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Research Article

Effects of Ecological Factors on Forest Site Productivity in Crimean Pine Stands of the Kastamonu Region

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Abstract

Aim of study: In this study, relationships between ecological factors including topography, climate, soil properties and site productivity of Crimean pine (*Pinus nigra* J.F. Arnold subsp. *pallasiana* (Lamb.) Holmboe) stands in the Kastamonu region of Türkiye were investigated.

Area of study: The study was conducted in Crimean pine stands of Kastamonu region, northwestern Türkiye.

Material and method: A total of thirty-six temporary sample plots inventoried from naturally regenerated pure Crimean pine stands were used in this study.

Main results: Our results indicated that climatic factors including precipitation and temperature had the greatest relationship between site productivity. Since climatic factors showed significant differences between the low and high site index classes, they can be reliably used for site classification for this species in the region. Besides, Principal Component Analysis (PCA) showed a strong separation between the poor and high productive sites, considering these variables. The PCA explained 68.7% of the total variation, with PC1 explaining 37.2% and PC2 explaining 31.5% of the data.

Research highlights: Crimean pine showed an abstemious characteristic in terms of soil requirements. However, it was also concluded that it has higher growth potential with higher precipitation. The results of this study shows not only an optimal site conditions of Crimean pine, but also additional insights for ecologists and forest managers in determining the decision making for forest management and afforestation applications.

Keywords: Climate, Ecological Factors, Environmental Factors, Site Index, Precipitation

Kastamonu Bölgesi Karaçam Meşcerelerinin Yetişme Ortamı Verim Gücüne Etki Eden Ekolojik Faktörler

Öz

Çalışmanın amacı: Bu çalışma kapsamında, Kastamonu Bölgesi'nde yer alan Karaçam (*Pinus nigra* J.F. Arnold subsp. pallasiana (Lamb.) Holmboe) meşcerelerinin yetişme ortamı verim gücü ile topografya, iklim ve toprak özellikleri gibi ekolojik faktörler arasındaki ilişkiler araştırılmıştır.

Çalışma alanı: Bu çalışma, Kastamonu Bölgesi'ndeki Karaçam meşcerelerinde gerçekleştirilmiştir.

Materyal ve yöntem: Çalışma materyali olarak saf Karaçam meşcerelerinden alınmış 36 adet örnek alan verisinden yararlanılmıştır.

Temel sonuçlar: Araştırma sonuçları, yağış ve sıcaklık gibi iklim özellikleri ile yetişme ortamı verim gücü arasında kuvvetli bir ilişki olduğunu göstermiştir. İyi ve fena bonitet sınıfları için iklim özellikleri önemli farklılıklar göstermektedir ve bu özellikler bölgedeki Karaçam meşcerelerinin bonitet sınıflandırması için kullanılabilecektir. Bunun yanında, ekolojik faktörler kullanılarak uygulanan Temel Bileşen Analizi (Principal Component Analysis, PCA) iyi ve fena bonitet sınıfları için kuvvetli bir ayrışma olduğunu göstermiştir. PCA toplam varyansın %68.7'sini açıklamıştır (PC1: %37.2, PC2: %31.5).

Araştırma vurguları: Karaçam toprak istekleri bakımından oldukça kanaatkar bir türdür. Buna rağmen, yüksek yağış alan bölgelerde yüksek büyüme potansiyelleri gösterebilmektedir. Bu çalışma sonuçları Karaçam için optimal yetişme ortamı koşulları hakkında önemli bilgiler sunmaktadır. Ayrıca, bu çalışma ışığında orman yönetimi ve ağaçlandırma çalışmalarında uygun kararların alınabilmesi açısından orman yöneticilerine önemli çıkarımlar sağlayacaktır.

Anahtar Kelimeler: Iklim, Ekolojik Faktörler, Çevresel Faktörler, Yetişme Ortamı Verim Gücü, Yağış

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Introduction

Site quality generally refers to potential site productivity and often described as the ability of a stand to support tree growth (Skovsgaard and Vanclay, 2008). Information about the forest site productivity allows to make correct decisions in forest management process and to identify appropriate silvicultural treatments (Vanclay and Henry, 1988; Bravo-Oviedo et al., 2011; Seki and Sakici, 2017; Özçelik et al., 2019). There is a strong relationship between site productivity and environmental factors such as soil properties, topography and climate (Wang and Klinka, 1996). Therefore, an effective forest management is possible by accurate determination of the site productivity which is influenced by a complex set of these factors (Weiskittel et al., 2011). Methods based on the stand variables correlated with site productivity are more often preferred in practical forestry applications for reasons such as; *i)* the time, labor and cost required to measure the variables in the model to be used, *ii)* unsatisfactory level of relations to be determined for contented species especially in terms of soil and climate demands, *iii)* complexity of multidisciplinary knowledge necessary to explain the relationships between a large number of ecological factors and site productivity.

