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Diameter-Height Growth Performance of Natural Species of Central Anatolian Forest Steppe in Terms of Influencing Site Conditions

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ABSTRACT

Trees' height (H) and diameter (D) growth depend on many factors and vary between species. This study examined H and D growth of *Juniperus excelsa, J. foetidissima*, *Pinus nigra*, *Quercus cerris* and *Q. pubescens*, growing naturally in the Central Anatolian forest steppe and the site conditions (human impact, woody plant coverage, tree density, altitude, exposure) that influence H and D growth. The present study hypothesises that the decline of height growth might indicate limited rainfall in the region. Two datasets were distinguished for the statistical analysis: the first comprised maximum height (MH) and diameter (MD), human impact, woody plant coverage, and tree density of the sampling plots, and the second comprised all measured Hs and Ds of the sampling plots, exposition, and altitude. Variance and correlation analysis were applied to both datasets to determine the relationships between parameters. Non-linear regression analysis was applied to both datasets to provide H-prediction equations. According to the results of statistical analyses applied to two datasets, each tree species reacted differently to the site conditions. However, the most relevant relationship was found between height and diameter growth for all species. The MH-MD and D-H of *P. nigra* (except the altitude) and *Quercus cerris* + *Q. pubescens* (except the human impact) did not respond to any of the site conditions remarkably, while those of *J. foetidissima* responded to all of the site conditions examined. The H and D of each species were affected by the exposure. While the highest number of trees was found on N-exposed slopes, the heights trees of each species were found on N- and NW-exposed slopes. The results of non-linear regression analysis applied on both datasets of H-prediction equations of each species involved different parameters, even though the diameter was the only relevant variable for height prediction. Although it is not possible to reach a definite conclusion for other species within the scope of this study, *P. nigra* had a shorter height in Central Anatolia than in areas with better environmental conditions. Height growth might indicate water limitations of Central Anatolian region, but genetic code might be an important factor of how a species will cope with drought.

Keywords: drought; variation of maximum height and diameter; height decline; human impact; height prediction

INTRODUCTION

The relationship between diameter (D) and height (H) in trees provides fundamental information for forest research (Sumida 2015). The H–D relationship changes with environmental conditions and over time (Sumida et al. 2013). Indeed, each tree may follow a different path in terms of growth (King 2011). Moreover, depending on local conditions, this relationship can vary between locations and regions (Fulton 1998). Central Anatolia as an arid region and it can have disadvantageous characteristics for tree growth due to droughts, which can also reduce forest productivity by changes in photosynthesis rate (Grassi and Magnani 2005), carbon assimilation (Lawlor and Cornic 2002), phenology (Misson et al. 2011), and tree morphology (Aspelmeier and Leuschner 2006). These characteristics have adverse impact on ecosystem stability, can determine the existence of species within a region, and have a wider distribution related to geographical conditions (Chambers et al. 1999). Moreover, various species living in the same region may show diverse growth characteristics (Bond et al. 2000), as distinct plant groups can apply different resource-use strategies (Lyon and Sagers 1998).

Plant growth depends on photosynthesis, stored reserves of non-structural carbohydrates, and other physiological functions (Chapin et al. 1990). The mechanism of radial growth is affected by five factors: water, carbon, nutrients and temperature, auxin (a plant hormone involved in the cambial activity), and mechanical stress (Zweifel et al. 2006). Radial growth depends primarily on the current tree water levels and secondarily on carbon balance. However, different mechanisms are involved in height growth. Trees are thought to have a mechanism that slows their growth with increasing age because the relative top heights of the young stands are significantly higher than those of the older stands (Gulyás et al. 2019). Several mechanisms have been proposed to explain this phenomenon and the differences in H growth and maximum H within species, including reduced respiration rate, limitations of nutrient availability, maturational changes, and hydraulic limitations (Ryan and Yader 1997). Furthermore, genetically programmed slowing of growth may explain the decrease in H growth with age (Greenwood 1989).

Central Anatolia is a semi-arid region with low precipitation and high evaporation rates, unfavourable natural environmental conditions, and long-term history of human activity and land degradation resulting in a significant decrease in the number of trees and reduced woody vegetation cover (Kahveci 2017). Although it may seem difficult to distinguish the extent to which these phenomena have been caused by human and natural influences, it will become easier to reach clear conclusions as the number of research studies increases. Some native tree species have survived under the adverse conditions of Central Anatolia: *Pinus nigra* J. F. Arnold (Austrian pine), *Quercus cerris* L. (Turkey oak) and *Q. pubescens* Willd. (white oak); *Juniperus excelsa* M. Bieb *(*Crimean juniper*); and J. foetidissima* Willd (Foedit odour juniper). These are generally distributed in relict areas of the mountain forest steppes (Makunina 2016, Kahveci 2017). These trees also occupy many other environments. However, tree growth varies among regions because of site conditions (Bariboult et al. 2012).

