of third increment pattern in *Juniperus communis* (n = 10). The black line shows the average increment for the individuals of this increment pattern.

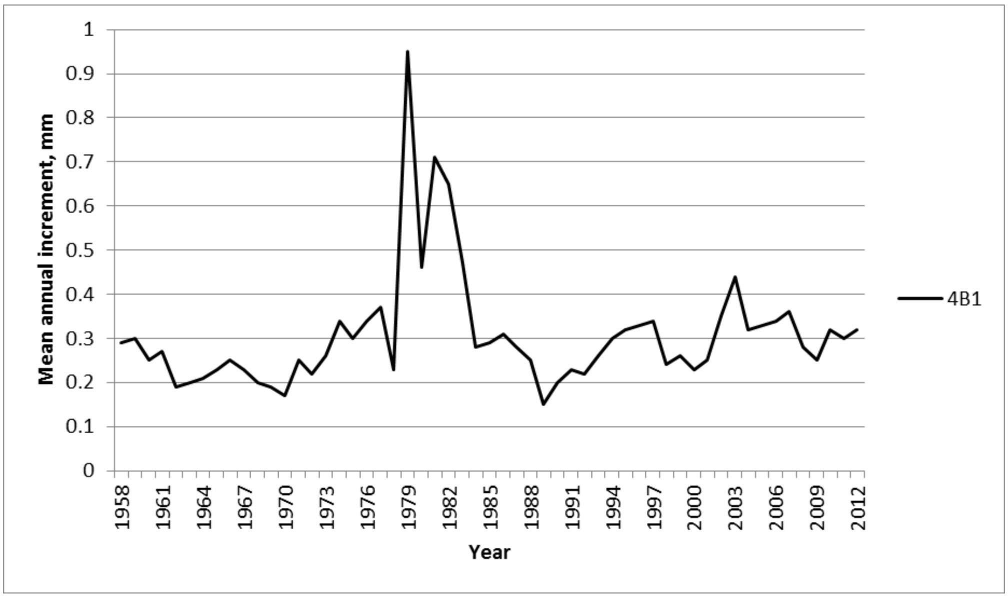

Figure 6. The long-term dynamics of fourth increment pattern in individuals (n = 10). The black line shows the average increment for the individuals of this increment pattern.

The highest synchronicity could be observed for the radial increment dynamics of populations from Šaukliai (Pr = 0.74), Siberija (Pr = 0.84), Dubakalnis (Pr = 0.77), and Arlaviškies (Pr = 0.64). Another part of the studied populations expressed low or close to medium synchronicity (populations from Bradesiai, Pamerkys, Margupis, and Kulaliai).

The populations from Baluošas expressed a big variability in synchronicity, even within the same stand, from 0.34 to 0.78.

In addition to the granulometric composition of the soil and the level of ground water, the dynamics of the radial increment of *Juniperus communis* were affected by the conditions in the beginning of growth. Those junipers, which started their growth in unfavorable conditions, for their whole life had smaller increments compared to the other junipers in the same location.

3.3. Sensitivity to the Climatic Factors

The effect of climatic conditions on the juniper increment was also strongly dependent on the growth conditions, such as the soil composition and ground water level. Climatic conditions had the most uniform effect on the increments in the juniper stands of Kulaliai, Siberija, and Šaukliai. The individuals in these stands showed the biggest reactions to the temperatures in the beginning and end of the vegetation period. At the same time, in the juniper stand of Baluošas, growing on the sandy gleysols, the biggest influence on increment was caused by the precipitation in winter and spring. In the juniper stands, growing on the slope, the effect of climatic conditions was different even in the different parts of the slope, which could be explained by the different hydrologic conditions within the different parts of the terrain (Table 3).

Table 3. Correlations between the radial increment and climatic factors in different juniper stands (temp—temperature; prec—precipitation, SIB—Siberija, KUL—Kulaliai, ŠAU—Šaukliai, BAL—Baluošas, ARL—Arlaviškes, VIL—Vilkokšniai, tp—top part of the slope, bt—bottom part of the slope). Highlighted in bold indicate significant relations at the significance level of 0.05.

