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# Growth dynamics and drought impact on *Quercus macrolepis* trees from southwestern Albania

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## Abstract

Trees in the Mediterranean region are facing high growth variability and increased drought stress. Investigation of these issues is critical to understand species-level responses to altered climatic conditions. In this study it was explored the growth variability of *Quercus macrolepis* trees from southwest of Albania. Growth variables such as height, diameter at breast height, crown area, age, sapwood and inter annual radial growth (earlywood, latewood and tree-ring widths (TRW)) were measured. Basal area increment (BAI) and growth change using a 5 and 10-year window were calculated based on tree-ring width data. Regression analysis was performed between growth variables to figure out the relationship among them. Correlation analysis was employed to assess the drought impact (standardized precipitation index) calculated at cumulative time scales (1-24 months) on radial growth (TRW and indexed BAI (iBAI) of the studied species. The growth variables showed high variability among trees and strong significant positive relationship with each other. Several periods of growth change were identified considering the 5 and 10-year window, principally due to human disturbances. Significant positive response to drought index were observed for both TRW and iBAI, mostly during summer months at cumulative time scales >4 months. TRW showed higher and longer response to drought index as compared to iBAI. These results are crucial to understand the vulnerability of *Quercus macrolepis* radial growth to increased drought stress in the region and to apply adequate management strategies to mitigate future effects of changing climate conditions on tree growth.

**Keywords**: *Quercus macrolepis*; tree growth variability; disturbances; drought impact.

## 1. Introduction

*Quercus* forests, spread all over the Mediterranean region, are considered highly valuable due to the ecosystem services they provide including air and water quality, carbon sequestration, soil formation and protection, ecotourism, etc. [5]. They are also an important component of flora in Albania as there are found 12 *Quercus* species in the country which cover about 31% of the total forest area [12]. *Quercus* forests constitute a significant resource for the economy of the country not only because they serve as a source of timber but also for the high nutritive values of their leaves and acorns for the animals. This is the case of *Quercus macrolepis* Kotschy (Valonia oak) stands located in southern Albania which were considered highly valuable in the past due to the socioeconomic benefits they provided for the local communities. Consequently, they have been managed and transformed over time through their use for tannins extraction and fuelwood but nowadays are mostly used for pruning and animal grazing. Forest disturbance events related to anthropogenic or natural factors can be investigated and understood when reconstructing historical growth variability from the tree ring series [8]. Forest disturbances affect stand structure, species composition and threaten the sustainability of forests ecosystems [22]. The frequency and intensity of disturbance events affects the forest growth and dynamics, regeneration of trees, sustainability and spatial distribution of forest resources [3]. Several studies have emphasized the role of climate change in the recent intensification of forest disturbances [22,27]. According to these authors, drier conditions facilitate the spread of forest fires, droughts, the expansion of pathogens and pests, the increase in wind velocity which in turn affects the dynamics of forest growth. The changing climate conditions in the Mediterranean region and particularly South Eastern Europe characterized by warmer and drier climate, associated with increases in the frequency and severity of drought events [7,20], may compromise tree health and survival of *Q. macrolepis* forests in Albania, leading to reduced tree growth and mortality events. Increased rates of tree mortality events have recently been reported for many forest ecosystems and have been associated with the temperatures increase, drought and extreme climatic events [2]. As a matter of fact, growth of *Q. macrolepis* trees and other deciduous oak species is determined to a large extend by climatic variations particularly summer temperature and rainfall amounts [1,9]. The investigation of tree growth responses to water shortages quantified by multi scale drought indexes is essential to identify the time and season when drought affects the tree growth [26]. Tree growth responses to drought are time-dependent due to the physiological and anatomical strategies of trees in dealing with drought [21,26]. Therefore, it is essential to properly consider and quantify drought duration, severity and the season in which drought stress occurs when dealing with tree growth responses to drought. The Standardized Precipitation Index (SPI) has proven to be useful in capturing the delayed growth response to drought stress because it can be obtained at different time scales allowing the determination of duration, magnitude and intensity of droughts [26]. Understanding how *Quercus* forests respond to drought events in disturbed landscapes is fundamental to mitigate the consequences of aridification on Mediterranean oak forests ecosystems and predict their vulnerability to changing climate conditions in the future. This becomes particularly important for Albania as *Quercus* forests are distributed in areas with high climatic variability and intensively managed (acorn collection, pruning, overgrazing, wildfires and illegal cutting) along with their history [12]. This is also the case of the studied *Q. macrolepis* stand which grows in an area with pronounced summer drought in southwest of Albania. This stand constitutes a good case for reconstructing disturbance chronology to retrace development history as well as investigate the influence of drought stress on tree growth. The objectives of this study were to: (1) describe the variability of basic tree growth parameters in *Q. macrolepis* trees from southwest Albania (height, dbh, crown area, sapwood, earlywood width, EW; latewood width, LW; tree-ring width, TRW; basal area increment, BAI) and investigate their relationships, (2) detect the disturbance events by means of tree rings and identify the stand development patterns, (3) investigate the response of radial growth increment (TRW; iBAI) to drought index SPI.

