International Journal of Design & Nature and Ecodynamics
Vol. 18, No. 4, August, 2023, pp. 975-982
Journal homepage: http://iieta.org/journals/ijdne

Influence of Climatic Changes on the Dendrochronological Features of Tugai Forests along the Syr Darya and Ili Rivers in the Territory of Kazakhstan

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https://doi.org/10.18280/ijdne.180425

Received: 28 February 2023
Revised: 7 August 2023
Accepted: 15 August 2023
Available online: 31 August 2023

Keywords:
climate, dendrochronological features, Ili, river, Syr Darya, Tugai forest

ABSTRACT

Tugai forests, unique island plant communities, are intricately linked to the activities of specific river systems. Anthropogenic degradation of Central Asian Tugai forests is primarily attributed to the regulation of river flow. This study seeks to illuminate the impacts of climatic changes on the dendrochronological characteristics of certain Tugai flora. A critical assessment of the tree-ring chronology of Populus diversifolia, found in the floodplains of the Syr Darya and Ili Rivers, reveals a sensitivity to extant regional climate changes. This is manifested as an increasing trend in the annual ring width over calendar time, mirroring rising trends in air temperature and precipitation observed over recent decades. Consequently, Populus diversifolia may serve as a viable indicator of long-term climatic changes.

1. INTRODUCTION

Tugai forests, unique insular plant communities, owe their genesis and existence to the activities of specific river systems [1, 2]. The establishment of vegetation within the contemporary Tugai landscapes is largely contingent upon the overall structure of the riverine coastal surfaces and the geological formations underlying these lands [3].

The diminution of Tugai areas precipitates the loss of numerous valuable, rare, and relict species of flora and fauna. This loss also undermines the water protection, water regulation, coastal protection, and reclamation functions of Tugai forests, leading to a degradation of human habitats and a downturn in certain forms of economic activity [1-3]. In light of these conditions, the importance of comprehensive phytomeliorative research, pivotal in thwarting degradation processes in arid regions, is underscored.

Employing tree-ring analysis correctly enables the exploration of the natural variability of environmental and climatic factors in the past and the projection of future global changes in the natural environment [4, 5].

The current study is committed to discerning the impacts of climatic shifts on the dendrochronological attributes of select Tugai flora. The study is structured into six sections: introduction, literature review, materials and methods, results, discussion, and conclusion.

The analysis of the chronology of the tree rings of Populus diversifolia growing in the floodplains of the Syr Darya and Ili Rivers showed that the trees are sensitive to the current regional climate change. This is expressed in an increasing trend of changing the width of the annual rings from time to time (in calendar dates), which well reflects the increasing trends in air temperature and precipitation over the past few decades. In this regard, Populus diversifolia can be effectively used as an indicator of long-term climatic changes.

2. LITERATURE REVIEW

Floodplain forests or Tugai occupy a special place among other forests and have a rich diversity, are unique objects of wildlife [6]. For this reason, Tugai forests are included in the World Wide Fund for Nature's List of 200 Ecosystems [7]. Modern Tugai of Kazakhstan consist of woody, shrubby and grass communities growing in the floodplains of southern rivers: Syr Darya, Chu, Ili, etc. Their total area is about 400 thousand hectares, of which about 150 thousand hectares are covered with forest. Tugai forests have great soil protection, water protection, and shore-strengthening significance. In some cases, they also perform a protective role, perform biodrenage in swampy floodplain areas [8].

The main cause of anthropogenic degradation of the Tugai of Central Asia is the regulation of river flow, which leads to a change in the regime of flood flooding (usually leading to a decrease in floodplain flooding), a change in the nature and intensity of soil formation and the loss of the possibility of natural renewal of Tugai tree-shrub and grass communities [9, 10].

Climate change, along with anthropogenic regulation of runoff, is also the main reason for the widespread degradation of relict Tugai ecosystems in Central Asia, since the main trends of climate change (temperature rise and precipitation reduction in the warm half-year, summer and autumn, as well as the lengthening of the warm period) contribute to an increase in the desiccation of floodplain and delta territories during the growing season [11].

