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Radial Growth Characteristics and Climate on the East and West Banks of the Nestos River, Greece: Vegetation Strategic Management Insights †

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Abstract: In Greece, water scarcity is a key factor limiting forest growth, with a strong correlation observed between water availability and tree ring growth in Mediterranean forests. The LIFE-PRIMED project in the Nestos Delta, northeastern Greece, studied tree growth patterns on both riverbanks, noting significant fluctuations towards the east and varying increases towards the west. The drought index revealed a decrease in drought over time, and no clear link between tree growth and drought conditions was found. Severe droughts and dam-induced flooding appear to affect tree growth by altering hydrological patterns. Years of significant decline with notable growth deviations include 1995, 1998, 2000, 2002, 2007, and 2017 in the eastern region, and 2002, 2004, 2007, and 2017 in the western region. Significant droughts in 1990, 1993, and 2001 had limited immediate impact but may have affected growth in subsequent years. Further research is needed to understand the impact of climatic conditions and prolonged floods on tree growth to improve management decisions.

Keywords: climate–growth relationship; *Alnus glutinosa*; Nestos River; LIFE-PRIMED; riparian forests

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1. Introduction

Forests face significant challenges as they endure pressure from climate fluctuations. Over the past century in Southern Europe, forests have been subjected to direct abiotic disturbances such as droughts and high temperatures, occurring not only in the summer months [1–4]. Decreased precipitation and high temperatures are most likely the main threats to the diversity and survival of Mediterranean forests [5].

This often results in reduced productivity, higher mortality rates, and the decreased resilience of ecosystems to secondary infestations by fungi and insects [6–8]. Tree growth serves as a quantitative measure of tree vitality and its capacity to withstand environmental constraints [9]. According to the literature, warming-induced drought can exacerbate physiological stress on long-lived woody vegetation, leading to a sudden reduction in tree growth. Additionally, a decline in growth due to severe droughts may trigger widespread mortality, altering the structure, composition, and mid-term dynamics of forest stands and landscapes at regional scales [10]. In recent decades, severe drought events characterized by high temperatures and low precipitation have led to intense episodes of forest dieback across Europe [9,11]. Furthermore, numerous recent instances of drought and heat-related tree mortality worldwide indicate that no forest type or climate zone is immune to anthropogenic climate change, even in regions not typically considered water-limited [2]. A comprehensive review by Dobbertin [9] emphasized an increase in tree growth as an indicator of their vitality in response to environmental changes, suggesting that tree ring width can serve this purpose.

In Greece, water scarcity is likely the main climatic factor limiting forest growth. Research has demonstrated a strong correlation between water availability and tree ring width and growth across various Mediterranean forests and tree species [12–16].

2. Methodology

The LIFE-PRIMED project area is in the Nestos Delta, Kavala, Greece, covering 22,484.630 hectares (SCIGR1150010). The Nestos area includes priority habitat 91E0 (Annex I Dir. 92/43/EEC), which has two subtypes: alder stands (*Alnus glutinosa*), white poplar (Populus alba) and elm (Ulmus minor) stands. Recent studies highlighted the invasion of *Amorpha fruticosa* and the negative effects of its expansion on the ecosystem [17]. Habitat 91E0* includes alluvial forests along European riverbanks.

In plots with IDs 7 and 15 (area circa 707 m^2 each), five dominant or co-dominant *Alnus glutinosa* L. trees were selected randomly for wood core sampling. Two cores per tree were extracted at breast height using a 400 mm long and 5.15 mm wide increment borer from Haglof (Haglof Inc. Sweden), spaced at least 5 m apart. Cores were carefully stored in straw and transported to the laboratory, where they were air-dried, hand-sanded, and measured using LignoVision software (version 1.40). The trees range in age from 9 to 33 years at plot 7 (elevation 23 m, east of the riverbank) and from 16 to 22 years at plot 15 (elevation 20 m, west of the riverbank) (Table 1).

Table 1. Characteristics of the research area (sampling plots 7 and 15) and the ages of the trees selected for core sampling.

No.	Elevation	Age	Distance from the Main River Channel
Plot 7 (east) Lat 40.973 Lon 24.744	23 m		783 m
1		22	
2		9	
3		28	
4		33	
5		25	
Plot 15 (west) Lat 40.997 Lon 24.750	20 m		226 m
1		16	
2		22	
3		18	
4		19	
5		21	

The time series data were plotted against the corresponding years, along with a fitted curve and its equation. Typically, these curves are adequately estimated using a two-parameter exponential decay function fitted to the data:

$$y_t = y_0 + ae^{-bx}$$

where a and b are variable values that vary from series to series depending on the slope of the curve required to fit the data, and y is the expected increase in a given year t [18]. The evaluation of ring width models was based on the adjusted coefficient of determination (Radj), root mean square error (RMSE), and significance ($p < 0.05$).

