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Original Article

Climate-Growth Relationships in Managed and Unmanaged Kazdağı Fir Forests

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ABSTRACT

Climate change can affect tree growth, stand productivity, and tree mortality. The sensitivity of tree species to the changing climate may vary in managed and unmanaged forests. Thus, the main objective of this study was to examine whether the effects of climate vary in managed and unmanaged Kazdağı fir (*Abies nordmanniana* subsp. *equi-trojani*) forests in northern Turkey. Individual tree-ring chronologies from the managed and unmanaged forests of the species were used. Results indicated significant effects of climate (i.e., the standardized precipitation-evapotranspiration index (SPEI)), and forest type (i.e., managed and unmanaged) on radial growth of Kazdağı fir trees ($p < .05$). Trees in the unmanaged forest exhibited a lower radial growth rate and a higher sensitivity to climatic conditions compared to the managed forest. This can be associated with the reduced tree density following silvicultural treatments, which result in increased resource availability to the remaining trees in the managed forest. Initial findings would create a basis for future decisions that aim to enhance the resistance of Kazdağı fir forests against the future climate extremes of the region. Long-term monitoring is needed to observe the effects of forest type on the response of Kazdağı fir trees to the climate over time.

Keywords: Abies, drought, global warming, radial growth, silviculture

Introduction

Projections of future climate forecast higher drought intensity and frequency across the world including Turkey (Hepbilgin & Koç, 2019). Forests are known to be sensitive to the changes in climate because trees' adaptations to environmental changes are usually difficult. Studies regarding the climate effects on forest ecosystems have revealed that changes in climatic conditions and frequent incidents of climate extremes such as droughts can affect tree growth, stand productivity, and tree mortality (Frelich et al., 2015; Kunz et al., 2018; Pederson et al., 2014). Recently, enhancing the resistance and resilience of forests against the effects of global climate change has gained recognition by the scientists (Fadrique et al., 2018).

Response of forest trees to changing climate may vary depending on several factors such as tree species, species mixture, stand structure, and management history (McDowell et al., 2008; Pretzsch et al., 2013; Rubio-Cuadrado et al., 2018). Several researches have revealed that some silvicultural treatments such as stand thinning can mitigate the impacts of climatic extremes on tree growth (Linder, 2000; Sohn et al., 2016), while some studies pointed out that reducing stand density and stand complexity may result in increased susceptibility of trees to drought (Clark et al., 2016; Jones et al., 2019). Moreover, some studies have found that the sensitivity of tree species to the changing climate may vary depending on the management type and management history of forests (Bosela et al., 2016; Mausolf et al., 2018). Thus, these previous studies highlight the remaining uncertainty in our knowledge of the relationships between forest management and climate.

As severe and long-period of droughts due to global climate change have been monitored across the world for the last 50 years (IPCC, 2007), the mean annual precipitation has decreased while the mean annual temperature has increased for the last 40 years in northern Turkey (Bolat et al., 2017). Recurring drought events have historically been limited in this region. However, the concern of scientists over the future of trees has increased given

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the recent changes in climate as well as the projected climate scenarios (Hepbilgin & Koç, 2019). Kazdağı fir (*Abies nordmanniana* subsp. *equi-trojani*), which is one of the most economically and ecologically important tree species of the country, is considered a drought intolerant tree species (Kara & Lhotka, 2020a). Since increasing drought can likely result in a growth decline in trees (Martin-Benito et al., 2018), Kazdağı fir may also be threatened by the changing climate in northern Turkey (Köse, 2012).

Current researches regarding the influence of climate change on different tree species and different forest types (i.e., managed and unmanaged) have been limited (Mausolf et al., 2018; Sohn et al., 2016). Relevantly, the effect of forest type on the influence of climatic conditions has not been well documented for Kazdağı fir forests. Thus, it is apparent that the foundational climate-growth relationships in managed and unmanaged Kazdağı fir forests need to be quantified so that better management strategies could be promoted to reduce the impacts of the increasing climate warming in these forests. Therefore, in this study, the main objective was to examine the effects of climate on the radial growth of Kazdağı fir trees in northern Turkey. Moreover, the study also aimed to compare the influence of the climate in managed and unmanaged Kazdağı fir forests. It was hypothesized that the response of Kazdağı fir trees to climate may vary in different forest types.