3. MATERIALS AND METHODS

3.1 Collection, transportation and storage of wood samples

All dendrochronological studies were carried out according to the methodology of Shiyatov et al. [12]. Drilling cores were used for dendrochronological analysis. With their help, radial cores of wood with a diameter of 4-5mm and a length of 10-50cm were drilled [4]. The cores were taken along one or more radii strictly oriented in relation to the cardinal directions or in a random direction. If the length of the drill allows, then the tree was drilled through and a sample was taken at one time along two opposite radii. In tilted trees, samples should be taken from the sides of the trunk perpendicular to the plane of its inclination. It is desirable that the drill passes through or near the core ring. When drilling old trees, taking a whole sample was sometimes hindered by the presence of trunk sections containing rotten wood. Therefore, the same tree was often drilled several times from different sides and at different heights in order to obtain a sample of satisfactory quality. Drilling was performed in a direction perpendicular to the longitudinal axis of the tree trunk. A slight deviation in the direction of drilling from the perpendicular is allowed if only the dimensional characteristics of the increase (the width of the annual rings, the width of the zones of early and late wood, etc.) are measured. Drilling cores were used at a height of 1.0-1.3m from the ground surface. In small trees and shrubs, especially those that grow in extreme environmental conditions and have narrow rings, samples were taken here at a height of 0.2-0.3m or lower. In this case, the duration of individual tree chronologies increases significantly (up to 50-100 years). Usually, to construct one generalized chronology, wood samples were taken from 15-30 trees of the same species, and from each tree-by two radii. In extreme habitat conditions, where there is high variability and synchronicity in the variability of growth from year to year, they were limited to taking samples from 10-15 trees. Each sample of wood was encoded, while the code was written on the surface of the sample or container. In dendrochronology, the encoding consisting of six characters is most widely used. The first three characters are a combination of letters of the Latin alphabet, which denote the habitat code (for example, SOB-the Sob River). The next two numeric characters (from 01 to 99) denote the model tree number, and the last numeric character (from 1 to 9) denotes the radius number. The most important information about the sample was written on the wood sample or container (site and core code, type of tree, height and date of collection, surname of the collector). The collected wood samples were transported in containers and solid containers to prevent their breakage. In the field, the samples were dried to an air-dry state so that the surface of the cores and cuts would not be covered with mold. The samples used to construct one chronology were stored together in cardboard boxes or wooden boxes.

3.2 Preparation of wood samples

The wood samples collected in the field were analyzed in the laboratory. In order for the boundaries of the rings and cells to be clearly visible during measurements in reflected light, the end surface of the wood sample was carefully cleaned. To obtain a better contrast between the boundaries of cells and narrow rings, as well as when processing severely cracked and rotten samples, the surface along the selected radial direction was cleaned with a sharp cutting tool (razor, scalpel, knife, chisel).

3.3 Measurement of characteristics of annual layers of wood in dendrochronological analysis

To measure the quantitative characteristics of annual trees, specially designed semi-automatic complexes were used, which consisted of a binocular microscope, a moving table, a device that converts an electronic signal into a digital one, a signal interrupter and a computer with special software. Processing of all samples was carried out by the Lintab 3 measuring complex using a specialized program TSAP 3.5.

4. RESULTS

4.1 Absolute tree-ring chronologies on the Ili River

The samples are marked “ILI”. The cambial age of the studied trees at a trunk height of 0.5-1m at the time of sampling is not the same and varies from 22 to 65 years. It was revealed that in most of the trees used for the study, the synchronicity of the change in the width of the annual rings (the synchronicity of absolute tree-ring chronologies) is quite high: paired correlation coefficients between the chronologies R=0.56-0.88 at $P \geq 0.95$. Thus, the 10 trees selected for dendrochronological study synchronously respond to changes in external factors and reflect the course of growth of the entire tree population in this place (Figure 1). The reference years 1983, 1987 and 2007 are distinguished with favorable growth conditions, when most trees formed relatively wide annual rings. The width of annual tree rings for the entire period from 1957 to 2022 varies from 2.66 to 4.66mm, the average for trees is 4.07mm. The largest average value of the annual ring width is characterized by the ILI-15 tree, and the smallest is ILI-12, nevertheless, the latter in 1987 formed the widest ring of all measured on experimental samples-9.44mm.

The intensity of decreasing ring width in older trees during the first 20 years is similar to that of a group of younger trees during the first 20 years (Figure 1). The beginning of the 1980s is characterized by a sharp increase in the width of the annual rings (Figure 1). The average width of annual rings in these groups of trees differs markedly: in the first (1957-2022), this indicator was 3.25mm, and in the second (1980-2022)-4.08mm, which is 1.3 times more. Thus, Figure 1 highlights the beginning of the 1980s with a sharp increase in the width of the annual rings. It should be noted that the second time period, according to the available data of the Bakanas weather station (Figure 2), is characterized by greater aridity of the spring months, especially April, which corresponds to the time of the beginning of growth and intensive formation of the annual ring. The air temperature in spring is also slightly higher, although the difference is not as pronounced as in precipitation (Figure 2). In this climatic situation, assuming that precipitation is a limiting factor, one could expect a noticeable decrease in the average width of the ring in recent decades compared to the previous period, but the opposite trend has been revealed. It is obvious that another factor can have a significant impact on this indicator, most likely a change in the hydrodynamic regime of the soil towards a greater abundance of water in the floodplain of the Ili River due to the more intense melting process in the mountains. This hypothesis could be verified by monitoring the hydrodynamic regime in the place of growth of experimental trees. A detailed analysis of the dynamics of radial growth of trees under the influence of weather conditions of growth seasons will be carried out below, after removing the age trend from the absolute tree-ring chronologies of radial growth and obtaining indexed chronologies.