The measured ring widths (Wt) were converted into average ring width indices (RWI) by dividing each width for year t by the expected growth (Yt), using the following equation:

$$RWI = \frac{w_t}{y_t}$$

This conversion both removes the trend in growth and scales the variance so that it is approximately the same throughout the entire length of the time series.

3. Results

The ring width index (RWI) was calculated for two out of the (15) total selected sample plots of the project, specifically on plot 7 (Figure 1) on the eastern bank of the river and plot 15 (Figure 2) on the western bank. Figures 1 and 2 present the standardized radial growth increments per plot.

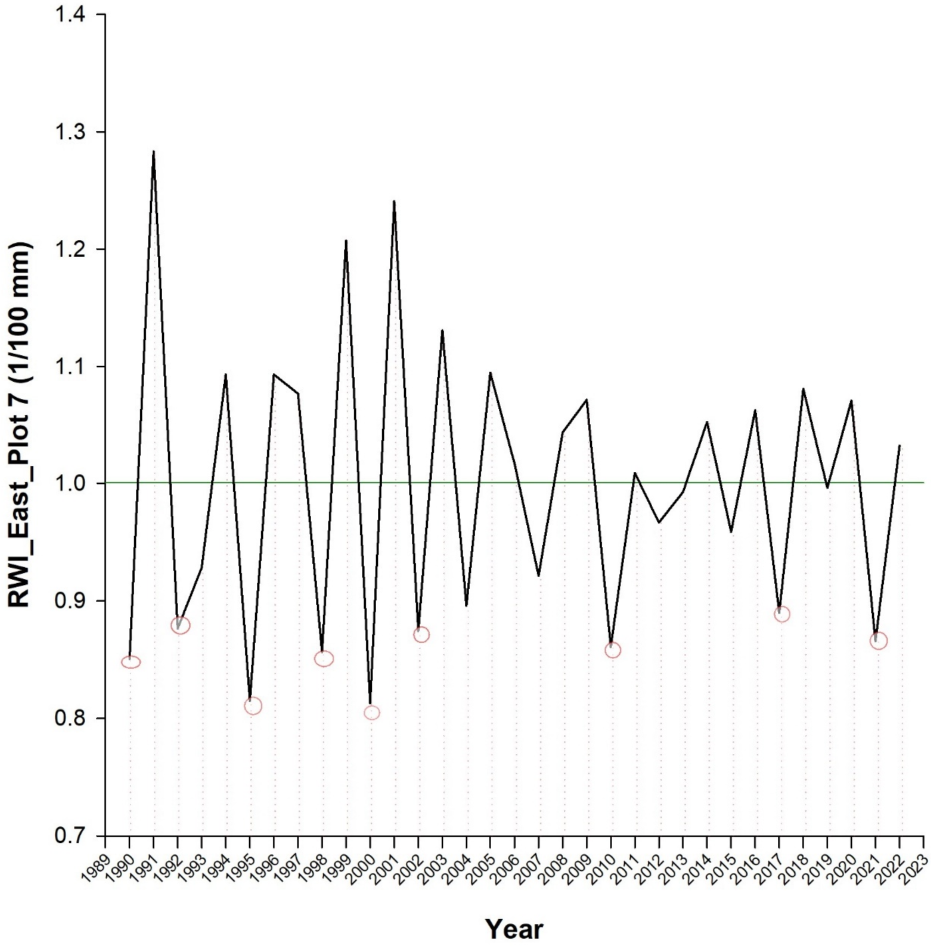

Figure 1. Average ring radial growth index for plot 7 (east).