Methods

Study Area and Design

The unmanaged and managed forests of Kazdağı fir were selected within the Regional Forestry Directorate (RFD) in Kastamonu city, northern Turkey (Figure 1). The study area is located within the natural distribution range of Kazdağı fir on the transition zone between the Black Sea climate and the continental climate of Turkey exhibiting colder winters and rainy summers The average annual temperature and average total annual precipitation of the study area are 5.2°C and 1080 mm, respectively. The growing season in the area lasts about 137 days between April and August. The average slope varies between 12 and 60% across the study area. Brown forest soil is known to be the dominant soil group, and soil depth is generally moderately deep, ranging from 50 to 90 cm. Brown forest soils develop on the main material with high lime content. The main ingredients are mostly lime-rich clay stones, mica schists, and gneiss. The elevation ranges from 1200 to 2100 m in the study area.

Apart from Kazdağı fir, Scots pine (*Pinus sylvestris* L.) is the other dominant tree species within the study area. Other tree species that can be found are black pine (*Pinus nigra* Arnold.), Oriental beech (*Fagus orientalis* Lipsky.), and oaks (*Quercus* spp.). Common understory species are common juniper (*Juniperus communis* var. *saxatalis* Pall.), mastic tree (*Pistacia lentiscus* L.), tree heath (*Erica arborea* L.), common hazel (*Coryllus avellana* L.), Cornelian cherry (*Cornus mas* L.), and blackberry (*Rubus fruticocus* L.).

The unmanaged forest has an area of about 1.100 ha, and no silvicultural disturbances have been conducted since the early 1970s within the forest. Small scale disturbances caused by bark beetles, snow, and wind damage likely occur. It should be noted that stands within the unmanaged forest were overstocked, and no sign of any large-scale over story disturbance was present where our study plots were located. Thus, it is likely that natural stand dynamics prevail within the unmanaged forest for the last 50 years. The managed forest with an area of about 9.000 ha has been mainly managed for timber production under the selection silvicultural method. A 10-year cutting cycle and target diameter of 52 cm at breast height (DBH) has been used in the managed forest. It should be noted that both forests were located in the same district (Figure 1), and thus, almost identical climatic and soil conditions were present in both forests. In each forest type (i.e., unmanaged and managed), thirty 100-m^2 square study plots were randomly installed in 2018 at an elevation of 1800s m. Moreover, the study plots were located on similar aspects (northern and north-eastern aspects) within the study area in order to eliminate the influence of aspects on the response of trees to climate. Although mixed stands were present within the study area, study plots were located only within the pure stands of Kazdağı fir.

Measurements and Tree-Ring Analysis

DBH (centimeter) of trees larger than 5 cm were measured in each study plot of both forest types using a diameter tape. Next, stand basal area (SBA) (m^2 ha^{-1}), quadratic mean diameter (QMD) (cm), and the number of trees per hectare (TPH) were calculated for each study plot (Table 1). Within each study plot, a dominant Kazdağı fir tree from the upper canopy was randomly selected, following Mausolf et al. (2018). We paid attention to select the cored trees in similar DBHs in managed and unmanaged forests (Table 1). However, the ages of the cored trees varied. Average ages of cored trees were 88 and 57 in unmanaged and managed forests, respectively. From each selected tree, one bark-to-pith wood core was extracted at 1.3 m height (DBH_{COR}), parallel to the contour lines, using an increment borer in November 2018. The wood cores were prepared following the standard methods.

Next, the wood core samples were air-dried, and their high-resolution pictures were taken using a Canon EOS 600D camera from the same

