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INFLUENCE OF CLIMATE AND ROOT ZONE SOIL WETNESS ON RADIAL GROWTH OF BLACK PINE (*Pinus nigra* Arnold subsp. *pallasiana*) AT ARIT (BARTIN) IN THE WESTERN BLACK SEA REGION OF TÜRKİYE

UTJECAJ KLIME I VLAŽNOSTI TLA U ZONI KORIJENA NA RADIJALNI PRIRAST CRNOG BORA (*Pinus nigra* Arnold subsp. *pallasiana*) U ARITU (BARTIN) U ZAPADNOJ CRNOMORSKOJ REGIJI U TURSKOJ

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SUMMARY

Black pine is the third most widespread tree species (4.2 million ha) in Türkiye and due to its important position in Turkish forestry, it has been studied in many ways. In this study, the influence of the main climatic variables with soil wetness in the root zone on the radial growth of black pine was investigated. Tree ring widths were measured with Cdendro and CooRecorder, and standard dendrochronological techniques were used for cross-dating, standardization, and statistical analysis based on the xDateR and dplR packages in R. According to the result of this study, spring and summer precipitation mostly plays a significant positive role for the radial growth of black pines in Arıt in the western Black Sea region. Although maximum temperature has no influence, minimum and average temperatures in November and December of the previous year affect the radial growth significantly and negatively. In addition, soil moisture of the root zone in June and August has a clearly positive effect on radial growth.

KEY WORDS: Anatolian black pine, Bartın, climate response, dendroecology, dendroclimatology

INTRODUCTION
UVOD

Global warming and climate change have affected terrestrial and other ecosystems, and this process has altered the growth dynamics of species in forest ecosystems. In the Mediterranean region, mean annual temperatures are now 1.4 °C higher than they were in the late 19th century. Forests and their important components, the trees, in this region are affected by mean and seasonal changes in temperature and precipitation, as well as by extreme changes (Cramer et al. 2018). Regional and local tree chronologies are essential for a better understanding of site dynamics and the impact of climate variables on radial tree growth. Since *Pinus nigra* Arnold is a drought-sensitive species (Janssen et al. 2018), various taxa of the black pine in the Mediterranean region have been intensively studied using tree ring characteristics. The Iberian Peninsula and Anatolia in the Mediterranean are among the places where the black pine is

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best studied. The growth response to climate and drought in the suppressed and dominant black pine trees was studied comparatively in the Cazorla Mountains of south-eastern Spain (Martin-Benito et al. 2008). In the Iberian Peninsula, tree ring width of *Pinus nigra* was analysed along 500 km latitudinal transect to study the temporal trend and climate forcing in the radial growth of black pines over the last century (Martin-Benito et al. 2010). In addition, the subregional temperature and precipitation trends and the basal area increment (BAI) of *Pinus nigra* subsp. *salzmannii* (Dunal) Franco were studied in the Natural Park of Sierra de Cazorla, Segura y las Villas (Linares and Tiscar 2010). Also, growth responses of black pines to climate and drought along a drought gradient in Baetic mountains (southern Spain) and Rif (northern Morocco), where their southernmost relicts are present, were studied by Camarero et al. (2013). The radial growth-climate relationships for the different subspecies and provenances of black pines in a common garden from Northwest Tunisia were compared by Fkiri et al. (2018). In tree-ring chronology constructed from black pines from the region of Dobrostan in the Rhodope Mounths of Bulgaria, the climate-growth relationship was studied by Shishkova and Panayotov (2013). The climate response of black pine and Kefalonian fir (*Abies cephalonica* Loudon) was determined in a mixed stand on Mount Timfiristos, Greece (Katsaiti 2021). In managed and unmanaged stands under similar Mediterranean climatic conditions, the growth response of black pine (*Pinus nigra* subsp. *salzmannii*) to climatic variability and drought events was recently analyzed by Lucas-Borja et al. (2021).

The black pine (*Pinus nigra* Arnold subsp. *pallasiana* (Lamb.) Holmboe) is one of the ecologically and economically valuable tree species in Türkiye. It spreads in mountainous areas (between 400 and 2100 m a.s.l.) in the western parts of the Anatolian diagonal (Akkemik 2018). Black pine is Türkiye's third most common tree species, and black pine forests, pure or mixed with other species, cover 4.2 million hectares of land (18.3%) (OGM 2020). This species, which adapts to different climates in which it spreads, is found in central Anatolia, the Black Sea and the Mediterranean regions of Türkiye. Tree ring analysis has been widely used to understand climatic effects and site dynamics on radial growth of black pine in different parts of Türkiye (Akkemik 2000, Akkemik & Aras 2005, Makineci & Sevgi 2005, Sevgi & Akkemik 2007, Köse et al. 2011, 2012, Doğan & Köse 2019). Recently, the long-term growth trends of *Pinus nigra* subsp pallasiana in Anatolia were reported by Janssen et al. (2018).