## 2. Material and Methods

### *2.1. Study area*

The forest stand considered in this study is located in Porto Palermo (40°04’51”N; 19°46’39”E), district of Vlora, in southwestern Albania. The site is located on very steep slopes (53%), west aspects and 200 m a.s.l. The area is under the influence of Mediterranean climate, characterized by hot (dry) summers and mild (wet) winters. The soil type is regosol lying on limestone substrate and characterized by weakly developed mineral soil and low water holding capacity [14].The overstory vegetation is dominated by pure stand of *Quercus macrolepis* Kotschy (Valonia oak) accompanied by rich understory vegetation composed mostly of herbaceous species such as *Asparagus acutifolius* L., *Cirsium arvense* (L.) Scop., *Phlomis fruticosa* L., *Dittrichia viscosa* (L.) Greuter, *Rubus ulmifolius* Schott, *Hieracium* sp., *Iris* sp., etc.

### *2.2. Field sampling and dendrochronological methods*

In autumn 2015, 15 dominant *Q. macrolepis* trees were randomly selected and two radial cores were extracted (perpendicular to the slope) at breast height from opposite sides of each tree using a Pressler increment borer. At the stand we recorded elevation, aspect, slope, and GPS coordinates. In addition, for each tree were recorded the diameter at breast height (dbh), the height, the crown radius and evaluated the age. All wood samples were prepared following standard dendrochronological methods [16]. They were air dried, mounted and sanded with sandpapers until tree-rings were clearly visible with a binocular microscope. They were visually cross-dated and the earlywood (EW), latewood (LW) and tree-ring (TRW) widths were measured to the nearest 0.001 mm using a stereomicroscope and a LINTAB measuring device (Rinntech, Heidelberg. Germany). The accuracy of visual cross-dating was evaluated with the COFECHA program, which calculates cross correlations between individual series of each core and a master chronology, obtained by averaging all measured series at each site [19]. The climatic signal of each cross-dated TRW series was obtained using a double detrending and a standardization procedure incorporated in Arstan software [10]. Each TRW series was detrended using firstly negative linear or exponential functions and secondly cubic smoothing spline functions with 50% frequency response of 32 years to reduce non-climatic variation [11]. Temporal first-order autocorrelation was removed on each detrended TRW series by using autoregressive modelling. The indexed pre-whitened residual TRW series of all trees were then averaged using a biweight robust mean to obtain mean site residual chronologies of tree-ring width. The raw tree ring width series were converted to basal area increment (BAI) using the following formula:

$$BAI = \pi r_n^2 - \pi r_{n-1}^2$$

where r is the radius of the tree-ring width in a given year and n is the year of tree-ring formation. BAI series were pre-withened using a first-order autoregression process to normalize the variance [17]. This procedure keeps the low-frequency variability of growth integrated with climatic conditions and removes the age-related growth trends. Standardized series of indexed BAI (iBAI) and TRW were used for further statistical analysis.