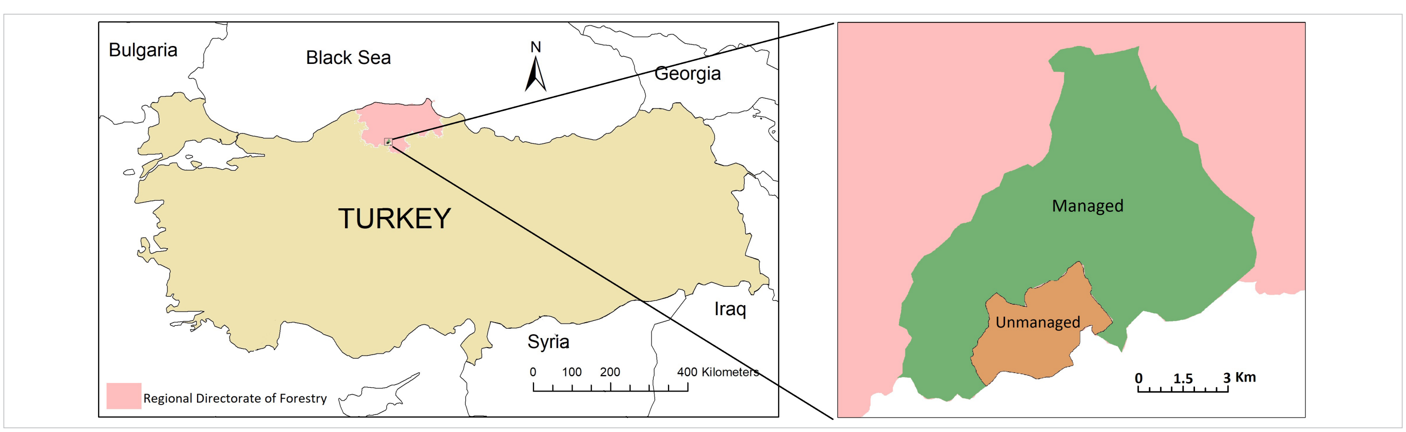

Figure 1.
Locations of Regional Forestry Directorate (RFD), Managed Forest, and Unmanaged Forest in Kastamonu, Turkey.

Table 1.
Descriptive Statistics for Unmanaged and Managed Kazdaği Fir Forests.

	Unmanaged Forest ($n=30$)				Managed Forest ($n=30$)			
Variables	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
SBA (m^2/ha)	69.4	123.8	98.8	14.8	26.2	75.3	49.4	16.7
TPH	500	1100	775	153.9	300	1025	596	121
QMD (cm)	35.1	50	40.6	3.6	29.9	44.3	39.9	4.8
DBH_{COR} (cm)	36.2	52.6	42.9	4.3	29.5	44.3	40.0	3.3

Note: SBA = stand basal area; TPH = trees per hectare; QMD = quadratic mean diameter; DBH_{COR} = diameter of cored trees; SD = standard deviation; n = number of study plots.

distance. A ruler was placed next to the cores to maintain the true scale while taking the pictures. The annual tree rings were visually cross-dated. The tree rings of each cored tree were measured to the nearest 0.01 mm using an image processing software, ImageJ (Rueden et al., 2017). Tree-ring analyses were concluded for the 1987–2017 period due to the climatic fluctuations in this period (Bolat et al., 2017). Moreover, this period was more relevant for the unmanaged forest since no forestry activities were done within the area since 1976.

Tree-ring width data of each tree chronology were standardized for minimizing the influence of tree age on the yearly growth rates, as suggested by Mausolf et al. (2018). First, we calculated the 5-year moving average of each chronology. Next, the tree-ring index (TRI) of each chronology was attained by dividing the measured tree-ring width by the 5-year moving average of the same year. It should be noted that a negative TRI refers to a growth decline, while a positive TRI indicates a growth stimulation (Mausolf et al., 2018).

Climatic Data

The effects of climatic conditions on radial growth were examined using the mean standardized precipitation/evapotranspiration index (SPEI), which is widely used to quantify the influence of droughts on tree growth for varying time scales (Vincente-Serrano et al., 2010). The 12-months SPEI was calculated for each year from 1987 to 2017, as well as for the previous year ($SPEI_{PRE}$) in the study. SPEI data were obtained using the "SPEI package" in R-Statistical software (Beguería et al., 2013). SPEIs were calculated utilizing measured monthly precipitation and calculated potential evapotranspiration (Bhuyan et al., 2017). The potential evapotranspiration was attained using the monthly mean temperature and a correlation coefficient obtained from latitude to compute day length (Thornthwaite, 1948). Negative SPEI values refer to periods with water deficit, while positive values of SPEI indicate climatic water balance (Mausolf et al., 2018). Negative SPEI values may usually refer to growth decline especially for drought-sensitive tree species (Mendivelso et al., 2014). We attained the climate data from the General Directorate of Meteorology for the study period. Climate data from the climatic station, which is located in close proximity to the study area, were limited covering only the years from 2014 to 2020. Thus, climate data were interpolated from a station located in Kastamonu using the Schreiber formula (Hepbilgin & Koç, 2019). The similarities of data from the stations for the 2014–2020 period suggested that the interpolated data were reliable.