Studies on the dendroclimatology of the black pine in Türkiye have generally been conducted in inland areas with a continental climate. Investigations on the climatic and site factors affecting black pine growth in Bartın Province, which has an oceanic climate, are limited. With the exception of the black pine, the dendroclimatology of some forest tree species such as Scots pine (*Pinus sylvestris* L.) and oriental beech (*Fagus orientalis* Lipsky) has been studied in this province, which has a humid and temperate climate without dry periods (Yaman et al. 2021, Özel et al. 2021). However, in the black pine stands of the Arıt region of the province with deep, slightly alkaline and well-drained soils within the Alfisol order (Kara & Bolat 2009), the climatic and site-related influences on the radial growth of the black pine have not been studied so far. Therefore, the present study aims to investigate the most critical climate variables and root zone soil wetness affecting the radial growth of black pines in Arıt (Bartın) in the western Black Sea region of Türkiye.

MATERIALS AND METHODS
MATERIJALI I METODE

Site properties – *Obilježja lokaliteta*

The research area (forest compartment number: 69) was located near the village of Cocu in the town of Arıt, which belongs to Bartın Province in the western Black Sea region of Türkiye (Figure 1). Anatolian black pine (*Pinus nigra* subsp. *pallasiana*), oriental beech (*Fagus orientalis*) and Turkish fir (*Abies nordmanniana* subsp. *equitrojani* (Asch. &Sint. ex Boiss.) Coode & Cullen) are major forest tree species in this forest compartment, and these species form pure or mixed stands. While here at about 400-600 m a.s.l. pure black pine stands and oriental beech mixed stands with hornbeam (*Carpinus betulus* L.) occur, pure or mixed Turkish fir stands with oriental beech are found between 650 and 1000 m above sea level. Increment cores were collected in a pure Anatolian black pine stand at 600 m above sea level and the aspect and average slope of this stand were north and 17%, respectively. Triassic and Jurassic lithological structures (flysch) exist around Arıt, and brown forest soils and yellow-red podzol soils dominate (Turoğlu 2014).

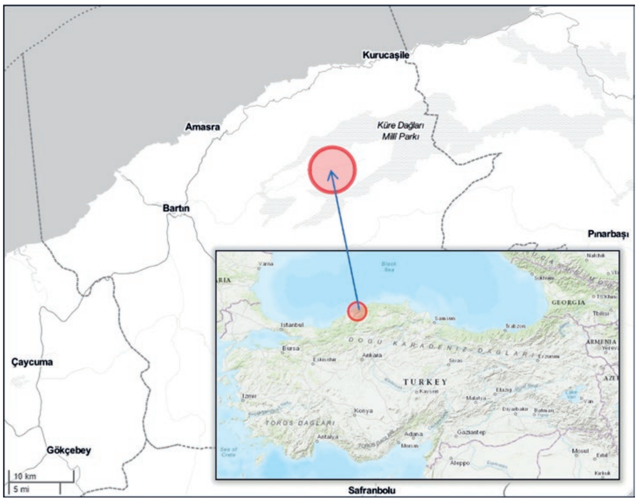

Figure 1. Sampled black pines located in Arıt, Bartın, Türkiye.
Slika 1. Uzorkovani crni bor smješten u Aritu, Bartın, Turska.

Tree-ring chronology – *Kronologija godova*

The number of sampling trees and the number of increment cores plays a crucial role in dendroclimatological research. By carefully selecting representative sample trees and extracting increment cores, researchers can obtain valuable insights into the relationship between tree growth and climate. Using the Haglöf increment borer, 32 cores were taken at a height of 1.30 m from 16 dominant black pines, placed in paper pipettes and coded. After the increment cores had air-dried, they were fixed to a slotted batten with wood glue, and then their transverse surfaces were sanded with sandpaper of different grit sizes (400, 600, and 1000, respectively) for polishing tree rings. After visual cross-dating was performed by marking the increment cores to the ten-year periods, Cdendro and CooRecorder were used to measure tree ring widths on the scanned photos of the cores (Maxwell & Larsson 2021). The quality control of the ring width series was carried out with the beta version of xDateR (Bunn 2010). While multiple increment cores can be taken from a single tree to provide a more accurate representation of its growth history, one core can also be selected from some trees (some unsuitable increment cores may be eliminated). Thus, we did not use 6 increment cores from 6 trees for further analyses due to inconsistencies with the master chronology. The ring width series of 26 cores from 16 trees were standardized using the spline method in dplR, a dendrochronology library in R's statistical computing environment, and the mean ring width index chronology (RWI) was calculated based on Tukey's Biweight Robust Mean, unaffected by outliers (Cook et al. 1990a, 1990b; Bunn 2008). The rigidity of spline function is determined by two parameters: frequency response *f* at a wavelength of *nyrs* years (Cook & Peters 1981). Here, we used default values: a spline where the frequency response is 0.50 at a wavelength of 0.67.