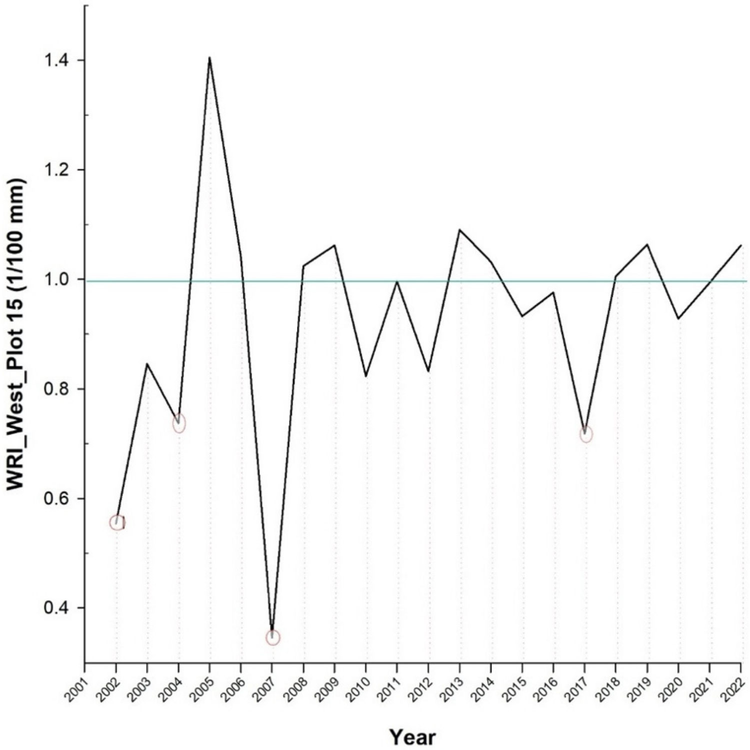

Figure 2. Average ring radial growth index for plot 15 (west).

The Palmer Drought Severity Index (PDSI), ranging from −10 (dry) to +10 (wet), was used to track long-term drought, typically between −4 and +4 (Figure 3). Data came from the TERRACLIMATE and CHIRPS datasets, as noted by Huntington [19].

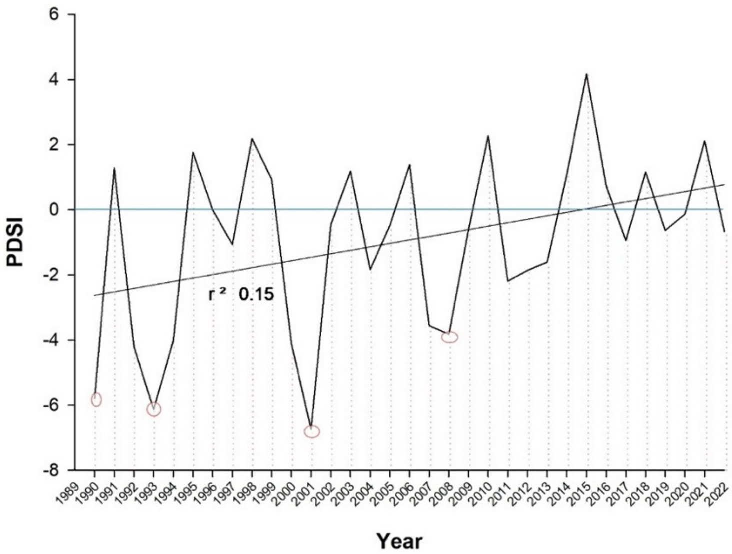

Figure 3. Increasing trend of the Palmer Drought Severity Index (PDSI) in the riparian forest during the years 1989–2022.

4. Management Insights and Conclusions

From the analysis of tree rings, the drought index, and the assessment of results, the following conclusions emerged:

- During the study period, tree growth on both riverbanks followed a similar trajectory, with significant growth fluctuations occurring eastward first, followed by either significant or less pronounced increases westward.

- Significant decline years were identified (marked as circles in Figures 1 and 2), where most trees showed exceptional growth deviations compared to adjacent years. Examples include 1995, 1998, 2000, 2002, 2007, 2010, 2017, and 2021 east of the river, and 2002, 2004, 2007, and 2017 west of the river. Younger trees provided less growth and climate information.
- Four significant drought events (indicated by circles in Figure 3) were identified, and we retained three of them (1990, 1993, and 2001), where PDSI < -4. These events appear to have had a limited impact on tree growth during the drought year itself, but potentially affected growth in the following year (e.g., the 2001 drought possibly reduced growth in 2002 to the east). This phenomenon seems to be sporadic and requires additional research for confirmation.
- On-site observations by the LIFE-Primed working group have shown that dam overflows in the northern Nestos River result in heightened wet conditions, which could potentially hinder tree growth and lead to mortality events. However, no mortality has been observed thus far.
- The frequency and quantity of water released from dams need monitoring, as severe and prolonged floods can disrupt riparian forest hydrology, altering water levels, flood duration, and groundwater replenishment, thus affecting tree growth and nutrient access.
- Severe floods can lead to the loss of ecosystem services provided by the ecosystem [20].
- These specific conditions may be more significant in terms of their impact on site tree growth, suggesting a more limited role of climatic conditions. However, further investigation is needed to draw more conclusive findings.

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Abbreviations

The following abbreviations are used in this manuscript:

RMSE	Root Mean Square Error
RWI	Ring Width Index
PDSI	Palmer Drought Severity Index

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