This study examined the H and D growth of natural tree species and the influence of the site conditions (human impact, woody plant coverage, tree density, altitude, exposure) on H and D growth in the Central Anatolian forest steppe. The aims of this study were: (i) to determine the variation of both maximum height (MH) – maximum diameter (MD) and H-D growth between natural tree species of Central Anatolia, (ii) to ascertain the extent to which site conditions influence both MH - MD and H-D growth, and (iii) to develop height prediction equations in terms of affecting site conditions. Even though the limiting factor (light, soil properties, water, ext.) of tree growth varies between forest ecosystems (Gao et al. 2018), water-stressed environments, especially severe drought, can cause the growth decline of trees (O'Brien et al. 2017). Therefore, it is expected that the species that spread over large areas have shorter tree heights in the semi-arid conditions of Central Anatolia.

MATERIALS AND METHODS

Research Site

The present study was carried out in the following six provinces (including 16 locations) of Central Anatolia: Ankara (Elmadağ, Bala, and Nallıhan), Eskişehir (Mihalıççık, Alpu, Seyitgazi, and Çifteler), Kırıkkale (Bahşılı, Yahşıhan, and Delice), Çorum (Sungurlu, Boğazkale, and Uğurludağ), Yozgat (Merkez), and Konya (Merkez, and Ilgın) (Figure 1, Table 2). The most common lithological units at the research site were limestones: crystallised, lacustrine, neritic, and andesite (Balkan 2017). Leptosols, calcisols, and cambisols were the dominant soil types according to the soil classification system of the World Reference Base for Soil Resources (Dinç et al. 1997).

Based on the Köppen–Geiger climate classification, the research site had type Bsk (cold semi-arid) and type Dsa or Dsb (continental with either hot or cold dry seasons) climates (Köppen et al. 1954, Öztürk et al. 2017). Meteorological data

Figure 1. Research site in Central Anatolia. Locations: 1- Mihalıççık, 2- Alpu, 3- Seyitgazi, 4- Çifteler, 5- Nallıhan, 6- Elmadağ, 7- Bala, 8- Bahşılı, 9-Yahşıhani, 10-Delice, 11- Sungurlu, 12- Boğazkale, 13- Yozgat, 14- Uğurludağ, 15- Konya, and 16- Ilgın.

for the research site (monthly precipitation, temperature, and humidity) were obtained from the General Directorate of Meteorology (GDM) for the period from 1927 to 2020 (GDM 2020). The average annual total rainfall varied between 329.2 mm in Konya and 570.3 mm in Yozgat (Table 2). The highest average annual temperature was 12.45°C in Kırıkkale. The lowest average annual humidity was 60% in Konya and Ankara (Table 1). The average length of the growing season was 160 days at the research site (Atalay and Gökçe Gündüzoğlu 2015).

Humans have used forest resources for thousands of years. Oaks and junipers have been used as fuel and animal feed. Unlimited grazing, which is still ongoing, continues to degrade both forest areas and grasslands. These woody species survived despite these effects: *J. foetidissima*, *J. excelsa, J. oxycedrus* L., *Pinus nigra*, *Quercus cerris* L., *Q. pubescens* Willd., *Amygdalus communis* L., *Berberis crataegina* DC., *Crataegus orientalis* Pall. ex M.Bieb., *C. monogyna* Lacq., *Cotoneaster nummularius* Fisch. & C.A.Mey., *Colutea cilicica* Boiss. & Balansa, *Cistus laurifolius* L., *Jasminum fruticans* L., *Lonicera sp*., *Paliurus spina-christi* Mill., *Cornus sanguinea* L. subsp. *Australis,* (C.A.Mey.) Jáv., *Origanum minutiflorum* O.Schwarz & P.H. Davis., *Pistacia palaestina* Boiss., *Pyrus elaeagnifolia* Pall. *subsp. elaeagnifolia, Prunus domestica* L., *Rhamnus rhodopea* Velen., *Rosa canina* L., *R. pulverulenta* M. Bieb., *R. thymifolia* Bornm., *Spiraea crenata* L., and *Ulmus minor* Mill.

Sampling Methodology

The forest management plans of eight provinces were used to determine suitable locations with forest relicts. When selecting sampling plots in these locations, the primary motivation was the occurrence of groups of trees that were in relatively good condition. For this reason, plots were not chosen according to a specific method. Since it was not possible to find excellent and pure stands of each species in the same location, sample plots were taken from different locations (Table 2). Although all of these stands were located in the Central Anatolian region, climatic conditions vary between locations (Table 1). Rectangular plots (25 × 20 m) were used for recording: D at a breast H of 1.37 m (DBH), in cases with DBH >5 cm and Hs in each plot; longitude and latitude (Universal Transverse Mercator [UTM]); Alt; Exposure (°); slope (%); the number of trees; human impact rated as 0 = no impact, 1 = ancient and early medieval impact, 2 = tree cutting, 3 = commercial use, fire, or beekeeping; 4 = destruction of the forest; 5 = complete destruction of the forest (Samojlik et al. 2013); woody plant coverage according to the cover abundance scale (Domin 1928) rated as + = single tree, 1 = one to two trees, 2 = <1% cover, 3= 1–4% cover, 4 = 4–10% cover, 5 = 11–25% cover, 6 = 26–33% cover, 7 = 33–51% cover, 8 = 52–75% cover, 9 = 76–90% cover, and 10 = 91–100% cover by woody plants. In total, 148 plots were sampled from 2005 to 2020 (Table 2).