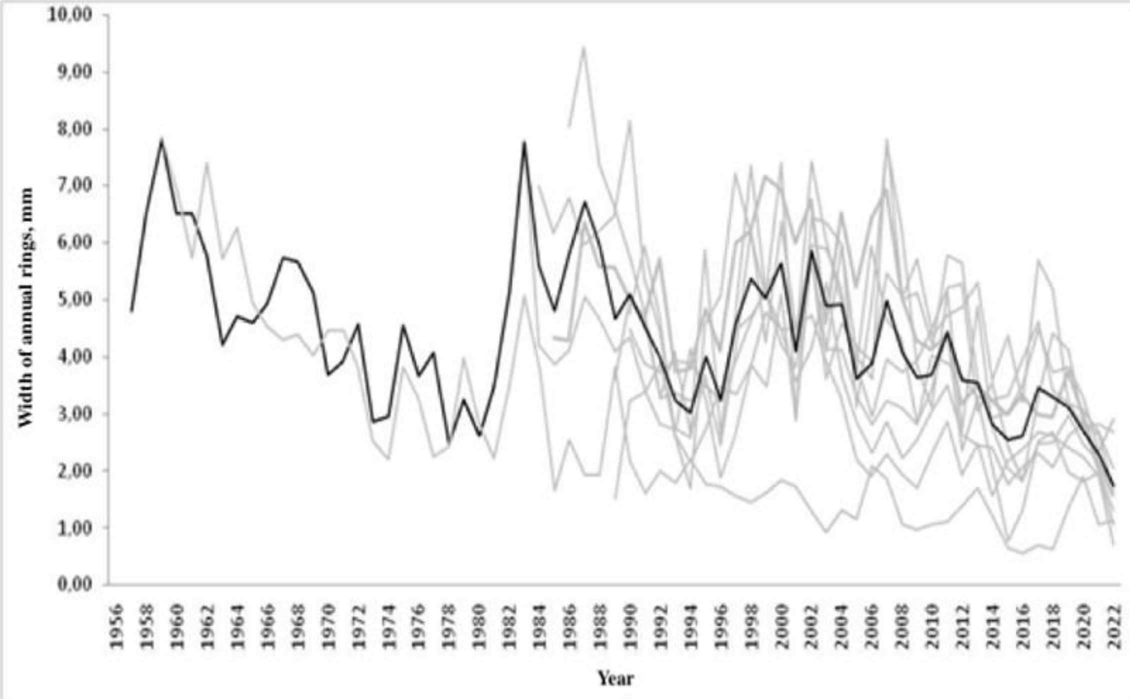

Figure 1. The width of annual rings (mm) in turanga trees depending on time (in calendar dates): The black curve reflects the average course of radial growth for trees, the gray curves correspond to experienced trees in the floodplain of the Ili River (Almaty region)