### *2.3. Drought index calculation*

The drought index SPI was calculated based on monthly precipitation series obtained from the global Climatic Research Unit (CRU) TS3.24.01 dataset (http://climexp.knmi.nl/) for the period 1930–2015 [18]. We considered the 0.5º-resolution grids of this dataset covering the study site (lat = 40.0–40.5N, long = 19.5–20.0E). The precipitation series were accumulated for several months starting from the current month and adding the preceding months up to a certain time scale (i.e. 1–24 months) [23]. The cumulative series were standardized using the Pearson Type III distribution, because it adapts well to the precipitation series at all time scales. The output is the drought index SPI with a mean value of 0 and standard deviation of 1. A SPI of 0 indicates precipitation corresponding to 50% of accumulated probability according to the Pearson Type III distribution. The complete method for SPI calculation, including the Pearson Type III distribution and L moments method for calculating parameters is described by [29].

### *2.4. Analysis of stand disturbances*

To detect releases in radial growth series we used the percent growth changes in yearly increments between intervals in average growth prior and past each year [25]. Growth change (GC) was calculated annually across the individual tree ring series using 5-year and 10-year windows.

$$\%GC = \left(\frac{(G_2 - G_1)}{G_1}\right) \times 100$$

where %GC = percentage growth change between preceding and subsequent 5(10)-yr means, $G_1$ = preceding 5(10)-yr mean and $G_2$ = subsequent 5(10)-yr mean.

Using adequately long intervals to calculate $G_1$ and $G_2$ filters out short-term climate-related responses and eliminates the need to adjust for age-related trends while allowing for detection of disturbance-related releases [25]. The two disturbance chronologies, using 5-year and 10-year windows were constructed by averaging GC annually. The resulting %GC is then compared to a predetermined threshold. Release events were identified as periods when the percent growth change exceeded 25% (moderate) or 50% (major) of the five (ten) -year preceding and superseding mean. This process excludes the first and the last five (ten) years of each series from the analysis as this method requires a five (ten) -year window prior and subsequent to each individual growth ring analyzed. Release signals in the tree rings of the collected samples were considered to be the main indicators of past disturbances [25].

### *2.5. Satistical analysis*

Linear regression analyses were employed to investigate the relationships among the growth variables considered in the study. The Pearson correlation coefficient (*r*) was used to identify the impact of drought severity on tree radial growth. In particular, correlation analysis were performed between the drought index SPI and the radial growth residual chronologies of TRW and iBAI, for the period 1930–2015. Prior to assess the drought-growth correlations, the trend in each SPI time series was removed by fitting a linear tendency in each monthly series at the different time scales [26]. This step avoided that possible SPI trends could disrupt potential relationships. The statistical analyses were performed in SPSS 20.0 (SPSS, Chicago, USA).

## **3. Results and Discussion**

### *3.1. Tree growth variability and dynamics*

Generally, all growth variables showed high variability among the sampled trees (Figure 1). However, higher growth variability was observed in the case of height, crown area and tree ring width as compared to earlywood, latewood, dbh and sapwood variables which showed somehow lower variability. The age of trees also varied considerably among the sampled individuals. The mean tree ring width and BAI series showed high inter annual growth variability probably related to climatic and site conditions, and stand management (Figure 3). The mean tree ring width was particularly high during the first 40 years of the forest stand, followed by a period of decreasing radial growth up to the years 1960 where the growth turns to increase again. A reverse growth pattern was observed in the case of BAI which was characterized by an increasing trend for all the study period.