Climate analysis – *Klimatske analize*

In Bartın province in the western Black Sea region of Türkiye, mean annual precipitation is 1049.1 mm, and annual mean maximum and minimum temperatures are 19.1 °C and 7.7 °C, respectively (MGM 2022). Bartın has no drought months (2*T °C <P_{mm}) based on the Walter & Lieth Climate Diagram (Walter & Lieth 1967). This climate diagram was drawn with the climate graph function {berry Functions} in R (Boessenkool 2022) (Fig. 2). Bartın's climate is classified as Cfb (temperate, no dry season, warm summer) based on the Köppen-Geiger climate system (Bölük 2016).

Climate variables needed to analyze the relationship between radial tree growth and climate were obtained using NASA's Power Data Access Viewer (URL-1 2022). Each parameter was obtained directly from or calculated using meteorological parameters taken from NASA's MERRA-2 assimilation model (Bosilovich et al. 2016). The span of climate data ranged from 1981 to 2021. Monthly mean (T_{mean}), maximum (T_{max}), minimum (T_{min}) temperatures and precipitation (Prec) were considered as climate variables

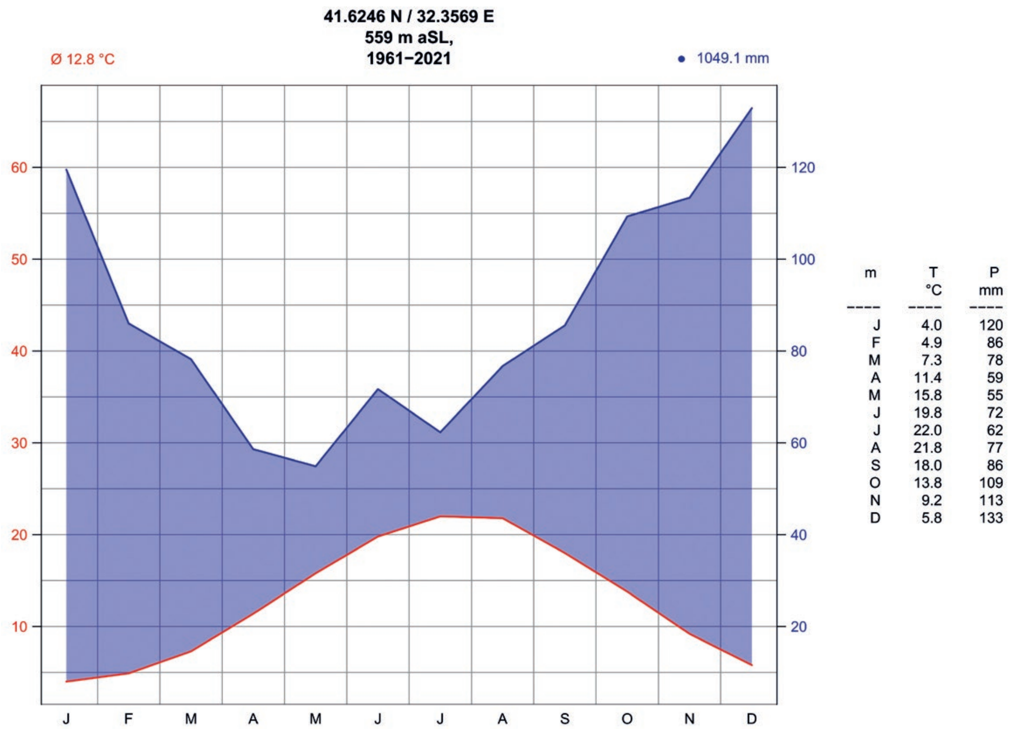

Figure 2. Bartın's climate diagram based on the Walter & Lieth method.
Slika 2. Bartınov klimatski dijagram temeljen na Walter & Lieth metodi.

influencing the radial growth of black pines in the studied stand (latitude 41.6698, longitude 32.6318, altitude 600 m). In addition, the root zone soil wetness (SW_{rz}) was also taken into account in the analysis. The root zone is defined as the layer from the surface from 0 cm to 100 cm below the soil surface, and SWrz ranges from 0 to 1, indicating soil type from completely anhydrous soil to completely saturated soil (URL-1 2022). Correlations between the RWI and all climate variables were examined using the dcc function {treeclim} in R (Zhang & Biondi 2015).