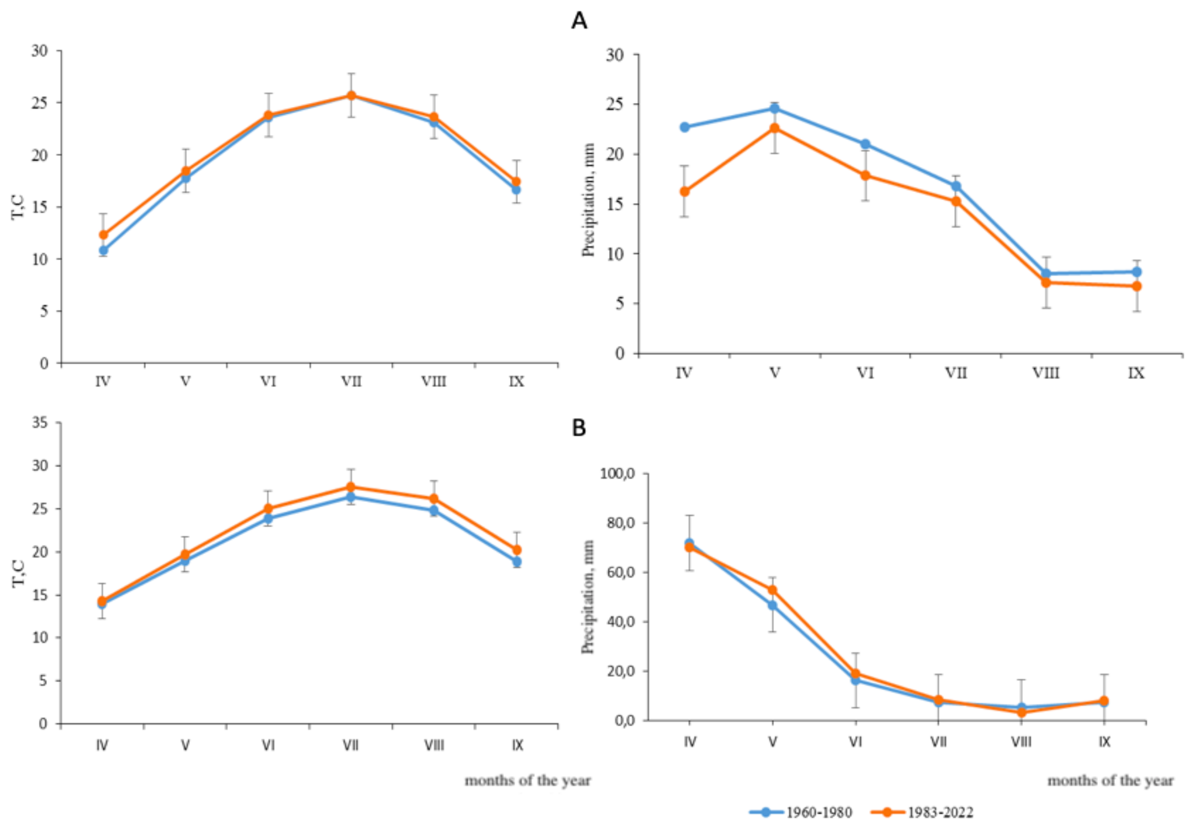

Figure 2. (A) Average annual monthly values of temperature and precipitation according to the Bakanas weather station, (B) Average annual monthly values of temperature and precipitation according to the Shymkent weather station. Blue curve – for the periods 1960-1980. Red curve – for the periods 1983-2022

4.2 Indexed tree-ring chronologies on the Ili River

Indexing of absolute tree-ring chronologies (removal of the age trend) was carried out by a negative exponential function, the most suitable negative exponential function, age decreasing trends present in absolute chronologies were leveled. The sharp increase in the absolute width of the annual rings in the early 1980s (Figure 3) on the indexed curves was not leveled after the removal of the age factor and was marked in Figure 3 by peak values in 1981-1984. It can be concluded that the increase in the width of the annual rings in the early 1980s was caused not by the age factor, but by a sharp change in local growth conditions (including weather conditions). The quality of the indexed chronologies obtained was evaluated by standard characteristics: sensitivity coefficient and standard deviation.