Juniper Stand	Factor	Months												
		IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	M.
SIB	temp	0.17				0.21	**0.31**		**0.37**			**0.33**	**0.49**	**0.39**
	prec	**−0.38**				0.19	**0.47**		−0.11			−0.06	−0.28	−0.32
KUL	temp	**0.34**				0.16	0.08		**0.59**			**0.39**	**0.48**	**0.48**
	prec	−0.22				0.25	0.29		−0.33			0.08	−0.10	−0.11
ŠAU	temp	−0.01				0.19	**0.40**		**0.47**			**0.31**	**0.47**	**0.38**
	prec	−0.20				0.15	**0.62**		−0.17			−0.07	−0.14	−0.15
BAL	temp	−0.19	0.01	−0.20	**−0.26**	0.08	0.01	−0.02	−0.14					
	prec	0.12	0.15	0.24	**0.26**	**0.27**	**0.30**	**0.35**	**0.29**					
ARL tp	temp	**−0.31**	**0.43**	**−0.37**			0.03	−0.10	0.21	0.20	**−0.36**	**−0.36**	−0.14	
	prec	−0.11	−0.14	−0.10			0.03	0.05	−0.18	0.08	**0.39**	0.06	−0.04	
ARL bt	temp	−0.09	0.07	0.15			−0.08	−0.12	0.03	−0.08	−0.22	−0.18	−0.19	
	prec	−0.03	−0.07	0.12			0.07	−0.08	−0.00	0.09	0.19	0.20	0.01	
VIL tp	temp	0.03	0.06	0.20			0.03	0.23	**0.29**	0.16	0.06	0.25	**0.29**	
	prec	**−0.53**	**0.32**	0.22			**0.37**	0.01	−0.06	0.20	−0.03	0.15	0.25	
VIL bt	temp	−0.14	−0.02	0.21			0.22	**0.38**	0.24	**0.39**	0.07	0.19	**0.54**	
	prec	**−0.59**	**0.39**	0.10			0.26	**−0.31**	**−0.52**	0.06	−0.23	−0.01	0.21	

Summarizing the effect of the climatic factors on the radial increment of *Juniperus communis*, we could notice that most of the individuals, regardless of the natural forest region of Lithuania, growth conditions, ground water level, or position on the slope, had a positive reaction to the temperatures in April, July, and August and to the precipitation in February.

The missing rings were present in individuals with all increment patterns and in all types of growth conditions. Our observations showed that the biggest number of missing rings (totally in 10 trees from different stands) could be noticed in 1993. That year combined two extremums: a low amount of precipitation in February and excess precipitation in July. Another factor causing missing rings was the low amount of precipitation in May and June. Our research did not reveal any correlation between the missing rings and temperature.

3.4. Increment Variability of Male and Female *Juniperus communis* Plants

The analysis of the increment of female and male juniper plants did not show any statistically significant differences between the radial increments of plants of different sex when the increment measurements were completed at 1.3 m. However, there were statistically significant differences between the radial increments of plants of different sex at 0 m as well as 0.5 m (Figure 7).

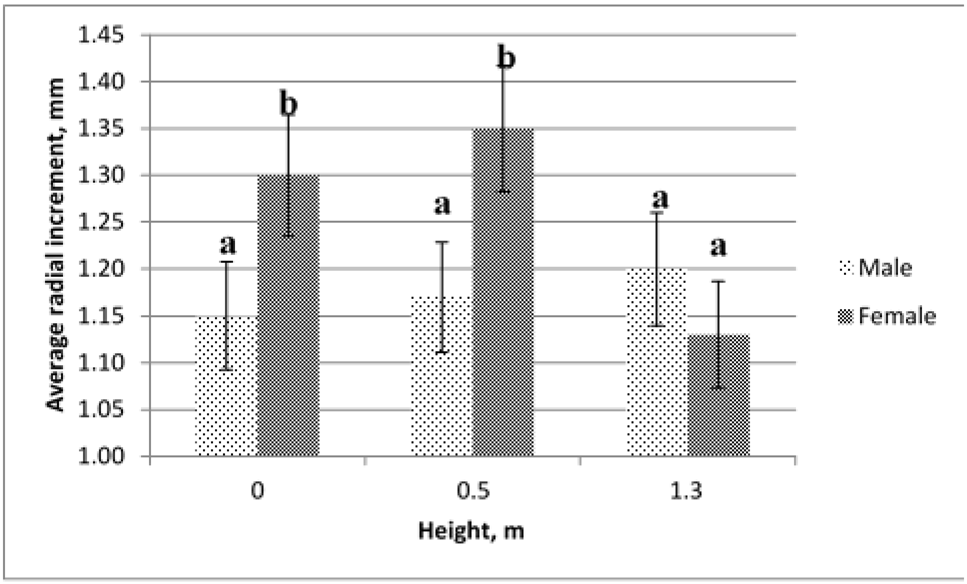

Figure 7. Average radial increment of female and male individuals on the different heights of the stem. Letters a and b indicate statistically significant differences at the level of 0.05 between male and female measurements completed at 0, 0.5, and 1.3 m.

Moreover, the overlapping data about the maximal and minimal increments of female and male individuals also show the bigger influence of other environmental factors on juniper increment (Table 4).

Table 4. Maximal and minimal mean annual increments of female and male *Juniperus communis* individuals in pure stands and in the undergrowth of the *Pinus sylvestris* stand.

Stand Type	Sex	Mean Annual Increment, mm	
		Maximal	Minimal
Pure stand (top of the slope)	F	1.66	1.26
	M	1.59	1.02
Pure stand (bottom of the slope)	F	1.89	1.50
	M	3.12	1.22
Undergrowth of the Scots pine stand	F	0.35	0.28
	M	0.67	0.17

4. Discussion and Conclusions

The results of our study neglected our hypothesis of the smaller radial increment of female individuals compared to the male ones in Lithuanian populations. Although other studies [37] showed that female juniper plants had a smaller radial increment than male ones, our study revealed that there were statistically significant differences between the radial increments of plants of different sex at 0 m as well as 0.5 m (Figure 7). In some juniper stands, we could notice the tendency, which is opposite to that stated by the above-mentioned authors: the average increment of the female plants was slightly higher than that of the male ones, although the biggest individuals were usually male. Still, the sex of *Juniperus communis* plants was not the main factor affecting their radial increment. The different radial increment and differences between the increments on the different heights of the stem show that the increment differences were more dependent on other environmental factors.