RESULTS
REZULTATI

Chronology statistics – *Statistika kronologije*

In the study, a mean site chronology of black pine (PnAr) from 1892 to 2021 was created. The mean intercorrelation (std dev) of the series and the mean (sdt dev) AR1 are 0.539 (0.102) and 0.714 (0.107) for crossdated series (rwl), respectively, and the mean sensitivity (ms) is 0.255. The following statistics were obtained during construction of the RWI with dplR: 0.545 (0.487-0.572) for mean correlation within trees (rbar.wt), 0.374 (0.345-0.408) for mean correlation between trees (rbar.bt), 0.431 (0.400-0.446) for the effective mean correlation (rbar.eff), 0.924 (0.828-0.928) for the expressed population signal (EPS) and 12.132 (4.827-12.810) for the signal-to-noise ratio (SNR), which is defined as the ratio of signal power to noise power (Tables 1 and 2). The mean EPS value (0.924) is above the 0.85 threshold and reflects how well the RWI represents a theoretically infinite black pine population in our study area. Other statistics can be seen in Table 1 and Table 2. The sample depth and mean RWI of 26 series of tree rings obtained from 16 dominant black pines are given in Figure 3.

Table 1. The statistics obtained during construction of the RWI using dplR.
Tablica 1. Statistika dobivena tijekom konstrukcije RWI korištenjem dplR.

n.cores	n.trees	rbar.tot	rbar.wt	rbar.bt	c.eff	rbar.eff	eps	snr
26	16	0.380	0.545	0.374	1.412	0.431	0.924	12.132

Table 2. The statistics obtained during the construction of the RWI using dplR .
Tablica 2. Statistika dobivena tijekom konstrukcije RWI korištenjem dplR prema različitim vremenskim razdobljima.

start.year	mid.year	end.year	n.trees	rbar.tot	rbar.wt	rbar.bt	c.eff	rbar.eff	eps	snr
1897	1921	1946	6	0.413	0.487	0.408	1.200	0.446	0.828	4.827
1922	1946	1971	16	0.401	0.567	0.396	1.333	0.444	0.928	12.795
1947	1971	1996	16	0.395	0.572	0.389	1.412	0.445	0.928	12.810
1972	1996	2021	16	0.351	0.528	0.345	1.412	0.400	0.914	10.669

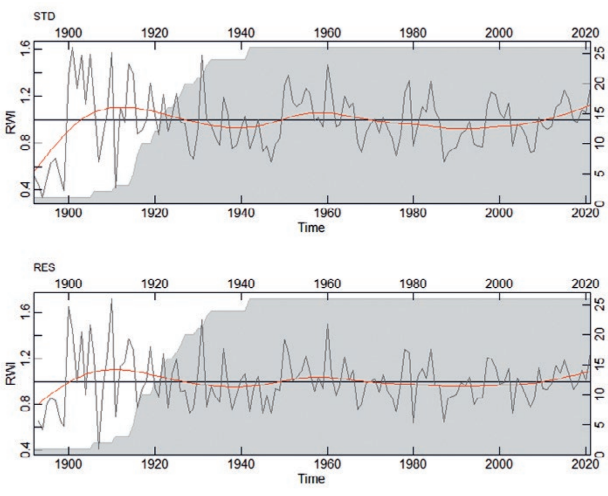

Figure 3. The mean RWI obtained from 26 increment cores in 16 dominant black pines.
Slika 3. Prosječna RWI i veličina uzorka 26 nizova godova dobivenih od 16 dominantnih stabala crnog bora.

Climate growth relationships – *Odnosi klimatskog rasta*

The time period in the analysis spans from 1981 to 2021. Correlations between the RWI, the selected climate and stand variables are shown in Figures 4 to 8. According to the analysis based on the dcc function {treeclim} in R, the Prec of February, April, June and August have a positive effect on the radial growth of black pines in the current year [r = 0.30, 0.39, 0, 31, 0.26, respectively (p<0.05)]. The Prec of November in the previous year and in the current year has a negative effect [r = -0.42 and -0.29, respectively (p<0.05)]. T_{mean} and T_{min} in November and December of the previous year [r = 0.31, 0.31, 0.33 and 0.29, respectively, (p<0.05)] and T_{mean} in November of the current year [r = 0.26 , p<0.05] positively influence radial growth. T_{max} has no significant impact on radial growth either in the previous year or in the current year. The study also examined