Data Analysis

In order to examine whether the climate-radial growth relationships vary with forest type (i.e., unmanaged vs. managed), linear mixed-effects models were utilized at $\alpha=0.05$. In the mixed-effect models, TRI was used as the response (i.e., dependent) variable, while SPEI, $SPEI_{PRE}$, tree size (DBH_{COR}), tree age, SBA, forest type (i.e., unmanaged and managed) were used as the independent variables. In addition, all possible two-way interactions were included in the analyses. Study plots, which were also treated as the experimental units (i.e., replicates), were used as the random effect in the analyses. We also used the first-order temporal autocorrelation using the AR(1) structure in the analyses since it is a necessity with tree-ring chronology data (Zuur et al., 2009). The model fit process was started with all parameters mentioned above, and the parameters with *p*-values larger than $\alpha=0.05$ were sequentially removed from the model, and the model was refit following the removal of each insignificant variable. This process was repeated until only the variables with *p*-values greater than $\alpha=0.05$ were included in the model. In order to quantify the mean differences of the influence of forest type (i.e., unmanaged and managed) on TRI, Hedges' d effect size was utilized (Hedges & Olkin, 1985), which was calculated based on the observed TRI values (Mausolf et al., 2018). Koricheva et al. (2013) stated that Hedges' d of 0.2, 0.5, and 0.8 refer to small, moderate, and large effects, respectively. During all the analysis, R-statistical software (R Development Core Team, 2010) was utilized.

Results

The negative and positive trends in the annual SPEI series show drier and wetter conditions in this time period, respectively (Figure 2). In the study region, in general, the annual SPEI values at the 12-month time scale have indicated a fluctuating pattern (Figure 2). However, the regional annual SPEI showed that drought intensity, which refers to water deficit, has particularly increased in the last 5 years (i.e., 2013–2017) during the study period. This drought event seemed to be the largest within the last 30 years (Figure 2). Other major dry periods occurred in 1994–1996 and 2006–2008 periods. The wettest period was 2008–2012 during the study period.

The mean annual radial increment was significantly higher in the managed forest of Kazdağı fir than in the unmanaged forest ($p < .05$) (Figure 3). On average, the radial growth rate was 75% higher in the managed forests compared to the unmanaged forest during the last 30 years. The average radial increment in the unmanaged forest was 1.30 mm while it was 2.28 mm in the managed forest during the study period (i.e., 1987–2017) (Figure 3).

The best-fitting radial growth model included the effects of SPEI and the interaction between the management type and SPEI (Table 2). Thus, the sensitivity of Kazdağı fir trees to climatic conditions in a given year was associated with the SPEI of that year as well as the forest management type (Table 2). Model coefficients mean that TRI of Kazdağı fir trees in a given year in the unmanaged forest was more strongly associated with changes in the SPEI of the year than trees growing in the managed forest. The influences of SBA ($p=0.79$), tree size ($p=0.99$), and previous years' SPEI ($p=0.25$) were not statistically significant.

The Kazdağı fir trees in both forest types did not show a significantly decreasing trend in TRI during the study period (Figure 4). However, the TRI has particularly decreased in the last 5 years in the unmanaged forest (Figure 4). It should be noted that the highest water deficit has particularly increased in the last 5 years during the study period. Since positive TRI values refer to growth stimulation, there was no growth decline in both forest types in this study during the study period (Figure 4).

The average TRI values in unmanaged and managed forests for the wettest (i.e., 2008–2012) and driest (i.e., 2013–2017) periods were calculated based on the SPEI values during the study period (Figure 5). The

