Postprint: Dry-wet Variations since 1872 at Changling Mountain, Southern Margin of the Tengger Desert

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Abstract

Changling Mountain, located on the southern margin of the Tengger Desert and sensitive to climate change, was selected as the study area. By analyzing the correlation between the tree-ring width chronology of the dominant species Qinghai spruce (Picea crassifolia) in Changling Mountain and climatic factors, it was found that the PDSI (Palmer Drought Severity Index) from May to July showed a strong correlation with the tree-ring width chronology ($r=0.621$, $P<0.001$), indicating that drought is the dominant climatic factor affecting tree radial growth. By establishing a linear regression equation between the tree-ring width chronology and PDSI, the drought variation of PDSI in the study area over the past 146 years was reconstructed. Furthermore, based on the interannual variability of the reconstructed PDSI, the study area experienced four drought periods during the past 146 years (1882–1894, 1915–1936, 1966–1978, and 1989–2015). Periodicity analysis results revealed that the reconstructed sequence exhibits variation cycles of approximately 2 years, 2.6–3 years, and 11 years, suggesting that climate change in the study area is primarily driven by El Niño-Southern Oscillation (ENSO) and sunspot activity. The conclusions of this study provide a scientific basis for exploring the patterns of dry-wet variation in northwestern China and for predicting changes in the subalpine forest ecosystem of this region under future climate change conditions.

Full Text

Drought-Wet Variation of Changling Mountain in Southeast of Tengger Desert since 1872

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Abstract

This study selected Changling Mountain, located on the southern edge of the Tengger Desert and sensitive to climate change, as the research area. By analyzing correlations between tree-ring width chronologies of the dominant species *Picea crassifolia* and climate factors, we found that the Palmer Drought Severity Index (PDSI) showed the strongest correlation with tree-ring width ($r = 0.621$, $P < 0.001$), indicating that drought is the primary climatic factor controlling radial tree growth. A linear regression equation between tree-ring width chronology and PDSI was established to reconstruct drought-wet variations in the study area over the past 146 years. Based on the reconstructed PDSI interannual variations, the region experienced four major dry periods (1882–1894, 1915–1936, 1966–1978, and 1989–2015) during this period. Periodic analysis revealed significant cycles of approximately 2.6–3 years and 8–8.6 years in the reconstructed sequence, suggesting that El Niño-Southern Oscillation (ENSO) and solar activity are the main drivers of climate variability in the study area. These findings provide a scientific basis for understanding drought-wet variation patterns in Northwest China and for predicting future changes in subalpine forest ecosystems under climate change scenarios.

Keywords: *Picea crassifolia*; PDSI; drought-wet historical variation; tree-ring width chronology; Changling Mountain; Tengger Desert

1. Introduction

Global warming has become an indisputable fact, with global mean temperatures rising by 0.89°C during recent decades, a trend projected to intensify in the coming decades [?]. The mid-to-high latitude regions of the Northern Hemisphere have experienced the most significant surface warming, particularly in Northwest China [?]. While some studies suggest that Northwest China' s climate has shifted from warm-dry to warm-wet conditions, especially in Xinjiang, the Qilian Mountains, and the Hexi Corridor [?], substantial uncertainty remains regarding regional climate change patterns. Understanding historical climate variability and its driving mechanisms is therefore essential for accurately predicting future climate trends.

Climate change has profoundly impacted global vegetation, with warming also expanding the scope, frequency, and intensity of drought worldwide [?]. Tree rings offer exceptional advantages for paleoclimate research due to their high sensitivity to climate, strong continuity, and high temporal-spatial resolution, making them invaluable proxy materials for reconstructing historical climate variations [?]. Changling Mountain, an independent landform on the southern edge of the Tengger Desert, represents the natural forest area closest to the desert in China [?]. Located in the transition zone between desert and loess regions and on the northwestern margin of the East Asian monsoon, this area' s dominant coniferous trees are highly sensitive to climate change, with tree-ring archives preserving abundant historical climate information [?].

Previous studies in Changling Mountain have primarily focused on tree growth-climate relationships and reconstructions of temperature, precipitation, and river runoff [?], while largely neglecting historical drought-wet variations. The Palmer Drought Severity Index (PDSI), based on water balance equations and incorporating precipitation, temperature, and soil moisture data, has been widely applied in arid region research [?]. Recent dendroclimatological studies using PDSI grid data have successfully reconstructed drought histories across Northwest China, demonstrating PDSI' s effectiveness in characterizing regional drought conditions [?]. This study therefore aims to reconstruct historical drought-wet variations in climate-sensitive Changling Mountain using tree-ring width chronologies of *Picea crassifolia*.