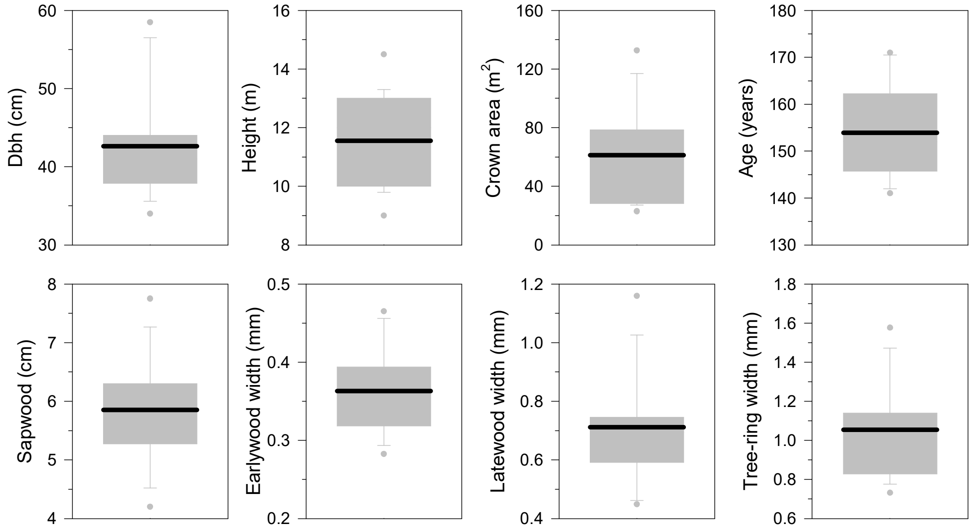

**Figure 1**. Variability of age, tree and radial growth features. Black lines in box plots correspond to mean values. Abbreviations: Dbh – diameter at breast height.

### 3.2. Growth variables relationship

Regression analysis indicated significant relationships among the growth variables (Figure 2). Strong and significant positive associations were observed particularly between dbh and earlywood width, dbh and crown area, tree ring width and earlywood width, tree ring width and latewood width, tree ring width and crown area, and sapwood and earlywood width.

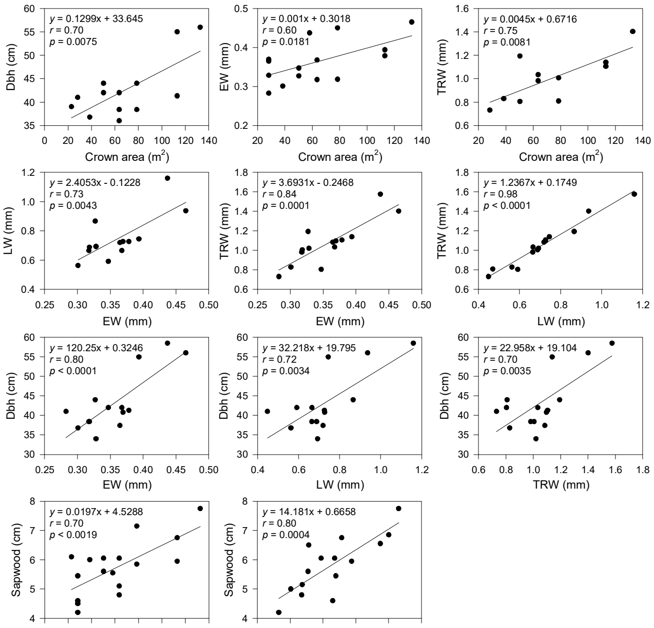

**Figure 2**. Relationships between the studied growth variables. Abbreviations: Dbh – diameter at breast height; EW – earlywood width; LW – latewood width; TRW – tree-ring width.

The strong positive relationship among the crown area and radial growth variables indicates that the increased canopy growth (e.g., shoot extension, leaf production) leads to higher photosynthetic activity causing an increase in cambial activity, hydraulic conductivity and radial growth [24,28]. Positive relationships were also observed among the other variables but somehow weaker as compared to the above mentioned associations.