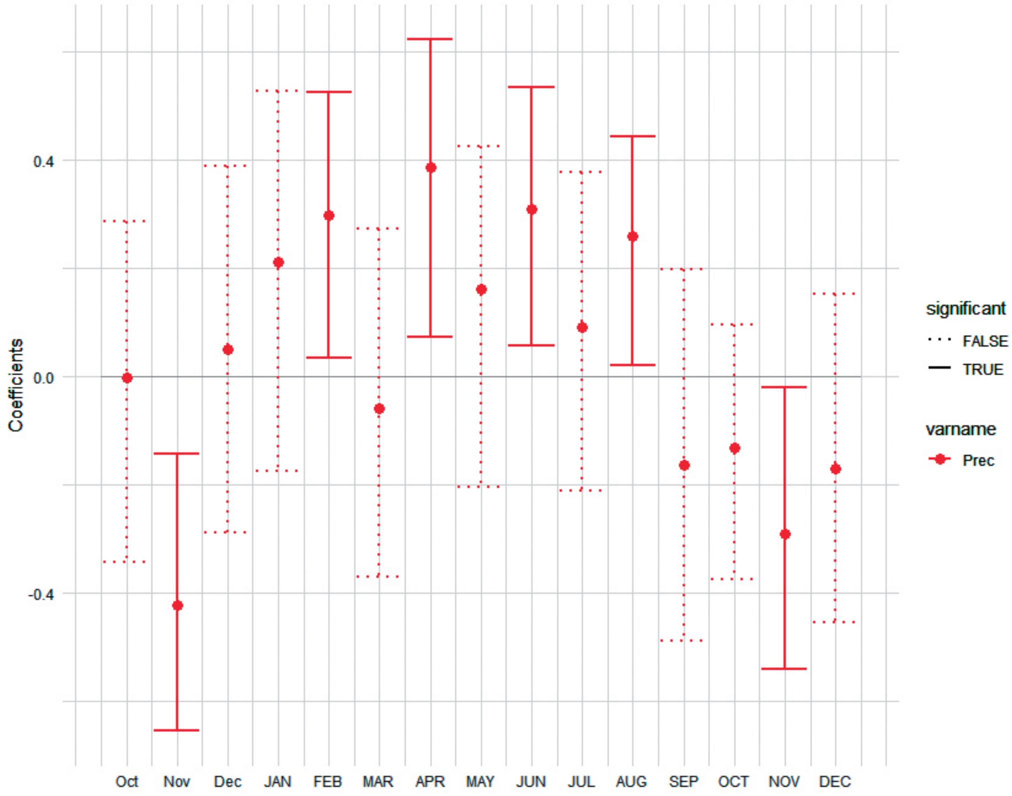

Figure 4. Correlation coefficients between RWI and Prec (solid line represents statistically significant results ($p<0.05$)).
Slika 4. Koeficijenti korelacije između RWI i Prec (puna linija predstavlja ststistički značajne rezultate ($p<0,05$)).

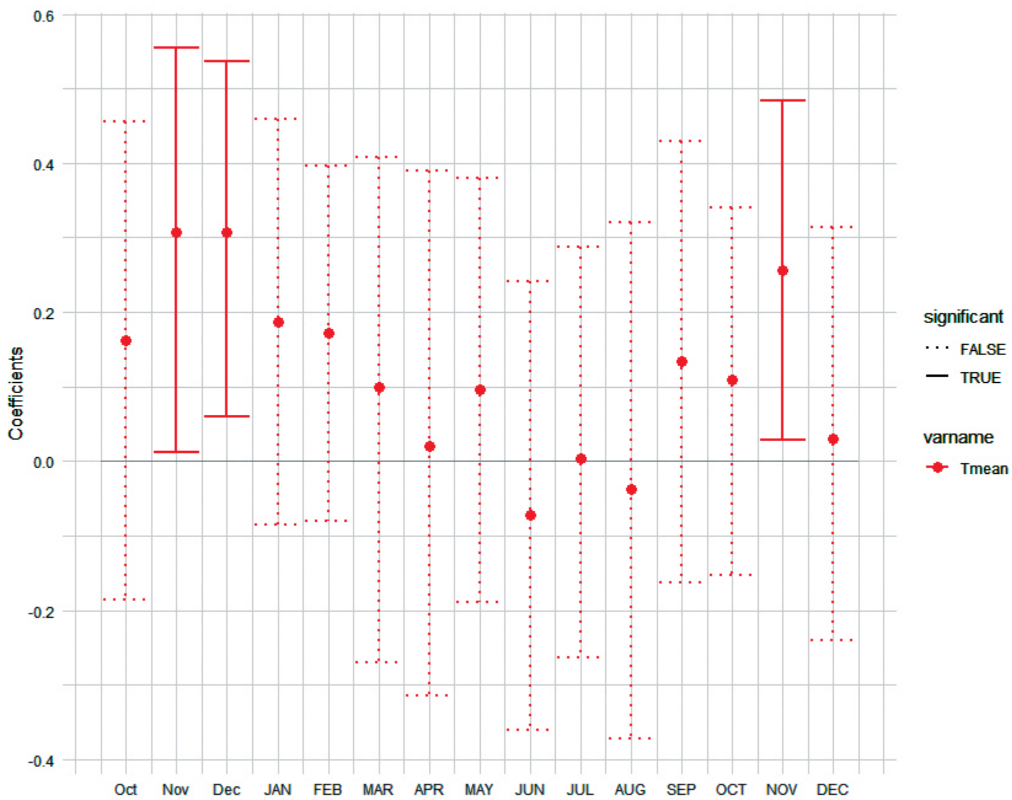

Figure 5. Correlation coefficients between RWI and T_{mean} (solid line represents statistically significant results ($p<0.05$)).
Slika 5. Koeficijenti korelacije između RWI i T_{mean} (puna linija predstavlja ststistički značajne rezultate ($p<0,05$)).