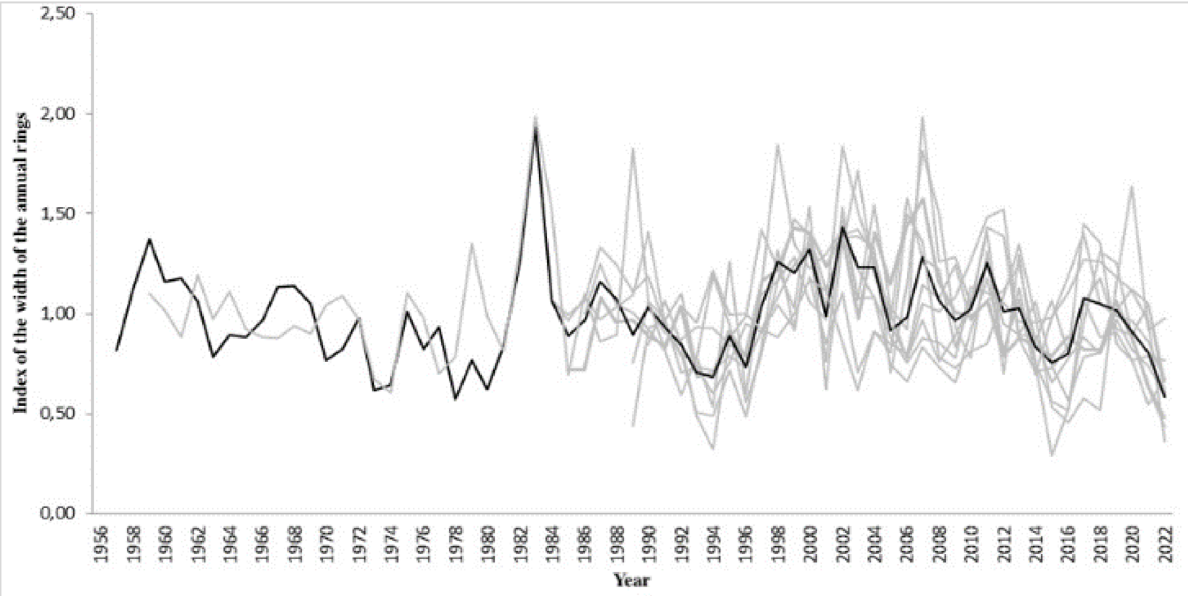

Figure 3. Indexed tree-ring chronologies of radial growth of turanga trees depending on time (in calendar dates): The black curve is the average tree-indexed tree-ring chronology, the gray curves are indexed chronologies of experimental trees in the floodplain of the Ili River

Judging by the average inter-series correlation coefficients (0.67), the synchronicity of indexed tree-ring chronologies is quite high. The average tree sensitivity coefficient of indexed tree chronologies ILI is 0.235, that is, above the lower limit of 0.20. This means that indexed chronologies are quite suitable for further dendroclimatic studies with the identification of a climatic signal. The standard deviation characterizes the amplitude of the weather variability of the radial growth indices relative to the average. The average tree standard deviation is 0.277. The average tree autocorrelation of the 1st order is 0.39.

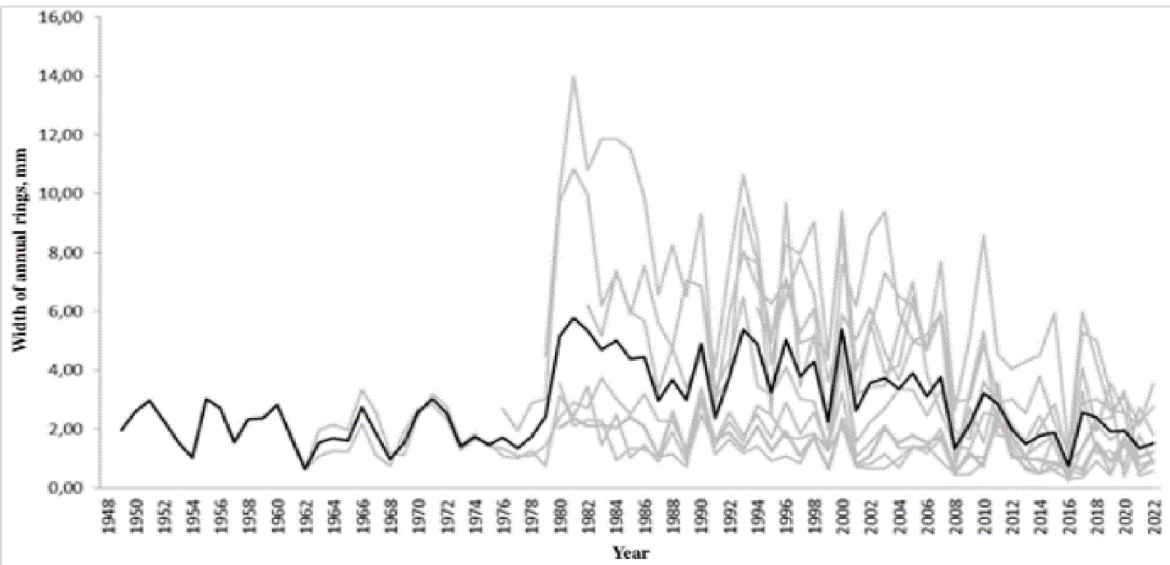

Figure 4. The width of annual rings (mm) in turanga trees depending on time (in calendar dates): The black curve is the average course of radial growth for trees, the gray curves correspond to experienced trees. The floodplain of the Syr Darya River (Turkestan region)

4.3 Absolute tree-ring chronologies on the Syr Darya River

Marking of samples-Sir. The cambial age of trees at a trunk height of 1.3m varies from 29 to 73 years. The average width of annual rings varies from 1.55 to 5.29mm, the average for trees is 3.35mm, which is 1.2 times less than on the Ili River. The correlation between the corresponding tree growth curves in Ili and Syr Darya is quite low, only 0.182. This means that the weather factors affecting the course of radial growth of trees on the Ili River and the Syr Darya River are different and unrelated.