Data Analysis

Statistical analysis was carried out in R (RStudio 2020). Variance analysis and Pearson correlation analysis were carried out on various versions of datasets, but only the results two datasets were statistically significant. Dataset 1 was prepared based on plots and it included: MD and MH of plots of five tree species (n = 143; *P. nigra* = 37; *Q. cerris* + *Q. pubescens* = 30; *J. excelsa* = 45*; and J. foetidissima* = 31), altitude, human impact, tree density (TD = number of trees per plot*10,000/500) and woody plant coverage. MH and MD of trees were used for analysis because maximum values may be the distinguishing features of species in the locations. On the other hand, it was previously stated that *Q. cerris* and *Q. pubescens* species grow naturally in the research area. Since *Q. pubescens* was dominant in the regions and had about 80% of individuals in the plots, and *Q. cerris* did not contain a scientifically acceptable number of individuals, both species were combined as oak (Quer) for the analysis. Dataset 2 comprised all D and H values of each species (n = 1.397; *P. nigra* = 441; *Q. cerris* + *Q. pubescens* = 331; *J. excelsa* = 417 *and J. foetidissima* = 208) measured in 143 sampling plots on the species basis, altitude, and exposure. Variable exposure only correlated with all measured H and D values. Height prediction equations were provided for both datasets by using non-linear regression analysis.

RESULTS AND DISCUSSION

Results of variance analyses applied on two datasets for comparing the species (*J. foetidissima*, *J. excelsa,* and *P. nigra, Q. cerris* + *Q. pubescens*) showed that all of the variables were statistically distinct from each other, and MD ($p<0.001$), MH ($p<0.001$), tree density ($p<0.001$), woody plant coverage ($p<0.05$), human impact ($p<0.05$), D ($p<0.001$) and H ($p<0.001$) were statistically significant. The results of the variance analyses were visualised in boxplots

Table 1. Long-term (1927–2020) average climate data based on observations from meteorological stations in the research site.

Station	Observation Period (Year)	Average annual total rainfall (mm)	Average annual temperature (°C)	Average annual humidity (%)
Ankara	93	393.2	11.9	60.0
Eskişehir	92	372.8	11.3	65.2
Kırıkkale	57	388.0	12.5	61.8
Konya	91	329.2	11.7	60.0
Çorum	91	430.7	10.8	64.6
Yozgat	91	570.3	9.2	66.8

Table 2. Main characteristics of the research site.

Location	Coordinates (N, E)	Altitude (m)	Species	Tree Density	Number of Plots
1-Mihalıççık *	39°51′18.9′′, 31°30′34.2′′	1077-1128	Jufo	40-280	8
2-Alpu *	39°54′50.2′′, 31°09′23.9′′	1235-1286	Jufo, Juex	200-540	9
3-Seyitgazi *	39°22′35.7′′, 31°02′20.1′′	1047-1202	Jufo, Juex	80-560	15
4-Çifteler*	39°11′41.8′′, 30°43′33.1′′	1359-1400	Jufo	100-420	8
5-Nallıhan*	39°45′39.5′′, 30°57′58.3′′	677- 946	Juex	120-260	4
6-Elmadağ*	39°47′29.8′′, 33°15′49.6′′	970-1099	Juex	100-240	12
7-Bala*	39°47′29.8′′, 33°15′49.6′′	1239	Pini	400-520	2
8-Bahşılı**	39°43′42.1′′, 33°21′21.2′′	980-1200	Juex	100-260	10
9-Yahşıhan**	39°47′37.8′′, 33°21′05.1′′	1010-1030	Juex	100-220	10
10- Delice**	39°56′57.1′′, 34°01′50.8′′	1150	Quer	400-430	2
11-Sungurlu***	40°09′54.7′′, 34°22′35.0′′	1085-1500	Pini, Quer	140-580	6
12-Boğazkale***	40°01′16.3′′, 34°36′50.4′′	1200-1518	Pini, Quer	80-480	16
14-Uğurludağ***	40°26′45.6′′, 34°27′20.1′′	1003-1260	Pini, Quer	200-500	40
13-Yozgat	39°48′18.7′′, 34°49′30.1′′	1550	Pini	180-200	2
15-Konya	39°47′29.8′′, 33°15′49.6′′	1390	Pini	100-320	2
16-Ilgın (Konya)	38°16′17.7′′, 31°54′54.6′′	1680	Pini	400-820	2
Total					148

* Province Eskişehir, **P. Ankara, *** P. Kırıkkale, **** P. Çorum, Pini = *Pinus nigra*, Jufo = *J. foetidissima*, Juex = *J. excelsa*, Quer = *Q. cerris* + *Q. pubescens*.