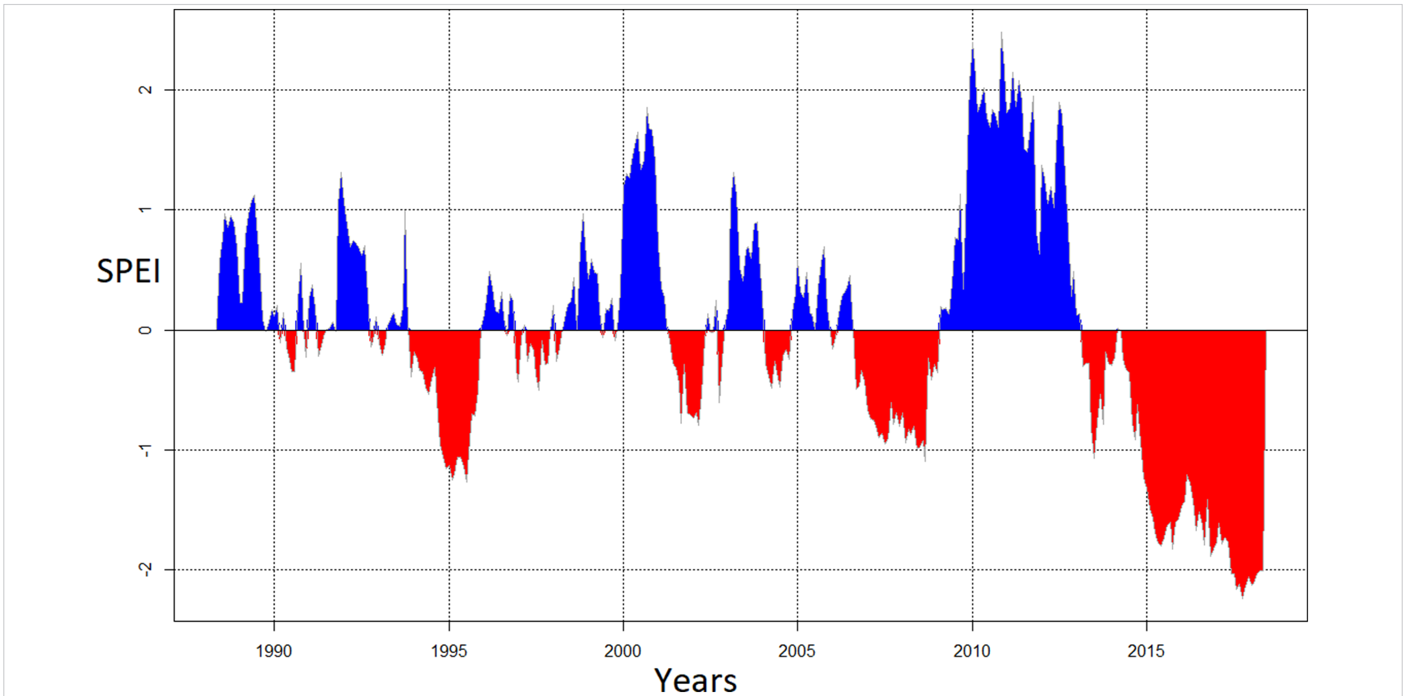

Figure 2.
Temporal Patterns of SPEI at the 12-Month Time Scale During 1987–2017 in the Study Area. Negative SPEI Values Refer to Periods With Water Deficit While Positive Values of SPEI Indicate Climatic Water Balance.

average TRI in the unmanaged forest from wet to dry period decreased by 9%, while it decreased by about 2% in the managed forest, indicating that unmanaged forest was more sensitive to increasing water deficit (Figure 5). However, the value of Hedges' d was found to be 0.31, which means that the differences between the effects of forest type (i.e., unmanaged vs. managed) on TRI was small during the droughts that occurred in the last 30 years.

Discussion, Conclusion and Recommendations

As forest management strategies aim to enhance forest ecosystems against future climate extremes, a better understanding of the relationships between forest management practices and trees' response to climate is needed. In this study, Kazdağı fir trees growing in the unmanaged forest seemed to be more sensitive to climatic variables

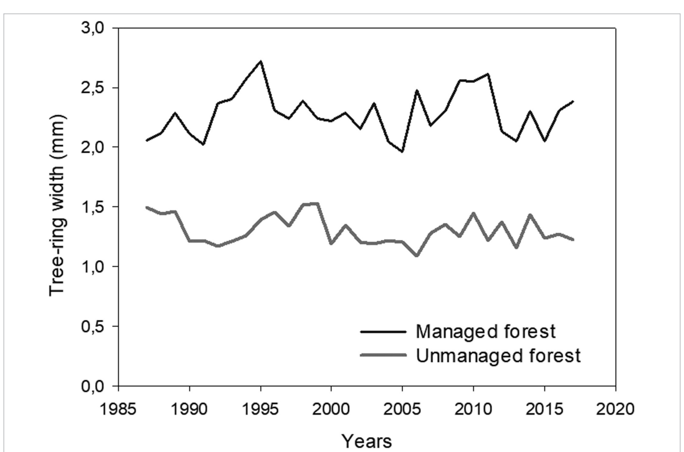

Figure 3.
The Mean Annual Tree-Ring Width at Unmanaged and Managed Forests of Kazdağı Fir.