2. Materials and Methods

2.1 Study Area Changling Mountain (37.44°N, 103.59°E) is located in Gulang County, Wuwei City, Gansu Province, on the southern margin of the Tengger Desert (Fig. [Figure 1: see original paper]). As an eastern extension of the Qilian Mountains oriented east-west, the mountain ranges from 2250 to 2900 m in elevation. The region experiences a temperate continental arid climate characterized by dryness, low precipitation, and large temperature variations, with a mean annual temperature of 8.8°C. January is the coldest month (average -12.2°C), while July is the warmest (average 28.9°C). Annual precipitation totals 185 mm, concentrated primarily in July. Vegetation shows clear vertical zonation: semi-arid desert steppe, deciduous broadleaf forest, evergreen coniferous forest, and alpine shrub zones. The dominant tree species include *Picea crassifolia*, *Sabina przewalskii*, and *Pinus tabuliformis*, with gray-brown forest soils developing under the forest canopy.

2.2 Sample Collection and Chronology Development In July 2018, we collected samples from a mixed forest of *Picea crassifolia* and *Pinus tabuliformis* near the upper timberline on the northern slope of Changling Mountain (2562 m elevation). To minimize microsite effects, we selected healthy trees without obvious fire damage or pest infestation. Using a 5.15 mm increment borer, we extracted two cores per tree at breast height (1.3 m) along both parallel and perpendicular slope directions. After discarding cores with rot or unclear ring boundaries, we obtained 70 cores from 35 trees.

In the laboratory, we processed samples following standard dendrochronological procedures. Cores were mounted in wooden slots with glue, air-dried, and sanded with progressively finer sandpaper (400–800 grit) until ring boundaries were clearly visible under a microscope. Ring widths were measured using a LINTAB measuring system with 0.001 mm precision. Cross-dating accuracy was verified using the COFECHA program. We removed growth trends from raw ring-width series using negative exponential or linear regression, and eliminated autocorrelation using autoregressive models in the ARSTAN software. This produced three types of chronologies: residual (RES), standard (STD), and autoregressive (ARS). Because the residual chronology retains high-frequency climate signals most suitable for climate-growth analysis, we selected it for subsequent analyses (Fig. [Figure 2: see original paper]).

2.3 Meteorological Data We used climate data from the nearest Jingtai Meteorological Station (37.11°N, 104.03°E, 1627 m), located 64.4 km from the sampling site, covering 1957–2018. Variables included monthly mean temperature, mean minimum temperature, mean maximum temperature, total precipitation, and PDSI (Fig. [Figure 3: see original paper]). Given that tree growth responds to climate with potential lag effects, we analyzed meteorological data from May of the previous year through July of the current growing season to identify the primary climatic constraints on radial growth.

2.4 Statistical Analysis We calculated Pearson correlation coefficients between the tree-ring width residual chronology and monthly climate factors using SPSS 25.0. After identifying the dominant climate factor, we developed a linear regression model for reconstruction. The reconstruction' s stability and reliability were assessed through split-sample validation using multiple metrics: correlation coefficient (r), reduction of error (RE), coefficient of efficiency (CE), sign test, and F-test [**?**]. We performed multi-taper spectral analysis on the reconstructed sequence to identify periodicities and conducted spatial correlation analysis with CRU gridded temperature, precipitation, and PDSI data (1872–2017) using the KNMI Climate Explorer.

3. Results

3.1 Chronology Statistics Statistical analysis of the 164-year tree-ring width chronology (Table) showed high signal-to-noise ratio (SNR = 31.91) and sample explained variance (EPS = 0.97) exceeding the minimum threshold of 0.85, indicating high chronology quality. High mean sensitivity (MS = 0.20) and standard deviation (SD = 0.24) demonstrated strong climatic sensitivity. High inter-series correlations (Rbt = 0.53) and mean correlation among all radii (Rbar = 0.49) indicated coherent growth patterns and strong common climate signals. The first principal component explained 48.7% of total variance. With SSS > 0.85, the chronology is reliable for dendroclimatic analysis beginning in 1872.

3.2 Climate-Growth Relationships Correlation analysis revealed that tree-ring width correlated significantly with PDSI from May to July of the current year (r = 0.621, P < 0.001) and with previous September PDSI (r = 0.360, P < 0.01) (Fig. [Figure 4: see original paper]). The strongest relationship occurred with current-year May–July PDSI (r = 0.621, P < 0.001), confirming that early-growing-season drought is the primary constraint on radial growth. The correlation coefficient exceeded the 0.269–0.605 range for significance at P < 0.01, meeting reconstruction criteria.

3.3 Reconstruction Model and Validation Based on the strong relationship between tree-ring width and May–July PDSI, we developed the following linear regression model:

$$\mathrm{PDSI}_{5-7} = 5.177 \times \mathrm{RES} - 5.094$$

where RES is the tree-ring width residual chronology. The model explained 38.6% of variance ($R^2 = 0.386$, P < 0.001). Split-sample validation (Table) showed stable performance across calibration (1957–1987) and verification (1988–2018) periods, with correlation coefficients of 0.64 and 0.60, respectively. Positive RE (0.38) and CE (0.35) values, significant sign tests, and F-test results (P < 0.01) all confirmed the reconstruction' s reliability.