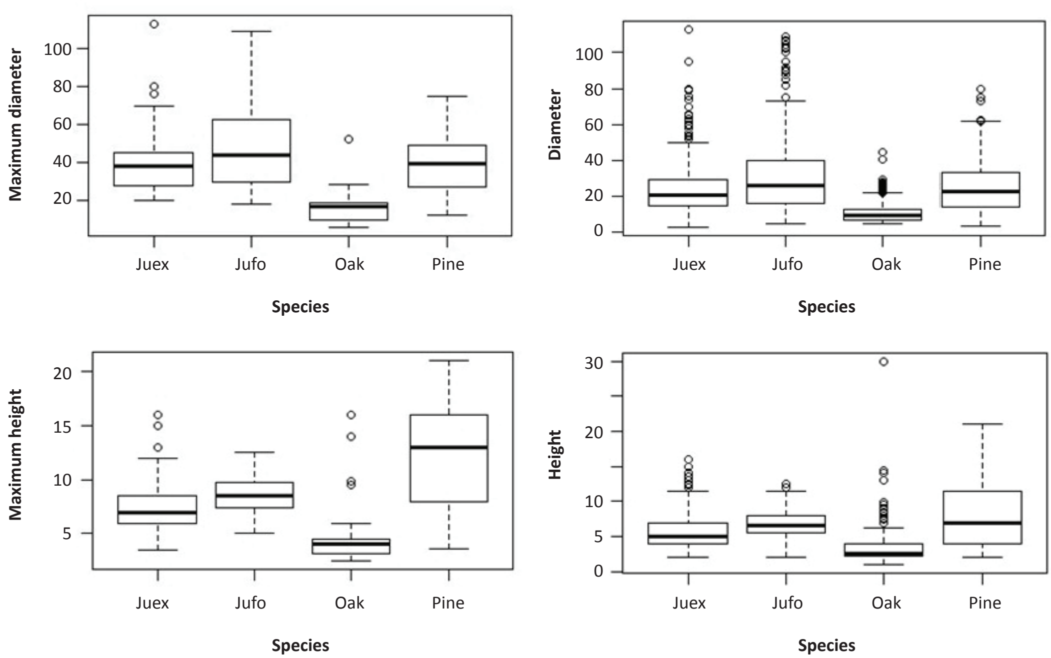

Figure 2. Comparison of maximum height (MH) – maximum diameter (MD) and height (H) – diameter (D) four tree groups visualised by boxplots.

showing the minimum, maximum, and median values of the measured parameters for the tree species (Figure 2, Figure 3, and Figure 5).

Comparison of Both MH – MD and H – D Growth

Tree growth varies with temperature and water availability. At global scales, tree height peaks in regions with mild mean annual temperatures (around 12–16°C), low water stress, and low seasonality (Larjavaara 2014). Each tree can survive between certain altitudes, but still, there is an optimal altitude at which trees grow best and build more stable stands. The forest relicts in the Central Anatolian region might have remained at this optimal altitude, where the tree species can reach maximum height and diameter (Kahveci 2021). This optimal altitude varies between species. The plots related to *P. nigra* were located at the altitude between 1,100 and 1,680 m above sea level (a.s.l.), whereas the plots related to *J. foetidissima*, *J. excelsa,* and *Q. cerris and Q. pubescens* were located at an altitude between 677 and 1,400 m a.s.l. (Table 2).

According to the results of variance analysis applied to both datasets, *J. excelsa* and *J. foetidissima* comprised a group concerning MH-H, while *J. excelsa* and *P. nigra* comprised another group concerning MD-D. By comparing the box plot of maximum diameter and all diameters of each species no significant differences between the boxplots were found. However, there are slight differences between the box plots of the maximum height and all measured heights. Nevertheless, many factors such as climatic conditions, environmental factors (altitude, location slope, slope direction, and human activity) (Jiao 2017), biological characteristics, and tree physiology (Zweifel et al. 2006) play an important role in tree growth. However, the genetic code also controls it (Martin-Benito et al. 2008). The genetic code might decide how much a tree is affected by the environmental conditions in which it grows, since natural species of Central Anatolia show different growth characteristics.