than trees of the managed forest. This can be associated with the water status of remaining trees in the managed forests following the silvicultural treatments. Decreasing tree density following the treatments can likely reduce inter-tree competition for soil moisture and increase the resource availability to the remaining trees, and consequently mitigate the vulnerability of these forests to drought (Navarro-Cerrillo et al., 2019). Our finding is supported and consistent with the previous researches. Relevantly, Sohn et al. (2016) found that reduction in tree density improved the resistance and recovery of Scots pine stands following and during drought events. In another study, Lechuga et al. (2017) indicated that decreasing tree density could minimize climatic change effects on drought-sensitive fir species due to the increasing resource availability to the remaining trees following the treatments.

The managed Kazdağı fir-dominated forests mostly possess a reverse J-shaped diameter distribution exhibiting highly diverse age structure and compositional diversity, while the unmanaged forests are often less diverse in structure and composition exhibiting close-to-normal diameter distribution (Kara & Lhotka, 2020b). Structural complexity can play an important role in climate-growth relationships. Being consistent with our findings, Jones et al. (2019) found that stand structural diversity can mitigate the negative effects of drought on tree growth. In addition to stand structure, tree species mixture plays an essential

Table 2.
Regression Coefficients From the Mixed-Effects Model for Tree-Ring Index (Tri) of Kazdaği Fir.

Variables	Estimate	Standard Error	*p*
Intercept	0.996	0.007	<.001
SPEI	0.025	0.011	.026
Forest Type (UM) × SPEI	0.042	0.015	.005

Note: Intercept = response of the managed forests; UM = unmanaged forest.

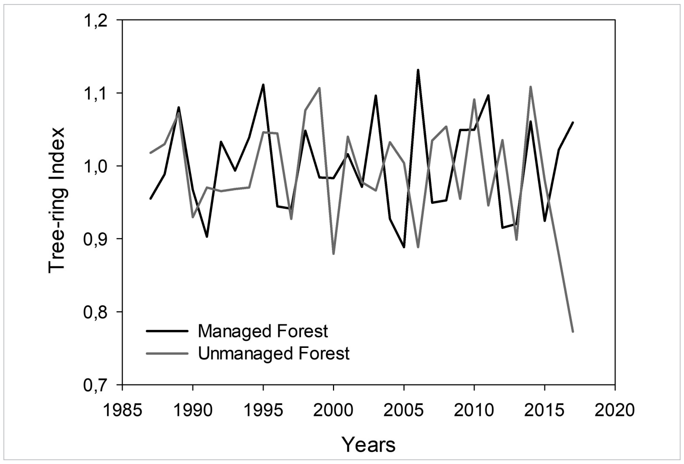

Figure 4.
Mean Tree-Ring Index (TRI) Between 1987 and 2017 in Unmanaged and Managed Forests.

role in species' response to drought as well. The overstory disturbances occasionally result in the introduction of other tree species of the region, such as Scots pine, black pine, Oriental beech, and oaks in the managed Kazdağı fir forests. Previous research stated that impacts of climate change are usually lower in mixed stands compared to pure stands (Pretzsch et al., 2017). Therefore, the contribution of other tree species to mixture following overstory disturbances may enhance the resilience of these forests against climate extremes expected in the region's future.