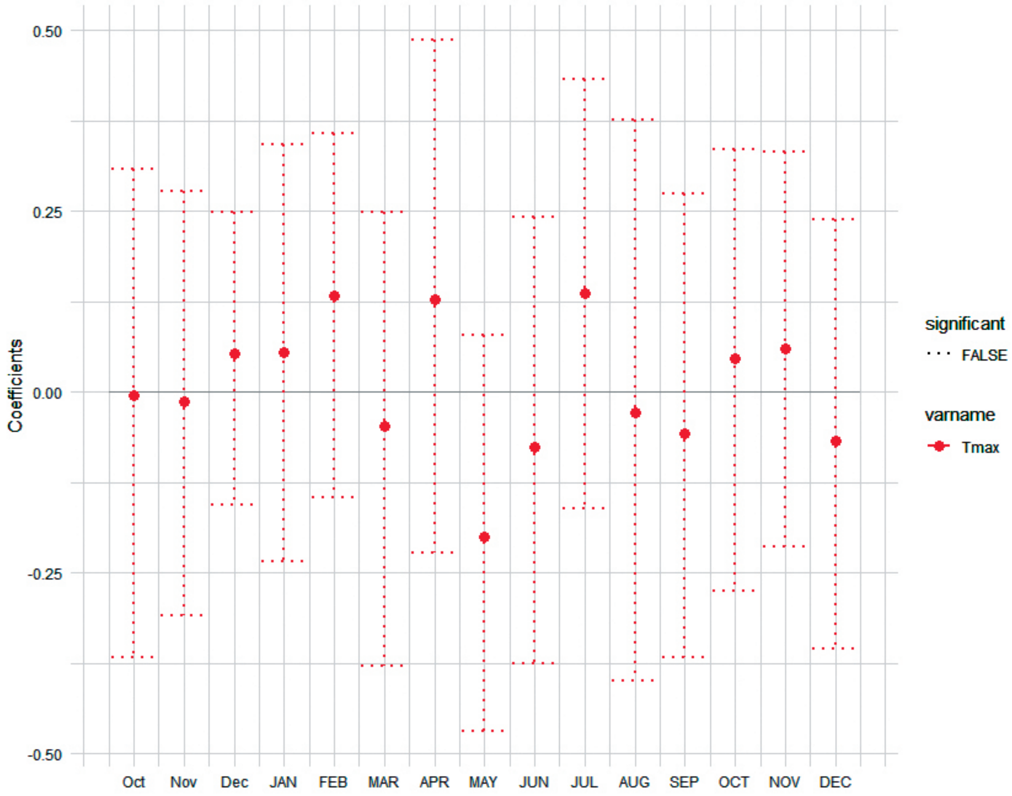

Figure 6. Correlation coefficients between RWI and T_{max} (solid line represents statistically significant results ($p<0.05$)).
Slika 6. Koeficijenti korelacije između RWI i T_{max} (puna linija predstavlja ststistički značajne rezultate ($p<0,05$))