The largest average value of the annual ring width (5.16mm) is characterized by the Sir-1 tree, and the smallest (1.41mm) is Sir-11. The widest ring of all measured on the prototypes was formed at Sir-3 (13.89mm), and the narrowest (0.24mm)-at Sir-5 (Figure 4). In the reference years 1981, 1993, 2000 and 2010, with favorable growth conditions, most trees formed relatively wide annual rings.

The synchronicity of the weather variation in the width of annual rings (absolute tree-ring chronologies) is quite high, but somewhat lower than on Ili River: paired correlation coefficients R=0.39-0.80 at $P \geq 0.95$). Thus, 10 trees in the Syr Darya floodplain selected for study by dendrochronological method represent the course of growth of the entire group of trees, growing in this place, the radial growth synchronously reacts to the weather change of external factors.

The intensity of the course of radial growth of older trees in the period from 1948 to 2022 has a very weak tendency to decrease, at the same time, in relatively young trees from 1980 to 2022, it has a much more pronounced tendency to decrease (Figure 4). The graph highlights the beginning of the 1980s with a sharp increase in the width of the annual rings (as well as on the Ili River). The average width of annual rings in these groups of trees differs markedly: in the first (older) this indicator for 1949-2022. it was 1.75mm, and the second (young, 1980-2022)-3.74mm, that is, almost 2 times more. At the same time, the second time period (the last 4 decades), according to the available data of the Shymkent weather station (Figure 2B), differs slightly from the previous time period (1960-1980), although there is some tendency to a very slight increase in May precipitation (i.e., during the high intensity of the annual ring formation). Could a very small increase in precipitation in May have led to an increase in the width of annual tree rings by almost 2 times, or was the "jump" in the value of the ring width in the early 80s due to the inclusion of the average growth curve of "young" trees in the calculation? Indirectly, the answer to this question can be given by indexed tree-ring chronologies, leveling the age factor, and correlative climatic response functions (see below).

In relatively old trees on the Syr Darya, the average width of annual rings is 1.8 times less than that on the Ili River, and in young trees on the Syr Darya, this indicator does not significantly differ from that on the OR. And this is despite the fact that in the spring months, about 4 times more precipitation falls in the Syr Darya floodplain (with the same temperature regime) than on Ili River. It can be assumed that it is not climatic factors (in particular precipitation) that determine the radial increase. In the first case, the age factor obviously plays a significant role, since the "old" trees on the Syr Darya are noticeably older than the "old" ones on Ili River. In order to clarify these features, we used indexed tree-ring chronologies and correlation climatic response functions.

4.4 Indexed tree-ring chronologies on the Syr Darya River

Indexing of absolute tree-ring chronologies (removal of the age trend) was carried out by the most appropriate negative exponential function, trends present in absolute chronologies were completely leveled. It can be concluded that the sharp increase in the width of the annual rings in the early 1980s (Figure 5) is due to the age factor, and not climatic or other local growth conditions.