Oak is the most widespread tree species in Central Anatolia (Davis 1971, Hedge and Yaltırık 1982). The genus *Quercus* has spread throughout the northern hemisphere in Asia, North America, Europe, and Africa (Axelrod 1983), down to the Equator, and comprises approximately 400–500 species (Nixon 1993, Valencia et al. 2016). However, it is challenging to find oak stands in good condition in Central Anatolia because of thousands of years of past exploitation. Modern forest management authorities have also been exploiting oak through coppicing with 20-year intervals for many years. Therefore, only individual older oak trees were found in the region. The oaks had regenerated through stump sprouting, which has an advantage over seedlings since ample carbohydrates are available from the parent stool and its root system, so new shoots thrive from the start (Hölscher et al. 2001). This can be seen as an advantage in H growth; however, growth and health decline can be experienced during coppice management (Desprez-Loustau et al. 2006). In this context, values of 14 m MH and 22 cm MD were measured at the research site. These values were relatively low compared to the same species in other regions. Berta et al. (2019) measured an MH of 22.30 m and an MD of 44.35 cm for *Q. pubescens* on the Croatian Adriatic coast.

P. nigra is a long-living tree growing across the northern part of the Mediterranean basin, from Spain to Turkey (Isajev et al. 2014). *P. nigra* has the ability to grow on poor and bare soils, is used for ecological restoration, and generally forms stands with trees belonging to the *Quercus* genus (Marchi et al. 2018). Although *P. nigra* is Turkey's second most common coniferous tree spreading, it shows a limited distribution in the Central Anatolian Mountains. It forms both pure and mixed stands with oak. According to the results of this study, *P. nigra* had an MH of 22 m in the best growing environment in Yozgat (Figure 2), which was not representative of the research site because the average rainfall (570 mm) in Yozgat was much higher than on other locations (Table 1). Another issue was that *P. nigra* had wide varieties in Anatolia, and one of the varieties with three-needle leaves was found in Yozgat (Saatçioğlu 1955). Although this is the subject of another study, *P. nigra*'s genetic characteristics might enable it to adapt to adverse conditions and may create varieties to increase its adaptability to changed climatic conditions. The average H measured for the *P. nigra* area was 8 m in the research site. Raptis et al. (2021a) researched H–D relationships in the Olympus National Park, Greece, which had relatively better climatic conditions, and measured an MH of 30.40 m and an MD of 85.40 cm. Raptis et al. (2021b) measured an MH of 29.80 m and an MD of 74.60 cm in the Troodos National Forest Park in Cyprus. Özçelik et al. (2013) measured H and D in nine locations dominated by the Mediterranean climate, where the annual precipitation varied between 882 and 1,351 mm. The results were as follows: MH 24.60–30.40 m, MD 61–86 cm and mean H between 17.09 and 20.72 m. There was a significant difference between these data and the data obtained from the research site.

Genus *Juniperus* is the second most diverse genus of conifers, with 67 species worldwide, and is mainly confined to the northern hemisphere (Adams 2004), as are *Quercus spp*. The species show a wide range of climatic plasticity, colonising sites that vary from sub-humid to the semi-arid steppe zone of the Mediterranean region (Quézel and Médail 2003). *J. excelsa* is a monoecious tree that occurs in south-eastern Europe and south-western Asia and can reach an H of 20–25 m (Boratyński et al. 1992). It is frequently seen in the arid regions of Anatolia, tolerates severe drought and cold conditions, and can grow on shallow and degraded soils (Akman 1979). However, *J. excelsa* stands have been degraded in Central Anatolia. The MH of *J. excelsa* was measured as 13 m (with an average tree density of 200) in the research area, which can be described as relatively short. However, Stampoulidis and Milios (2010) found MH values of 12 m and 14 m in medium- and good-quality stands, with tree density ranging from 80 to 580 in Prespa National Park in Greece, which had 817 mm rainfall. Douaihy et al. (2011) found MD values of 8–9 m with a tree density of 257 trees·ha^{-1} in Lebanon, where there was 600 mm precipitation.

J. foetidissima grows in the southeast and east Europe, Caucasus, and West and Central Asia, mainly above shallow rocky soils (Farjon 2021). Adult *J. foetidissima* trees are 6–25 m high with stem Ds up to 2.5 m (Kasaian et al. 2011). *J. foetidissima* is a tree species with the most significant D at 110 cm and had an MH of 14 m on the research site.

However, Carus (2004) measured an MH of 18 m and an MD of 62 cm in the Sütçüler region, which has 923.6 mm precipitation. Proutsos et al. (2021) measured *J. foetidissima* in the category of "very high trees (4%)" with an MH of 14 m and a D of 100 cm in Mt. Oiti, where there was an average annual precipitation of 790.2 mm.

Influence of Site Conditions on Height and Diameter

According to the results of correlation analysis applied to both datasets, the most vital relationship was found in diameter and height values for all species (Dataset 1: *J. foetidissima* = 0.70, *J. excelsa* = 0.72, *P. nigra* = 0.77, *Q. cerris* + *Q. pubescens* = 0.53. Dataset 2: *J, foetidissima* = 0.73, *J. Excelsa* = 0.71, *P. nigra* = 0.70, *Q. cerris* + *Q. Pubescens* = 0.52). Oak showed low correlation coefficient value in both datasets. Height and diameter variables of *Q. cerris* + *Q. pubescens* were composed of young individuals. This result was expected because various scientific studies has proven a positive correlation between diameter and height (Sumida 2015). In comparison to others, *P. nigra* had the highest correlation coefficient related to MD–MH and M–D relationships. Even though the site conditions (human impact, woody plant coverage, tree density, altitude, exposure) showed logical correlations among themselves, the relationship between MH – MD and H-D differed based on species (Figure 4).