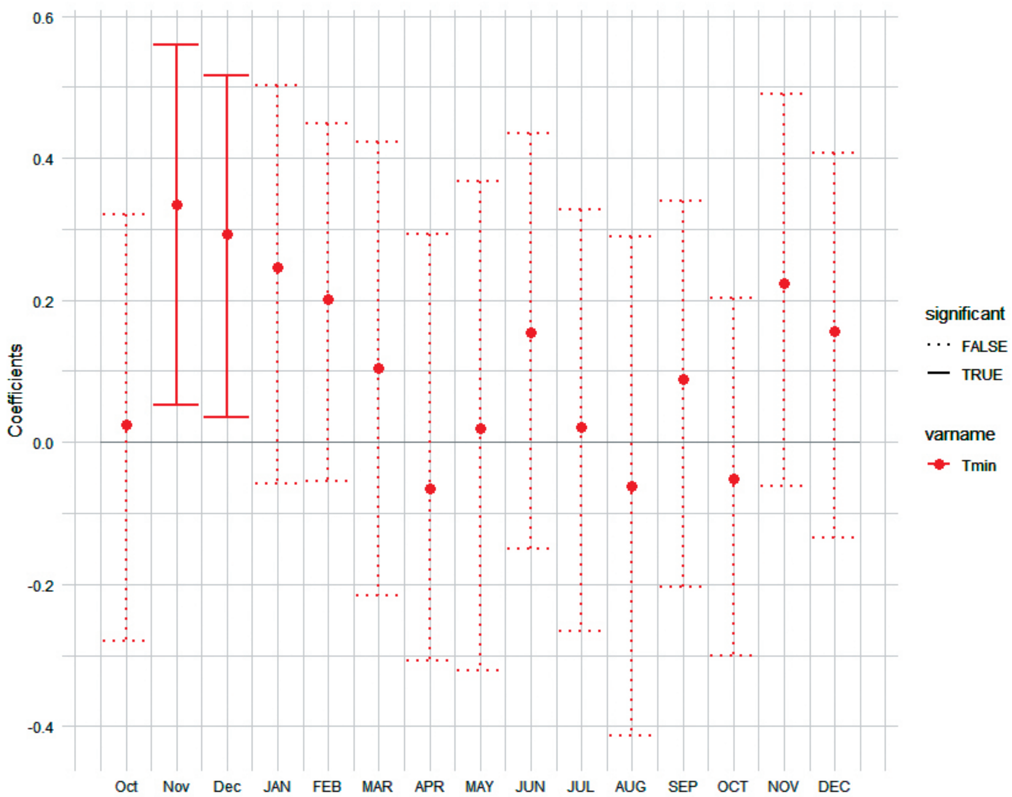

Figure 7. Correlation coefficients between RWI and T_{min} (solid line represents statistically significant results ($p<0.05$)).
Slika 7. Koeficijenti korelacije između RWI i T_{min} (puna linija predstavlja ststistički značajne rezultate ($p<0,05$)).

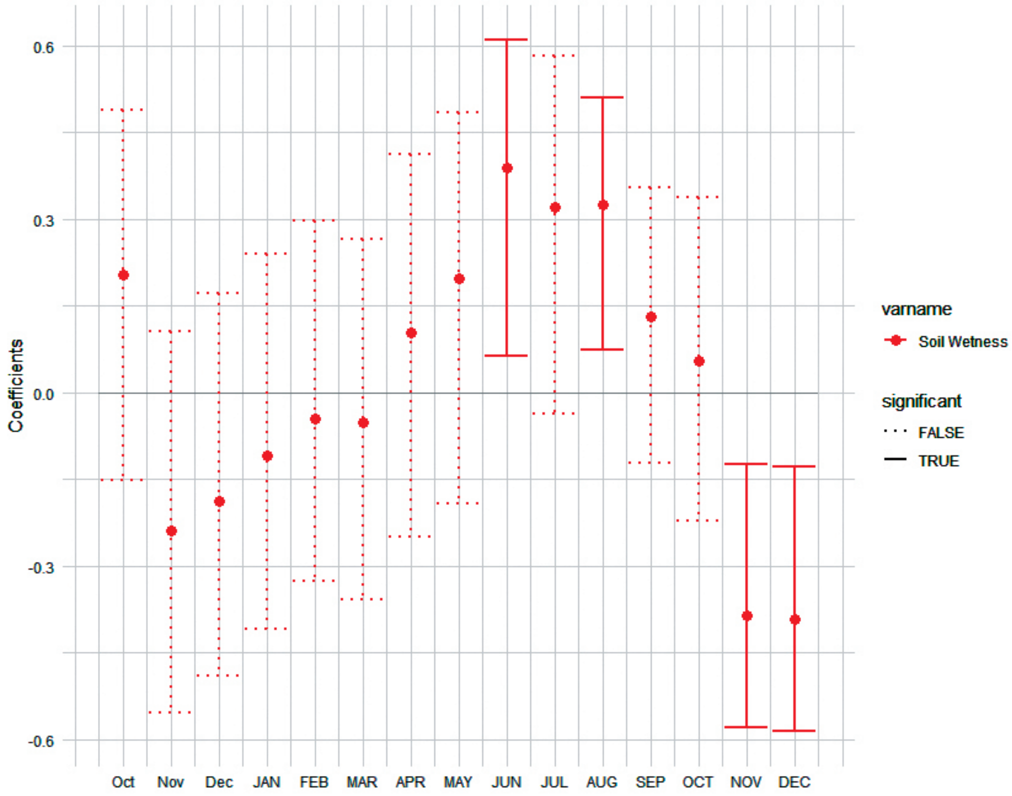

Figure 8. Correlation coefficients between RWI and SW_{rz} (solid line represents statistically significant results ($p<0.05$)).
Slika 8. Koeficijenti korelacije između RWI i SW_{rz} (puna linija predstavlja ststistički značajne rezultate ($p<0,05$)).

the influence of SW_{rz} on the radial growth of black pine. In the current year, although SW_{rz} has a positive effect on radial growth in June and August, it has a negative effect on radial growth in November and December [r = 0.39, 0.32, -0.39, and -0.39, respectively (p<0, 05)].

