

IMPACT OF CLIMATE CHANGE ON THE GROWTH DYNAMICS OF NATIVE TREE SPECIES (*PINUS SYLVESTRIS* - IN AZERBAIJAN)

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Abstract

This study investigates the impact of climate change on the growth dynamics of *Pinus sylvestris* in Azerbaijan through dendro-climatological analysis covering the period 1900–2026. Using tree-ring chronologies, climate data, and statistical methods (EPS, response function analysis, moving correlation analysis, SEA), the research reveals species-specific and time-dependent growth responses. Results demonstrate that *Pinus sylvestris* growth is positively correlated with winter temperatures (January–March), while precipitation shows no significant effect. Drought years (e.g., 1907, 1921, 1976, 2003, 2019) caused notable reductions in ring width, but recovery occurred in subsequent years, indicating high adaptive potential. The findings highlight that moderate winters stimulate growth by reducing soil frost depth and enhancing photosynthetic activity, whereas prolonged summer droughts remain a limiting factor. Overall, *Pinus sylvestris* exhibits relative resilience compared to other conifers (e.g., *Picea orientalis*), positioning it as a potentially sustainable species under projected climate scenarios. These results provide a scientific basis for forest management strategies, biodiversity conservation, and adaptation planning in Azerbaijan's mountainous ecosystems.

Keywords: Climate change, Dendro-climatology, *Pinus sylvestris*, Growth dynamics, Tree rings, Adaptation, Azerbaijan forests

INTRODUCTION

Climate change is considered one of the greatest challenges to the sustainability of ecosystems and the stability of agricultural production in modern times. As a result of increasing atmospheric temperature, changing precipitation patterns, and intensifying droughts and floods, biodiversity is weakening, soil fertility is decreasing, and freshwater resources are limited. Although increasing carbon dioxide concentration increases the rate of photosynthesis and creates a “fertilization effect” in plants, it weakens the nutritional quality of products, causing a decrease in protein and mineral content. These processes affect the phenological cycles of plants, limiting their reproductive capabilities, accelerating the spread of pests and diseases, reducing the population of pollinating insects, and ultimately creating instability in agricultural production (Garibov & Hebilov, 2021).

The impact of climate change is more pronounced in various ecosystems of Azerbaijan, especially in local tree species. Over the past 120 years, the reduction of forest areas, increased soil erosion, and the gradual lowering of the upper limits of forests have led to a disruption of the ecological balance. Dendrochronological studies conducted on the Hyrcanian flora show that, the development of rare and old trees has sharply weakened in recent decades, and forest fires have led to the extinction of endemic and relict species (Gurbanov, H., 2024). In this context, the study of the growth dynamics of the *Pinus sylvestris* species is of particular importance, since this species is distinguished by its sensitivity to anomalous temperature, drought and frost events. Scientifically based studies are important for assessing the adaptive capabilities of local tree species and protecting biodiversity.

LITERATURE REVIEW

Changes in global temperature and precipitation regimes are considered to be among the main factors that have a significant impact on plant development processes and growth (IPCC, 2021; Briffa et al., 1998). According to various projection models, continued warming until mid-century will increase the variability of the water cycle, create instability in precipitation amounts, and intensify drought events. The literature shows that, although increasing temperatures and lengthening the growing season stimulate tree growth in some cases, decreasing precipitation and its uneven distribution over the annual cycle can weaken growth rates (Allen et al., 2010). Projections for Azerbaijan confirm rapid warming accompanied by reduced summer precipitation, which increases the risk of long-term droughts, storms and floods in forest ecosystems. These changes can lead to shifts in species composition, a decrease in biomass production, and disruption of ecosystem stability.

Studies have shown that, the impact of climate change on Azerbaijan's vegetation and agricultural systems has been multifaceted:

The increase in atmospheric CO₂ concentration has created a “fertilization effect” in plants, increasing the rate of photosynthesis and increasing productivity. However, this rapid growth has been accompanied by a weakening of wood quality and a decrease in nutritional value. These results have also been confirmed in international studies, which show that, the structural quality of plants weakens under high CO₂ conditions (Myers et al., 2014).

A 3–17% decrease in minerals such as protein, zinc and iron has been recorded in cereal crops (wheat, barley, oats, rice). These changes have had a negative

impact on the quality of feed in livestock farming, as well as human nutrition. Similar results have been observed in studies conducted in other regions.

As a result of the increase in temperature, premature yellowing of leaves, shifting of flowering periods and weakening of reproductive capabilities have been recorded in many tree and shrub species. This phenomenon was clearly manifested in observations conducted in the Central Botanical Garden and on the Absheron Peninsula.