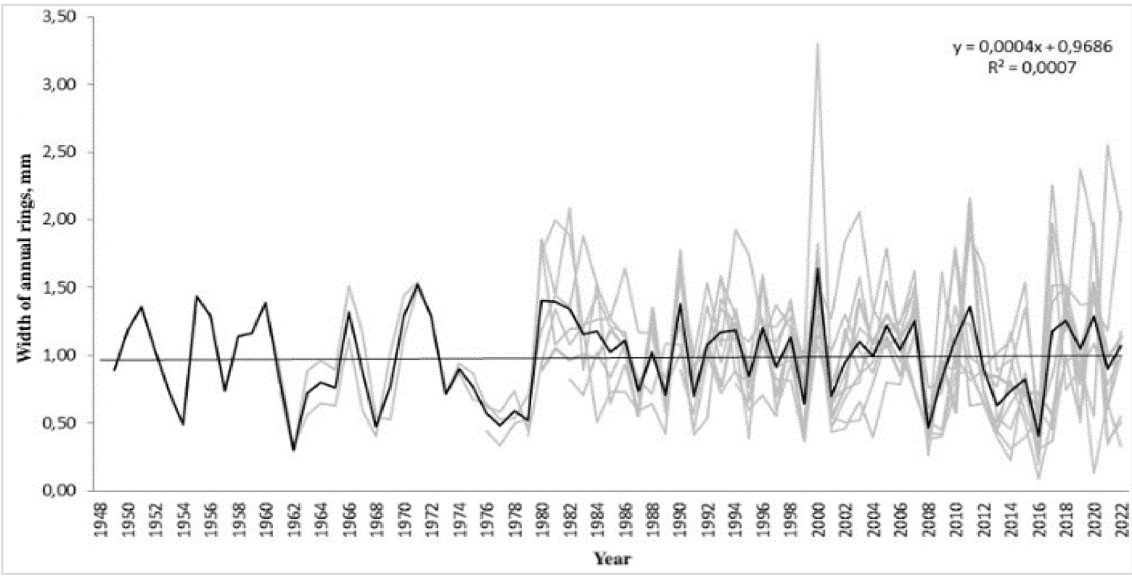

Figure 5. Indexed tree-ring chronologies of radial growth of turanga trees depending on time (in calendar dates): The black curve is the average indexed chronology for trees, the gray curves are indexed chronologies of experimental trees in the floodplain of the Syr Darya River

The synchronicity of indexed chronologies is lower than that of trees on the Ili River, the pair correlation coefficient varies from 0.41 to 0.69. The average inter-series correlation coefficient is 0.55. The average tree sensitivity coefficient of indexed chronologies of radial growth of Sir trees is 0.46, that is, higher than that of Ili trees. This means that the radial growth of trees on the Syr Darya is more sensitive than on the Ili River to annual changes in local conditions (including weather). The answer will be given by climatic correlation functions). The standard deviation characterizes the amplitude of the weather variability of the radial growth indices relative to the average. The average tree standard deviation is 0.44, which is also higher than on Ili River (0.277). The average tree autocorrelation of the 1st order, which reflects the influence of the weather conditions of the past year on the width of the annual ring of the current year, is insignificant and is equal to 0.07, about the same as on Ili River (0.05).

4.5 Climatic correlation functions of radial growth of turanga on the Ili and Syr Darya Rivers

As noted above, the variability of the absolute values of the radial growth of trees contains signals of climatic and non-climatic nature. We obtained information about the significance of the influence of climatic factors on the width of annual rings from the analysis of correlation climatic response functions (Figure 6).

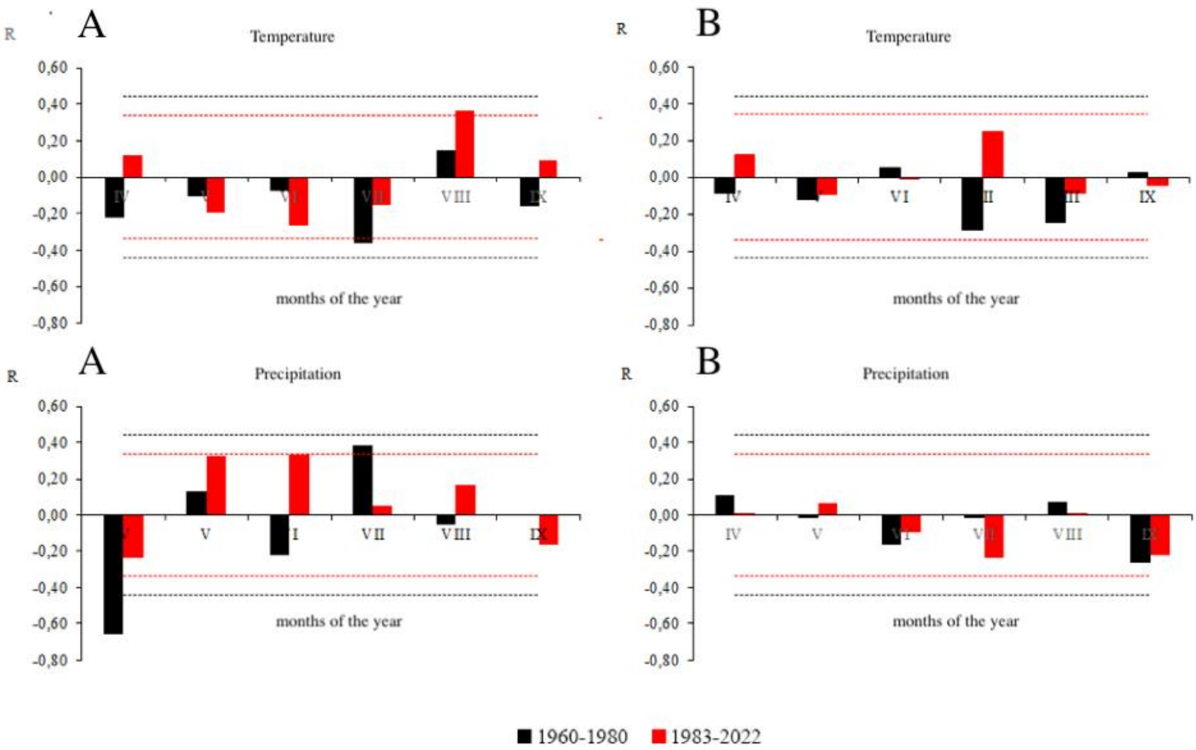

Figure 6. (A) Correlation climatic functions of the response of radial growth indices to the influence of air temperature and precipitation in turanga trees growing in the floodplain of the Ili River, (B) Correlation climatic functions of the response of radial growth indices to the influence of air temperature and precipitation in turanga trees growing in the floodplain of the Syr Darya River