DISCUSSION
RASPRAVA

The radial growth trend of black pines in southwestern Anatolia in the eastern Mediterranean has been reduced by increased temperatures and summer droughts (Janssen et al. 2018). Drought is known to affect the radial growth of dominant and suppressed black pine trees differently (Martn-Benito et al. 2008). In the present study, we selected only dominant trees. As a result, spring and summer rainfall play a significant positive role in the radial growth of black pines in Arıt in the western Black Sea region. Although T_{max} has no influence, T_{min} and T_{mean} in November and December of the previous year significantly influence radial growth. We conclude that higher November and December temperatures in the previous year (T_{min} and T_{mean}) cause the growing season to start earlier in the current year. In addition, this may also be the consequence of starch accumulation caused by a longer growth period in the previous year. In the current year, the soil moisture in the root zone in June and August has a clearly positive effect on radial growth. Although the effect of soil moisture in July is not significant, the correlation coefficient is still high. Thus, we can say that soil moisture in June, July and August is very effective on the radial growth of black pine. However, it has a negative effect in November and December. We conclude that the negative effect of root zone soil wetness associated with these two months on radial growth may be related to heavy rainfall in November (Figures 4 and 8), which may result in the next growing season starting late. For black pines, the limiting factor of average radial growth in western Anatolia is drought caused by low rainfall (especially in May). In the steppe transition region, central Anatolia and the Mediterranean, drought effect is stronger than in the Black Sea region (Köse et al. 2012). Higher temperatures play a positive role in the radial growth of black pine early in the growing season in almost all areas except the transition region to the steppe (Köse et al. 2012). However, the negative impact of the drought on black pines at different elevations on the northern slopes of Kazdagları, Anatolia, is unclear (Sevgi & Akkemik 2007). Higher summer precipitation has a positive effect on the radial growth of black pines in Mt. Rubnik, Serbia (Stajić & Kazimirović 2018). Black pines from the Bulgarian Rhodopes had negative responses to summer temperatures in the previous and current years (Shishkova & Panayotov 2013). The radial growth of black pines in Mount Timfristos, Greece, shows a statistically significant positive correlation with July precipitation and temperatures in March and April, and a negative correlation with temperatures in June and August (Kasaiti 2021). A 51-year-old common gardening experiment using black pines in northwestern Tunisia found that spring droughts reduce radial growth and that different subspecies of black pines respond differently to climate (Fkiri et al. 2018). Cool summers and cold, humid seasons favor radial growth of black pine populations along a 500 km wide transect in the Iberian Peninsula (Martín-Benito et al. 2010). In addition, while radial growth in the southernmost relic stands of black pine in Spain is negatively affected by dry conditions before tree-ring formation, it is positively affected by wet and cold autumns and warm late winters (Camarero et al. 2013). Most of the above studies on tree ring analysis in black pine have shown that this conifer species exhibits variable responses to climate across its wide native ranges. For this reason, it is important to study the relationships between climate and radial tree growth at a more local scale in the Mediterranean under the impacts of climate change.

CONCLUSIONS
ZAKLJUČCI

Trees in different locations in the same region may respond differently to climatic variables. Dendroclimatological and dendroecological research has gained importance in various locations in the Mediterranean where global climate change takes place. Climate variables such as temperature and precipitation significantly impact tree growth. On the radial growth of black pine, the study examined the influence of root zone soil wetness (SW_{rz}) as well as the two climate variables most commonly used in dendroclimatology, and the results show that SW_{rz} is also an efficient parameter in June, August, November, and December of the current year in the Mediterranean under the effects of climate change.

Conflict of interest – *Sukob interesa*

The authors declare no conflict of interest.

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SAŽETAK

Crni bor je treća najrasprostranjenija vrsta drveća (4,2 milijuna ha) u Turskoj i zbog svoje vrijednosti u turskom šumarstvu proučavan je na mnoge načine. U ovom radu istražen je utjecaj glavnih klimatskih varijabli s vlažnošću tla u zoni korijena na radijalni prirast crnog bora. Širina godova izmjerena je pomoću alata Cdendro i CooRecorder, a standardne dendrokronološke tehnike korištene su za unakrsno datiranje, standardizaciju i statističku analizu temeljenu na xDateR i dplR paketima. Prema dobivenim rezultatima, proljetne i ljetne oborine imaju pozitivnu značajnu ulogu za radijalni prirast crnog bora u Arıtu u zapadnoj crnomorskoj regiji. Iako maksimalna temperatura nema utjecaja, minimalne i srednje temperature u studenom i prosincu prethodne godine značajno i negativno utječu na radijalni prirast. Osim toga, vlažnost tla u zoni korijena u lipnju i kolovozu ima jasno pozitivan učinak na radijalni prirast.

KLJUČNE RIJEČI: anatolijski crni bor, Bartın, klimatski odziv, dendroekologija, dendroklimatologija.