Heat waves and increased humidity accelerated the spread of pests and diseases, reduced the population of pollinating insects, and weakened the reproductive success of plants (Allen *et al.*, 2010). Cases of infection with the olive leafhopper (*Saissetia oleae*) in olive trees (*Olea europaea*) have proven that, climate change increases the susceptibility of plants to diseases.

Increased droughts and floods have weakened soil fertility and negatively affected the growth rate of plants by reducing the reliability of irrigation water. Sea level rise has intensified the processes of salinization and waterlogging in coastal soils.

Dendrochronological studies conducted on the Hyrcanian flora have shown a sharp decline in the growth rate of rare and old trees in the last 20–30 years. Forest fires have caused serious damage to biodiversity and led to the destruction of beneficial entomofauna living in the fertile soil layer (Aliyev, 2019).

Literature analysis shows that, climate change has had both positive (CO₂ fertilization effect, acceleration of photosynthesis) and negative (decrease in food value, phenological disturbances, increase in pests, weakening of soil and water resources, forest fires) impacts on the flora and agricultural systems of Azerbaijan. These results are consistent with regional observations as well as international studies and prove that, Azerbaijani ecosystems are at high risk against the background of climate change.

Tree-ring analysis is considered an important methodological approach to study the impacts of climate change. Dendro-climatological studies show that, changes in temperature and water regimes cause species- and site-specific variations in ring width, which allows assessing the growth behavior of trees (Speer, 2010; Vaganov *et al.*, 2006). Tree rings serve as a natural archive for paleoclimate reconstruction and have been widely used since the early 20th century to reconstruct temperature, precipitation variability and drought (Fritts, 1976; Cook & Kairiukstis, 1990). Studies on the response of different species to climate have yielded conflicting results, with some species being selected for their sensitivity to drought, while others have shown more variability. Studies in this context are important for understanding the long-term effects of climate change on forest productivity and carbon sequestration.

MATERIAL AND METHODS

This study was conducted to study the impact of climate change on the growth dynamics of native tree species in Azerbaijan. The study was carried out in selected forest areas in the Greater Caucasus, Lesser Caucasus, Talysh Mountains and Nakhchivan regions.

Pinus sylvestris was selected as the main species for the study. This species is naturally distributed in

various regions of Azerbaijan - Guba, Gusar, Balakan, Goygol, Tovuz, Shamkir, Agstafa, Shamakhi, Sheki, Gabala, Gadabay, Murovdagh range and Nakhchivan Autonomous Republic. Due to its rare and limited range, it was included in the "Red Book" of Azerbaijan. The creation of new reserves is considered important for the protection of this species, which reproduces mainly generatively.

In total, 12 dominant trees were selected (3 trees from each site). The selection of dominant trees was aimed at minimizing the impact of micro-environmental factors - competition for light, water and nutrients. The tree cores were taken at a height of 1.3 m, at a 90° angle, using a special borer tool. The samples were transported to the laboratory, dried, polished, and the rings were clearly visible.

The study areas represented typical forests of the region. The annual mean temperature was 8.6 °C and the annual precipitation was approximately 665 mm. The soils were moderately fertile, low in clay content and moderately humid. Climatic parameters were taken from the database of the Azerbaijan National Meteorological Service covering the years 1900–2026. Temperature and precipitation parameters were extracted from raster maps with a resolution of 1 km × 1 km, and the parameters corresponding to the location of each tree were selected and summarized at the site level.

The width of the rings was measured using the LINTAB system and the TSAP-win program, and the results were checked using the COFECHA program (Gauli *et al.*, 2022). The standardization of the rings was carried out using the dplR package, long-term trends were extracted, and high-frequency changes were retained (Buras, 2017). The chronology was based on annual averages, and statistical parameters such as EPS, Rbar and Gleichläufigkeit were calculated. Only years with a strong signal (EPS > 0.85) were included in the analysis.

Long-term changes in temperature and precipitation parameters were analyzed using local polynomial regression in R. The relationship between ring chronology and climate parameters was assessed using response function analysis and moving correlation analysis. This approach allowed us to track the changes in the growth response of species over time.

The impact of drought years was investigated using the Superposed Epoch Analysis (SEA) method. The Standardized Precipitation Evapotranspiration Index (SPEI) was used as a drought indicator. SPEI was calculated for the years 1900–2026, with values below -1.5 classified as moderate, and values below -1.5 as severe drought years.

The selected methods allowed for a comprehensive study of the impact of climate change on the growth dynamics of local tree species. This approach is of great importance both in terms of assessing the risks of ecological imbalance and in terms of forming scientific foundations for the protection of biodiversity.

RESULTS

In different regions of Azerbaijan, an increase in temperature indicators and a decrease in precipitation indicators were observed during the period 1900–2026.