According to the results of variance analysis, *P. nigra* and *Q. cerris* + *Q. pubescens* comprised a group concerning human impact. Human impact and tree density created a minor correlation with the diameter and height values of *J. excelsa, P. nigra, Q. cerris* + *Q. pubescens.* While human impact values of *J. foetidissima* were correlated with MH – MD positively with a relatively high correlation coefficient (0.58 and 0.54), tree density values for MH – MD correlated negatively with a lower correlation coefficient (-0.43 and -0.41) (Figure 4). Human impact and tree density were directly related to human activity, such as habitat destruction, deforestation, fragmentation, and over-exploitation, which significantly affected forest structure and composition (Hauck and Lkhakvadorj 2013). Local people have used juniper branches as fodder for thousands of years all over Central Anatolia. Many studies have undoubtedly revealed that human influence causes the reduction of tree density in the stands and destroys the tree occurrence over time (Ritchie and Roser 2021, Kahveci 2022). Meanwhile, it is remarkable that the correlation values of *P. nigra* related to human impact and tree density were very low. *P. nigra* had the highest tree density of all species (Figure 3).

The results of variance analysis presented that *P. nigra* and *J. excelsa* comprised a group concerning woody plant coverage, whereas *Q. cerris* + *Q. pubescens* and *J. foetidissima* comprised different groups. The results of correlation analysis showed that woody plant coverage was correlated with human impact negatively and with tree density positively with a relatively high correlation coefficient, which is normally expected. However, woody plant coverage of all species provided a very low correlation with MD and MH except for *J. foetidissima* (MD = -0.44 and MH = -0.39). It means, as woody plant coverage increases, MD and MD decrease, which is ordinarily difficult to explain. However, several studies have pointed out the effect of competition on tree radial growth (Buechling et al. 2017). The increase in competition increased tree height growth compared to no competition, and additional competition negatively impacted tree height (Aleinikovas et al. 2014).

The correlation analysis was applied to both datasets, and the most substantial negative relationship was found between height and diameter values of *J. excels* and altitude, although it had a low correlation coefficient value (MH = -0.47, MD = -0.42 in dataset 1 and H = -0.34 and D = -0.36 in dataset 2). However, height and diameter values of all other species in both datasets were negatively correlated with altitude, including very low correlation coefficient. Altitude is one of the critical physiographic factors affecting tree growth. The high altitudes generally show different environments, such as low air temperature and atmospheric pressure, precipitation prediction complexity, and extreme climates (Naud et al. 2019). In the Central Anatolia region, trees especially prefer to grow at a certain height because the humidity rate is very low in flat areas. Nevertheless, the climatic conditions at high altitudes are not favourable (Kahveci 2022). Özkan and Gülsoy (2008) observed a negative correlation between altitude and the height growth of *P. nigra* in Sütçüler. They concluded that the most critical

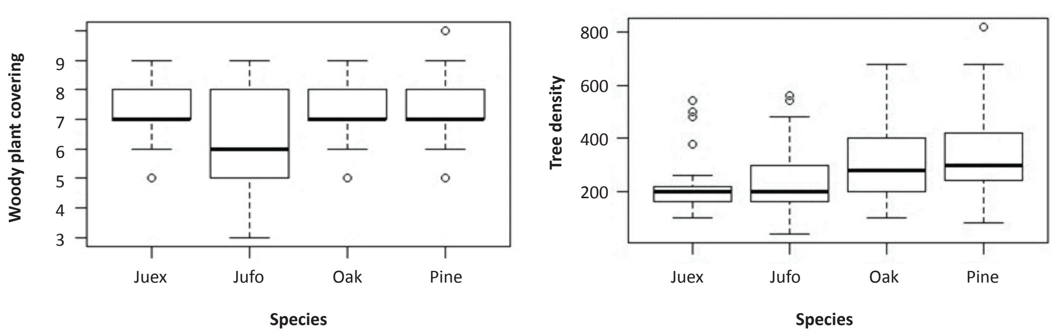

Figure 3. Visualised distribution of woody plant coverage and tree density values (TD = number of trees per plot*10,000/500) of four tree groups.

environmental factors in the height growth of *P. nigra* were altitude, slope, leaf-layer thickness, organic material in the soil, and humidity.