### *3.3. Radial growth release/suppression*

Growth change analysis identified several periods that could represent disturbance episodes (suppression/release pulses) in the studied stand (Figure 3). Both 5 and 10-year period considered for disturbance detection produced almost the same pattern of growth release/suppression with small differences in the frequency of disturbances. Based on 10-year intervals, one time period (1993-1998) was identified for *Q. macrolepis* stand representing moderate growth release and two periods (1858-1865; 1887-1890) showing high growth suppression, whereas the 5-year interval showed a higher number of periods characterized by moderate growth releases (1851-1854; 1911-1915; 1944-1945; 1995-1998) and growth suppressions (1858-1862; 1887-1990; 1950-1952) as compared to the 10-year interval. We lacked detailed long-term historical data of the site that can be used to explain the past disturbance events but the interviews with employees/managers of the Forest District associate growth releases/suppressions with specific forest management practices (thinning, pruning to stimulate acorn production, etc) and other community activities (fuelwood, pruning for animal nutrition, grazing, human-set fires etc.) which were particularly intense during the ‘90s. Such anthropogenic disturbance allowed for growth release events taking place afterwards as tree radial growth recover or benefit from better growth conditions such as reduced stand density and lower competition [8]. The suppression events observed in the growth of *Q. macrolepis* stand could be due to competition for light, soil, water resources, climate/drought and other environmental factors which, combined with human impact, can increase the intensity of the ongoing disturbances [22]. As a matter of fact, the study area is characterized by pronounced summer droughts which have negatively affected tree radial growth of *Q. macrolepis* [1].

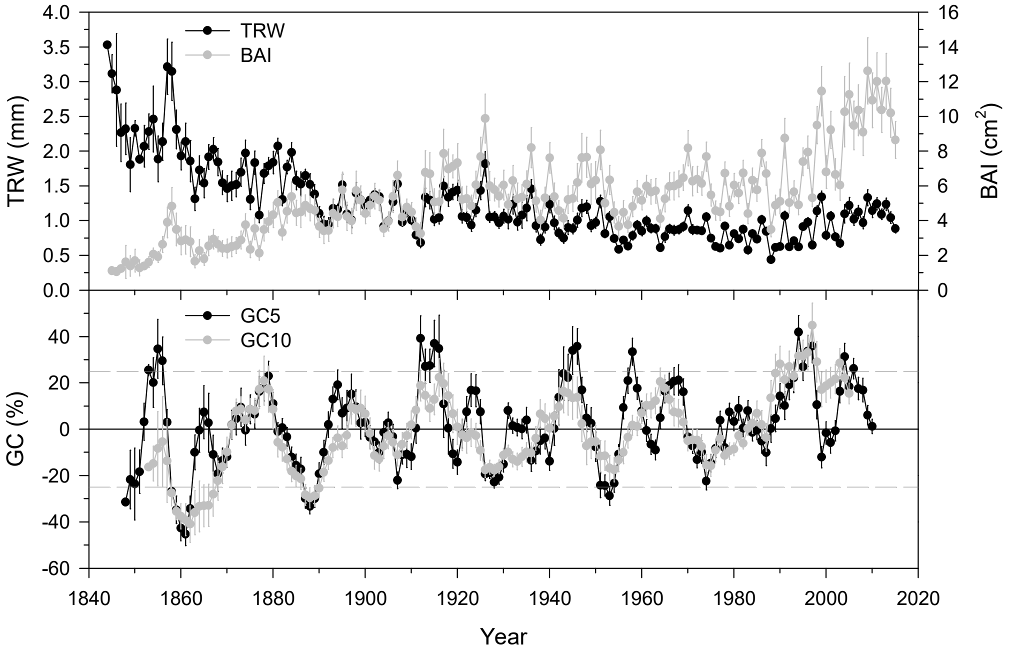

**Figure 3**. Mean chronologies of tree-ring width (TRW), basal area increment (BAI) and growth changes (GC) calculated annually using 5-year and 10-year windows.

The two radial growth variables (residual TRW and iBAI) were useful for identifying the drought impact on tree radial growth (Figure 4). Both residual TRW and iBAI showed significant positive response to the SPI drought index but the strength of response was different for each of them. The residual TRW series responded significantly to SPI up to 18 months cumulative time scale, showing the highest association at the time scale of 6 months in June ($r = 0.44$, $p < 0.0001$). iBAI demonstrated lower responsiveness to drought index SPI as compared to residual TRW but significant at cumulative time scales of 2–18 months. The highest correlation values of iBAI with SPI drought index were achieved at the time scale of 7 months in July ($r = 0.36$, $p = 0.0002$). BAI or ring area is a better representative of tree radial growth than TRW as it was shown to outperform TRW for evaluating overall tree growth and the response to drought stress [4,13]. Therefore, BAI provides a more reliable growth variable to identify responses to drought index SPI whereas the TRW seems to overestimate the drought impact on tree radial growth.