The hypothesis that the growth conditions of *Juniperus communis* populations have an effect on their sensitivity to the environmental factors was approved. The climatic conditions (temperature and precipitation) affected the individuals indirectly through the lithological composition and humidity of the soil, which resulted in favorable or unfavorable growth conditions. Thus, the growth of the individuals growing in analogical conditions was similar, irrespective of the geographical region of Lithuania. A similar finding was described in the study of junipers in Polar, Alpine, and Mediterranean regions, where they expressed the growth variability in all three biomes, depending on their growth form: shrub or tree [12]. Moreover, the same authors state a bigger precipitation role for the increment of junipers than temperature, which also corresponds to our conclusions. However, excess precipitation was also a limiting factor for the junipers growing on the Tibetan plateau [38]. Junipers' sensitivity to soil humidity and droughts was described in another study from the Mediterranean region [39], which describes the dieback after the period of hot and dry weather, which affected the growth conditions. Moreover, the study on junipers growing in the Arctics [40] also revealed the correlation between their sensitivity to precipitation, especially in summer. Similar to our study, junipers in the Arctics also reacted positively to the summer temperatures, which could be a sign that moderate conditions are the best for junipers' maximal radial increment.

The eccentricity of the juniper stems can be explained by the fact that they were often bended to the northern, north-west, and western sides. Usually, coniferous plants form wider annual rings on that side, where they are bended most often, which helps them to keep vertical [41,42]. Bigger annual rings can form in inclined trees as well. Inclined and horizontal *Juniperus sibirica* stems had wider annual rings on the side of inclination [43] The inclination and bending of the trees can be caused by multiple factors; for example, in the slope conditions, they can be caused by repeating soil sliding and snow loads [41,42]. In Lithuanian conditions, the main factor causing the bending of the stems is wind, especially regarding the dominating west, south-west, and south winds. The winds of these three directions blow in Lithuania in 54% of cases [44].

As long as *Juniperus communis* individuals are mostly bended into the side, which is opposite to the dominating winds, wider annual rings form on that side. The same effect of a significant increment to one side could be observed for the Scots pine individuals growing on the shore of the Baltic Sea. Moreover, the trees, which do not experience frequent bending, have a more symmetric radial increment than often bended trees [45].

The dynamics of radial increment strongly varied even within the individuals growing in the same stand. The dynamics varied also for the individuals growing in the slope conditions on the top and bottom of the same slope. The variability of the height increment and eccentricity of the stem resulted in the non-uniform synchronicity of radial increment in *Juniperus communis*. Similarly, in Ural Mountains, the stem discs even from the same individuals pronounced strong variability in growth patterns [16]. Thus, due to the very individual growth of every juniper plant, using tree-ring cores is impossible for this species, and the use of multiple stem discs from every individual is recommended, as was stated by previously mentioned authors [16].

The absence of multiple tree rings is typical for the coniferous trees growing in strongly unfavorable conditions [46]. The results of our study and bad conditions of Lithuanian *Juniperus communis* populations [25–27] let the authors state that the *Juniperus communis* populations in Lithuania were experiencing strong stresses during the 20th century. Still, the models of Lithuanian climate change assume that in the 21th century, there will be bigger amount of precipitation and higher temperatures, especially in winters [47,48]. Such changes in climatic conditions could be favorable for the populations of *Juniperus communis*; however, further observations are necessary.

It is important to highlight the limitations of this study. Only stem sections were measured, where the rings are clearly visible for an accurate determination of *Juniperus communis* annual ring increments. Therefore, it was necessary to cut the trees and develop a precise method for measurement. Additionally, during the measurements, we were not able to distinguish early and late wood in all rings; thus, it was not measured. Also, measurements were complicated by the high number of fallen rings in the root collar part. Only 17% of the root collar discs had no fallen rings. The number of fallen rings in this part was distributed as follows: 60% with 1 to 5 fallen rings, 10% with 6 to 15 fallen rings, and 8% with 16 to 20 fallen rings. The quantity of double rings was also the highest at the root collar part and they were present in 70% of stem discs. At a height of 0.5 m, double rings were available in 35% of stem discs, while at a height of 1.3 m, they were present in 13% of stem discs.

The cultivation of the juniper *Juniperus communis* in the region could enhance the following forestry strategies: the optimization of the growing conditions, selection of the suitable plant genetics, development of biological monitoring programs, adaptation to climate change, development of monitoring programs, improvement of sustainable forestry practices, and update on forest management plans.

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

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Acknowledgments: The authors would like to express their gratitude to the reviewers for their great efforts in reviewing this paper.

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

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