3.4 Reconstructed Drought-Wet Variations The 146-year PDSI reconstruction (1872–2017) revealed frequent fluctuations (Fig. [Figure 6: see original paper]). The lowest PDSI value (-4.29) occurred in 1917, while the highest (2.33) occurred in 1984, yielding a range of 6.62. Using PDSI thresholds of $±0.5 $ and $±1 , *weidentifiedextremewetyears*(*PDSI* > 1)*in*15*instances*(10.3 $) in 14 instances (9.6% of years), including 1929, 1936, 1969, 1975, and 2015. Dry and wet periods were defined as consecutive years exceeding $±0.5 $. The reconstruction identified four major dry periods: 1882–1894, 1915–1936, 1966–1978, and 1989–2015, with the 1915–1936 drought being the most prolonged (Table).

3.5 Spatial Representativeness and Forcing Factors Spatial correlation analysis with CRU gridded data (1872–2017) showed that our reconstruction correlates best with PDSI in the Qilian Mountains region (r = 0.46, P < 0.01), and moderately with precipitation across Northwest China, Mongolia, and eastern Kazakhstan (Fig. [Figure 7: see original paper]). Correlations with temperature were strongest over the Indian Ocean, eastern Atlantic, and western Pacific, indicating broad-scale climate teleconnections.

Multi-taper spectral analysis identified significant periodicities (P < 0.01) at 2.6–3 years and 8–8.6 years (Fig. [Figure 8: see original paper]). The 2.6–3 year cycle aligns with ENSO periodicity (2–7 years), which influences precipitation in Gansu Province and consequently affects drought conditions and tree growth in the Tengger Desert region. The 8–8.6 year cycle corresponds to the 11-year solar cycle, suggesting solar activity also drives regional climate variability.

4. Discussion

Tree rings serve as crucial archives for paleoclimate research, enabling both historical climate reconstruction and future climate prediction. In Changling Mountain, tree growth occurs primarily during May–July, with earlywood formation in May–June accounting for most annual ring width. Our correlation analysis confirms that drought during this critical growth period most strongly limits radial growth. The negative correlation with temperature and positive correlation with precipitation during these months further demonstrate drought stress as the primary growth constraint [?]. Physiologically, severe early-growing-season drought inhibits cambial cell division and photosynthate accumulation, thereby restricting radial growth.

Our reconstruction shows four major dry periods over 146 years. Comparing with regional studies, these dry periods correspond well with precipitation reconstructions from the southern Qilian Mountains [?] and Gansu Province [?], validating our results. The 1915–1936 drought aligns with dry phases identified in the eastern Qilian Mountains [?], while the 1989–2015 period matches the intensified aridity in Northwest China since the 1920s [?]. The reconstruction also corresponds with drought-wet variations in the Lenglongling Mountains [?], confirming its regional representativeness.

The increasing PDSI trend since 1989, concurrent with global warming, suggests that rising temperatures in the Tengger Desert region have exceeded the minimum temperature threshold for optimal tree growth, subjecting *Picea crassifolia* to intensified drought stress. Despite the regional shift from warm-dry to warm-wet conditions, radial growth remains drought-limited. Continued warming may further impact forest health, as evidenced by the declining trend in tree-ring widths since 2000. Enhanced monitoring and management strategies are needed to maintain ecosystem stability.

Periodic analysis revealed 2.6–3 year and 8–8.6 year cycles. The 2.6–3 year cycle closely matches ENSO periodicity (2–7 years), which significantly influences Gansu's precipitation and thus drought conditions in the Tengger Desert margin [?]. The 8–8.6 year cycle aligns with the 11-year solar cycle, indicating solar activity as another climate driver. These periodicities confirm that Changling Mountain' s climate responds to both regional and global-scale forcings.

5. Conclusions

1) Drought during the early growing season (May–July) is the primary climatic factor controlling radial growth of *Picea crassifolia* in Changling Mountain on the southern edge of the Tengger Desert.
2) The region experienced four major dry periods (1882–1894, 1915–1936, 1966–1978, and 1989–2015) over the past 146 years, with the early 20th-century drought being the most severe and prolonged.
3) Significant periodicities of 2.6–3 years and 8–8.6 years indicate that ENSO

and solar activity are the main drivers of drought-wet variations in the study area.

These results provide a scientific foundation for understanding historical drought-wet patterns in Northwest China and predicting future changes in subalpine forest ecosystems under global warming scenarios.

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Note: Figure translations are in progress. See original paper for figures.