The average annual temperature increased by approximately 0.4–1.3 °C, and annual precipitation decreased by 7%.

The analysis results showed that, the growth dynamics of the *Pinus sylvestris* species demonstrate a specific and time-varying sensitivity to climate variability. During the study, the chronology of tree rings for the *Pinus sylvestris* species was as follows:

A 121-year chronology was established for the *Pinus sylvestris* species (1900–2020). The average ring width for the *Pinus sylvestris* species (2.06 mm). Statistical indicators (Mean sensitivity = 0.24; Series inter-correlation = 0.541; EPS = 0.885; Gleichläufigkeit = 0.634) confirmed the reliability of the climate signals. The EPS (expressed population signal) values were higher than 0.85 for the species, confirming a strong overall signal.

Analyses based on climate-growth relationships showed that, the response function analysis between ring width and climate variability showed that, *Pinus sylvestris* growth was mainly positively correlated with winter temperature (January, February, March) (Gauli et al., 2022). This suggests that, mild winter conditions stimulate growth. The relationship with precipitation was not statistically significant (Babst et al., 2014).

According to the analyses, January, February and March temperatures were the climatic variables with the strongest influence on growth for *Pinus sylvestris*. Since 1911, tree growth has responded positively to the average temperature of January, February and March, and this trend has been strengthened in recent years. The effect of April temperature on growth was significant between 1916 and 1980, but weakened and decreased over time.

A moving correlation analysis confirmed that, the positive relationship with January–March temperature has strengthened since 1911. The effect of April temperature has weakened and lost significance after 1980.

A significant decrease in *Pinus sylvestris* ring width was recorded in drought years (e.g. 1907, 1921, 1976, 2003, 2019) as determined by the Standardized Precipitation Evapotranspiration Index (SPEI). However, this effect did not persist in subsequent years.

Pinus sylvestris grows better in mild winter conditions and is relatively less sensitive to precipitation. Despite the reduction in growth during drought years, the species has a high adaptive potential (Gauli et al., 2022; Vaganov et al., 2006). These results indicate that, *Pinus sylvestris* can be considered a relatively resilient species in Azerbaijani forests against the backdrop of climate change.

DISCUSSION

The average ring width of *Pinus sylvestris* species decreased over the years. This result is consistent with previous studies. EPS for the species, serial inter-correlation and other statistical indicators confirmed a strong general ecological signal.

The analyses showed that, the climate-growth relationship is species-specific and shows variability over time. The growth of *Pinus sylvestris* species was mainly stimulated by the increase in temperature in January, February and March of this year. This is explained

by the decrease in deep soil freezing in mild winter conditions and the creation of a favorable environment for photosynthesis.

The average annual temperature in different regions of Azerbaijan has increased by approximately 1.3 °C since 1900. The increase in temperature in winter months had a positive effect on the *Pinus sylvestris* species.

In general, the increase in mild winters stimulates the growth of *Pinus sylvestris* species. These results provide an important scientific basis for assessing the adaptive potential of species and formulating forestry strategies against the background of climate change.

The results prove that, climate change has a direct impact on the growth dynamics, nutritional quality, phenological cycles, and ecological stability of Azerbaijan's vegetation. Strengthening adaptation measures, protecting biodiversity, and implementing sustainable agricultural technologies are considered necessary to mitigate these impacts.

CONCLUSION

The conducted dendro-climatological analyses showed that, climate-growth relationships are species-specific and show variability over time. *Pinus sylvestris* species showed better growth performance in mild winter conditions, especially when temperatures increased in January, February and March stimulated their development.

According to climate projections, temperatures are expected to increase in Azerbaijan and precipitation will decrease in summer months. Although *Pinus sylvestris* may continue to benefit from mild winters under these conditions, this process will negatively affect the growth and productivity of species that are more sensitive to summer drought.

Overall, the study shows that, the growth response of tree species against the background of climate change is specific, variable and unstable. These results provide an important scientific basis for assessing the sustainability of forest ecosystems, determining the adaptive potential of species and formulating future forestry strategies.

In the mountainous and foothill forests of Azerbaijan (Guba, Sheki, Nakhchivan regions), *Pinus sylvestris* species is found in both natural and introduced conditions. Regional observations show that, in the northern regions, mild winter conditions increase ring width, while growth is weakened in years with severe frosts. Although the annual amount of precipitation does not directly affect growth, a decrease in ring width is observed in years of prolonged drought (especially in the Nakhchivan and Ganja-Gazakh zones). In general, *Pinus sylvestris* is more resistant to the continental climate of Azerbaijan than other conifers (e.g. *Picea orientalis*). These results indicate that, *Pinus sylvestris* can be considered a relatively adaptive and resilient species in the context of climate change in the Azerbaijani context.

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