The correlation analysis applied to both datasets showed that *Q. cerris* + *Q. pubescens* provided a low correlation with site conditions, if any, with a low correlation coefficient value. A key question was whether these results were due to younger individuals of oak compared to the other tree species or because oak had a higher tolerance threshold to environmental conditions (Dreyer et al. 1992). Colangelo et al. (2018) compared *Q. cerris* and *Q. pubescens* in terms of drought tolerance and complex responses to drought. They found different tolerances to the combined effects of climate and biotic stressors under the forecasted warmer and drier conditions. Abrams (1985) studied the relationship between age (D) and soil and slope as edaphic factors; the results showed that edaphic factors influenced the growth rates of oak species. Dai et al. (2020) also found a significant correlation (p<0.01) between height and altitude for *Quercus mongolica*.

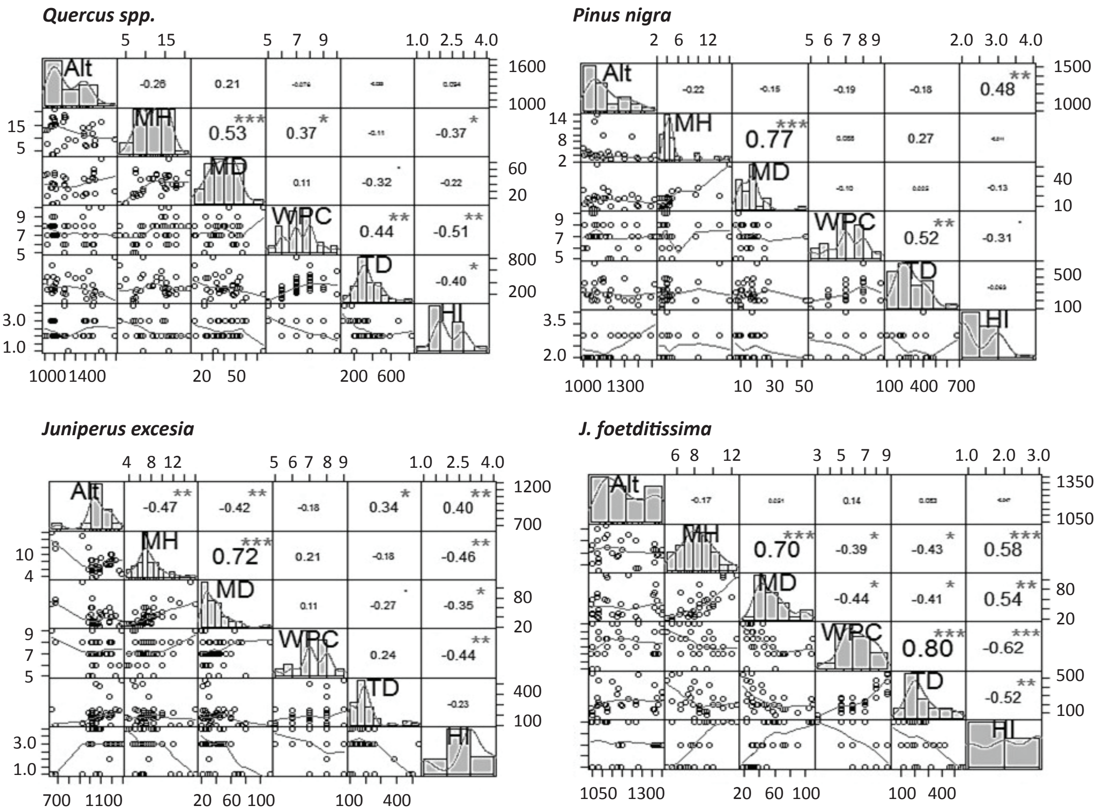

Figure 4. Comparison of the relationship between MH and MD and Altitude (Alt), woody plant coverage (WPC), tree density (TD), and human impact (HI) in species.

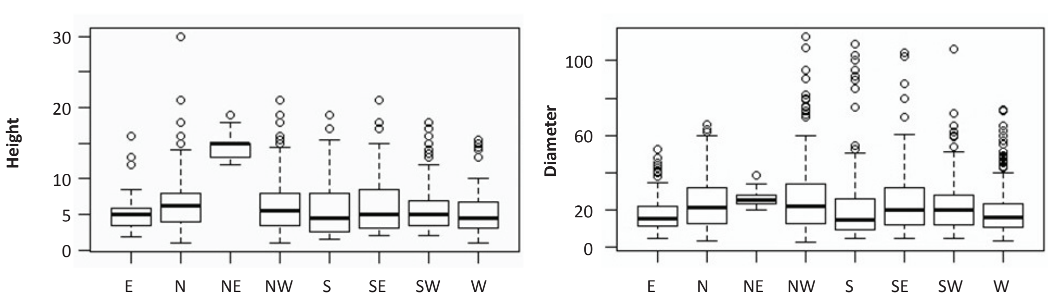

Figure 5. Visualised distribution of tree number related to H and D values in eight exposures (N - north; S - south; E - east; W - west; NE - northeast; SE - southeast; SW - southwest; and NW - northwest).