Our results showed that climatic conditions of the current year (i.e., SPEI) influenced the radial growth of Kazdağı fir trees while the effects of previous year's SPEI were not significant. Thus, it is likely that the tree-ring width of Kazdağı fir for a given year is mostly associated with the carbohydrates assimilated during that year. Kazdağı fir is identified as being relatively sensitive to drought (Hepbilgin & Koç, 2019); thus, high temperatures and low precipitations seem to be the main drivers for lower tree-ring width in given years. Relevantly, previous research has also found that tree-ring characteristics of firs are mostly related to spring and summer weather conditions of the current season (Martinez-Meier et al., 2008; Köse, 2012). Splechtna et al. (2000) stated that the mean August temperature of the current year had a significant

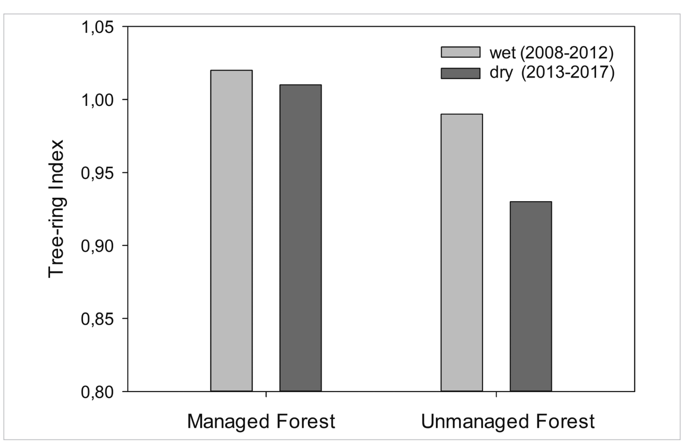

Figure 5.
The Average TRI Values in Unmanaged and Managed Forests for the Wettest (i.e., 2008–2012) and Driest (i.e., 2013–2017) Periods Are Based on the SPEI Values During the Study Period.

influence on the latewood formation of subalpine fir (*Abies lasiocarpa)*. In another study, Köse (2012) examined that temperature and precipitation of the current year mostly affected the tree-ring growth of Kazdağı in northern Turkey.

Although forest thinning and other silvicultural treatments that reduce tree density seem to play an important role in mitigating drought impacts, their role in the longer-term is still not well-understood. In a previous study, it was concluded that thinning could temporarily reduce the negative impacts of drought on forests, but, its efficacy to prevent a climate-change-induced dieback in the longer-term is insufficient (Elkin et al., 2015). Moreover, the effects of thinning used for enhancing the resistance of forests to drought may change over time. For example, lower resistance of thinned red pine (*Pinus resinosa* Ait.) forests compared to unthinned ones at older ages (76 years), and greater resistance of thinned forests at younger ages (49 years) were observed (D'Amato et al., 2013). Hence, previous researches point out the importance of evaluating adaptive management practices to mitigate the impacts of droughts in the longer-term (Elkin et al., 2015). Relevantly, future monitoring of the managed Kazdağı fir forests should be conducted to observe whether the response of trees to the changing climate will change over time in the managed forests.

Although unmanaged forests are considered to be more vulnerable to the changing climate (Sohn et al., 2016), some scientists have speculated that they have more potential to mitigate the impacts of climate change because they have a higher potential of carbon sequestration in dense live trees, deadwoods, and soil (Granata et al., 2019). Relevantly, Bosela et al. (2016) found that basal area increment of European beech (Fagus sylvatica L.) continues to increase in unmanaged forests while it has recently started to decline in its managed forests in Eastern Europe. Although interests in mitigating the effects of climate warming through forest management and afforestation have increased, recent studies have found that managed forests can contribute to climate warming rather than mitigating it (Naudts et al., 2016). Thus, better forest management strategies are recommended for mitigating the impacts of global warming while meeting human needs for wood products in managed forests (Noormets et al., 2015).

Relationships between climatic variables (i.e., SPEI) and radial increment of trees in unmanaged and managed forests of Kazdağı fir were examined in northern Turkey. Our data showed that management practices through selection silviculture could result in decreased drought sensitivity of the remaining trees in the managed forests. The study findings highlighted the importance of understanding how forest type interacts with the changes in climatic conditions. The assessment of the influence of climatic conditions on managed and unmanaged forests of Kazdağı fir would create a basis for future decisions that aim to enhance the resistance of these forests against the potential climate extremes of the region. Even though a reduction in stand density seemed to be an alternative practice to increase the trees' drought sensitivity in the managed Kazdağı fir forests, future monitoring is needed because the long-term influence of thinning against climate is unknown in these forests. Since trees' response to climate change can vary at different altitudes, future studies can examine the response of Kazdağı fir trees to climate at varying elevations.

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