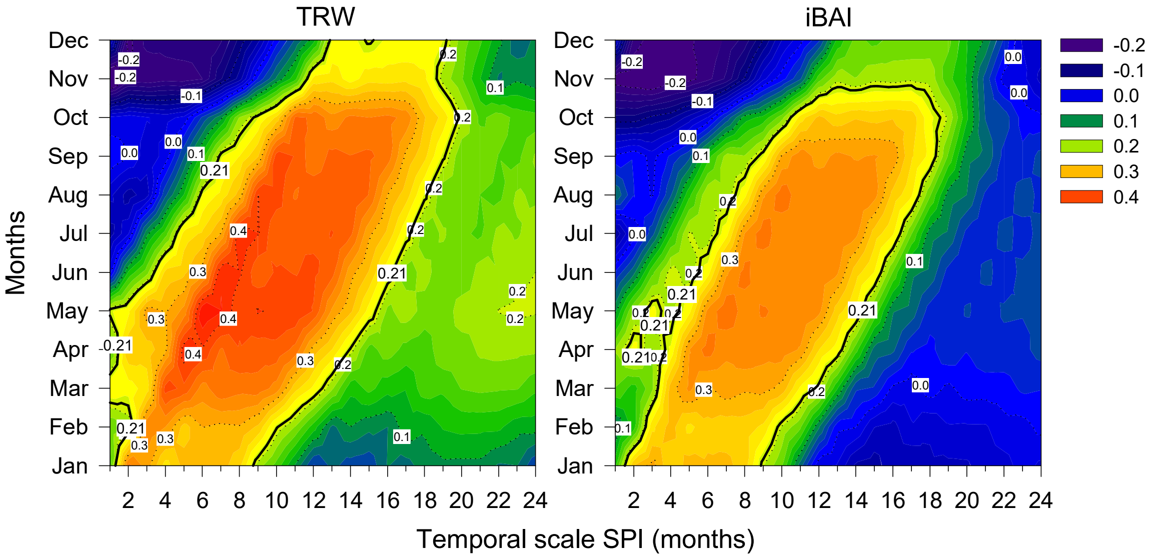

**Figure 4**. Response of radial growth (tree-ring width, TRW; basal area increment, BAI) residual chronologies to monthly Standardized Precipitation Index (SPI) series at cumulative time scales during the period 1930-2014. Bold black solid lines frame significant correlations ($P < 0.05$).

In general, *Q. macrolepis* growth showed great dependence on accumulated precipitation amounts (i.e. 5–8 months) particularly during summer months. This suggests that summed precipitation amounts in summer are essential for capturing the response of radial growth to drought stress at cumulative time scales [26]. Drought stress in early summer, when tree growth is high, affects negatively tree-ring widths as it reduces the xylem cell production, water conductivity and subsequent radial growth. *Q. macrolepis* trees showed low growth response to short-term drought conditions (i.e. < 4 months) but high responsiveness to the mid-term accumulated precipitation deficit. This indicates that although *Q. macrolepis* is a drought resistant species [15] which compensate for the short-term water shortages it may show functional growth thresholds in response to lasting and severe drought leading to growth decline.

## 4. Conclusions

We conclude that *Q. macrolepis* trees demonstrated pronounced growth variability in all variables considered in the study. The growth variability and dynamics was highly affected by drought stress and most likely by other factors related to site conditions and management/human disturbance the area was subjected to. All this factors have shaped the tree radial growth patterns in this forest stand. Accumulated precipitation conditions (5-6 months) appeared to be important for *Q. macrolepis* trees by exerting a high impact on radial growth in this forest stand. The predicted warming conditions for the South Eastern Europe [7] will likely pose severe threats to this species, triggering the tree radial growth decline. Therefore, the information provided in this study should be useful to undertake the appropriate measures to mitigate the impacts of drought and disturbances on *Q. macrolepis* stands.

## 5. References

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