Note: Black columns – correlation in the time period 1960-1980. Re – in the time period 1983-2022. Black and red dotted lines – corresponding confidence limits at P≥0.95: R>0.44 for 1960-1980, R>0.34 for 1983-2022.

It follows from Figure 6 that the weather conditions of the growth seasons do not affect the radial growth of trees in the floodplain of the Syr Darya River. On the Ili River the picture is different. In the period 1960-1983, a significant (judging by the value of the correlation coefficient) negative effect of the April precipitation on growth was revealed. It is obvious that heavy precipitation caused a higher level of seasonal flooding of trees in the floodplain with melt water, which negatively affected cambial activity at the beginning of growth and, as a result, relatively narrow annual rings were formed. The air temperature in the same time period (1960-1983) did not have a noticeable effect on growth.

In a later period, 1983-2022, there was a weak but significant positive effect on the temperature increase in August and a weak (but significant) positive effect of precipitation in May-June. We emphasize that the amount of precipitation in May-June in the period 1983-2022 significantly decreased compared to the previous period (Figure 2). The lack of moisture absorbed by plants is associated with an increase in the importance of the influence of precipitation on growth. The positive effect on the temperature increase in hot and dry August, in our opinion, is mediated through the replenishment of the river with meltwater. The more intense melting of glaciers in the mountains at elevated temperatures in August has a positive effect on the water regime of the river. At the same time, the shortage of available moisture in the floodplain decreases, which has a positive effect on the radial growth of trees.

5. DISCUSSION

The pronounced features and differences in the dynamics and weather variability of the radial growth of the studied turanga trees of different leaves growing in arid places in the valleys of the Ili and Syr Darya Rivers can be explained by the fact that in spring, at the beginning of the radial growth season, the experimental trees are in a submerged state with different duration and intensity of flooding [5]. This factor reduces the response of trees to the influence of weather conditions (air temperature and precipitation).

Thus, the weather conditions of the growing seasons do not significantly affect the radial growth of trees in the floodplain of the Syr Darya River. The weather variability of the width of the annual rings is associated with the inter-seasonal variability of the hydrological regime of the floodplain and the time when trees are in a submerged state [13]. It should be noted, however, that the influence of weather conditions on the growth of turanga variegated on the Ili River has increased in recent decades compared to the previous period [14].

The significance of the influence of climatic factors on the growth of turanga on the Ili River is noticeably higher than on the Syr Darya River. The weather conditions of the spring-early summer period [15], namely, the amount of precipitation, have a particularly noticeable effect on radial growth. In the last four decades, this influence has been positive, and in the previous period-negative. This difference is a consequence of changes in climatic conditions in the place of growth on the river or towards aridization [16]. At the same time, trees are also affected by the duration and intensity of flooding during spring floods.

6. CONCLUSION

The analysis of the chronology of the tree rings of Populus diversifolia growing in the floodplains of the Syr Darya and Ili Rivers showed that the trees are sensitive to the current regional climate change. This is expressed in an increasing trend of changing the width of the annual rings from time to time (in calendar dates), which well reflects the increasing trends in air temperature and precipitation over the past few decades. In this regard, Populus diversifolia can be effectively used as an indicator of long-term climatic changes.

In general, it is difficult to trace any stable influence of weather conditions (air temperature and precipitation during growing seasons) on the width of the annual rings of the studied trees due to the poor synchronicity of the variability of this parameter in trees.

Studies show that trees growing in the floodplain of rivers accumulate the influence of many other factors besides climatic ones. Most likely, they are more affected by the duration and intensity of flooding during seasonal floods. Turanga trees can be more sensitive to these factors than willow trees, so further research in this area is required.

Thus, according to the results of the study, it can be concluded that the radial growth on the Ili River is mainly influenced by climatic factors (mainly precipitation) and the water regime of the soil. Due to the pronounced sensitivity of radial growth, turanga trees of different leaves can serve in practice as indicators of extreme seasonal floods in the past.

ACKNOWLEDGMENTS

This study was funded by the Ministry of Ecology, Geology and Natural Resources of the Republic of Kazakhstan (Grant No.: BR10263776).

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