The effect of water stress usually increased on southern slopes because they received sunlight for a more extended period than other slopes and were thus more greatly affected by drought in Central Anatolia (Kahveci 2017). The juniper responded to changes in exposure and had narrower tree-ring width in southerly and westerly exposed slopes in Central Anatolia (Kahveci et al. 2018). Differences in the slope-related climate response of Scots pine were observed in Sweden (Kirchhefer et al. 2000). The results of variance analysis applied to the H and D values of the tree species and eight exposure supported these results. The total number of trees increased from NE (21), SE (132), E (148), W (172), SW (243) to N (250). While maximum heights are usually found on N-exposed slopes, maximum diameter was found on NW- and S-exposed slopes. When the average values were examined, it was observed that the highest MD and MH were found in the NE-exposed slopes (Figure 5). This led us to infer that on the southerly and westerly exposed slopes, drought worsened the conditions for growth, and the H growth remained at a certain level, whereas the D growth continued.

Height Prediction

The growth of trees, which occurs vertically and horizontally, is of great ecological significance. An adult tree is not only a reflection of the present conditions under which it grows, but it is also the result of all the genetic and environmental factors that have been operating as it has grown from seedling to maturity (Archibald and Bond 2003). Although H growth stops after a certain age depending on the tree's genetic code (Greenwood 1989), it is also affected by environmental conditions (Sumida et al. 2013). In this context, height growth may indicate various limitations in a tree's surrounding environment (Fulton 1998). Regression models applied to both datasets for height prediction were generated for tree species. The significant linear relationship ($p<0.001$) was between height and diameter in both datasets. Several equations relating to height prediction were compared, and the statistically most relevant equations were summarised in Table 3. The results of the regression equation applied to dataset 1 showed that the MH equations of each species involved different parameters. This led us to infer that the H of each tree was affected by different environmental factors while growing. In the equations created with dataset 2, the diameter was the only relevant variable for height prediction. Even in this case, it was seen that the coefficients of the equations differed from each other.

CONCLUSIONS

Semi-arid regions have a significant effect on global atmospheric carbon variations. Central Anatolia is a semi-arid region of great significance for ecological research. The H–D growth of five native tree species from Central Anatolia and some of the affecting site conditions were investigated in this study. The most relevant relationship was found between height and diameter in all species. According to the results of this study, each tree species gave more or less different reactions to the site conditions (human impact, woody plant coverage, tree density, altitude, exposure). The MH and MD of *P. nigra, Q. cerris + Q. pubescens* did not have a significant relationship with site conditions, while those of *J. excelsa* were negatively related to the altitude and human impact. However, the MH and MD of *J. foetidissima* responded positively to human impact, and tree density and woody plant coverage negatively except for altitude. In this context, *J. foetidissima* might have the preferred specific locations for growing. The results of this study indicated that *P. nigra* had a shorter height in Central Anatolia than in areas with better environmental conditions. *J. foetidissima* and *J. excelsa* trees also had a shorter height, but the evidence was less clear. Height decline may be a reaction to drought, but the tree's genetic code plays an important role in tree behaviour in semi-arid regions. Exposure as an environmental factor affected both H and D growth. While the highest number of trees was found in N-exposed slopes, the largest number of MH and MD were found on NE-exposed slopes. The H-prediction equations showed that site conditions affected the height growth of natural species of Central Anatolia in different ways. However, none of them is as constant as the diameter. The results of this study might play a crucial role in maintaining ecological stability and preventing desert expansion and erosion. Although their distribution was relatively scattered, these four tree species are one of the most critical components of the local, fragile, terrestrial ecosystem. Classical forest management should change the current practice and focus on improving growth and reproduction, reducing competition, and reducing human impact on vulnerable forest resources.

Table 3. Height prediction equations for the four tree species in each dataset according to linear regression.

Tree	Dataset 1 (MD/MH+HI+WPC+TD+Alt)	Dataset 2 (D/H+Exp+Alt)
Oak	MH = –1.523126+0.2733588 MD+0.006511 TD	H = 1.0117+0.2262 D
Pine	MH = –8.594521+0.190724 MD+1.066217 WPC–0.009208 Alt	H = 2.08768+0.22887 D
Juex	MH = –5.62974+0.09203 MD–0.65648 HI	H = 2.830257+0.118686 D
Jufo	MH = –8.542158+0.041330 MD+0.584186 HI–0.002821 Alt	H = 4.645919+0.066251 D

Pini = *Pinus nigra*, Jufo = *J. foetidissima* Juex = *J. excelsa,* Quer = *Q.cerris* + *Q. pubescens.* Altitude (Alt), woody plant coverage (WPC), tree density (TD), and human impact (HI).

Author Contributions

GK conceived and designed the research, carried out the field and laboratory measurements, processed the data, drafted the manuscript, and wrote the manuscript.

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Conflicts of Interest

The author declare no conflict of interest.

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