Since there is a significant correlation between height growth and site productivity (Bolat et al., 2022; Raptis et al., 2024), the estimation of site productivity generally depends on the variable height (Monserud, 1984). The most common variable used to determine site productivity in even-aged stands is site index (SI) which is calculated by averaging height of dominant trees at a specified base age (Payandeh and Wang, 1994; Barrio-Anta and Diéguez-Aranda, 2005). Even site productivity can be estimated for a wooded forest area with a suitable site index model and field measurements, however, it is not possible to determine the potential site productivity of treeless areas for any species. The success of the afforestation projects to be carried out in such areas is related to the determination of the tree species compatible with the ecological conditions. Therefore, it is important for forest managers, decision-makers and investors to define the relationship between ecological conditions and growth potential of tree species.

Studies examining the relationship between site productivity and ecological factors have gained great importance in the last few decades. For example, in Türkiye, relationships between ecological factors and site productivity of *Picea orientalis* (L.) Link (Ercanli et al., 2008), *Pinus brutia* Ten. (Özkan and Kuzugüdenli, 2010), *Pinus pinaster* (Kahyaoğlu and Güvendi, 2020; Özel et al., 2021), *Pinus nigra* J.F. Arnold (Özkan et al., 2008; Ozkan and Gulsoy, 2009; Özkan, 2013; Gülsoy et al., 2014; Oğuzoğlu and Özkan, 2015; Güner et al., 2016; Gülsoy and Cinar, 2019), *Pinus sylvestris* ssp. (Çepel et al., 1977; Güner, 2008; Güner and Yücel, 2015), and *Fagus orientalis* Lipsky (Guner, 2021) were investigated. In all these studies carried out on a regional or local scale, significant relationships were detected between ecological factors and the site productivity. However, more studies are needed for country forests with a highly heterogeneous topography and therefore high variation in climate, especially for distribution of primary tree species.

Forest assets of Türkiye are approximately 23.1 million hectares, of which 58% are productive and 42% degraded. *Pinus nigra* J.F. Arnold is the third most common tree species after *Quercus* spp. and *Pinus brutia* Ten. in terms of total forest areas (approx. 4.2 million ha), and it is the second most common species after *Pinus brutia* Ten. in terms of productive forest areas (approx. 2.9 million ha) (GDF, 2021). Besides, Crimean pine (*Pinus nigra* subsp. *pallasiana* (Lamb.) Holmboe as a subspecies of *Pinus nigra* J.F. Arnold) is the most widespread species in the studied Karadere and Taşköprü Forest Enterprises (FEs), northwestern Türkiye. This species, which has a wide distribution area both throughout the country and in the study area, has also been frequently preferred for afforestation projects. Therefore, planning strategies and success in afforestation projects highly depend on the accurate determination of the relationship of this species with ecological factors. The objective of this study was to investigate the relationships between forest site productivity of the Crimean pine stands located in the Karadere and Taşköprü FEs and ecological factors such as topographic, edaphic and climatic conditions.

Material and Methods

Study Area

The study was carried out in pure and even-aged Crimean pine stands of Karadere and Taşköprü Forest Enterprises (FEs) in the northwest of Türkiye (Figure 1). These FEs are among the most important ones in the Kastamonu Regional Directorate of Forestry (RDF) in terms of forestry activities and wood production. Forests cover approximately 90 and 177 thousand hectares in Karadere and Taşköprü FEs, respectively. Crimean pine is the most widespread species in the region, which covers approximately 34.7% and 39.4% of the total surface area of the Karadere and Taşköprü FEs, respectively (in both pure and mixed-species stands).

Figure 1. Study area

Data and Analysis

A total of thirty-six temporary sample plots (SPs) were inventoried from Karadere (sixteen SPs) and Taşköprü (twenty SPs) FEs. The SPs were selected to represent available range of site conditions. When the history of the sampled stands was investigated, there was no evidence of harmful effects such as forest fire, insect, etc.

Circular sample plot sizes were set as 400, 600 and 800 m^2 for crown closures of ≥71%, 41%-70%, and 11%-40%, respectively. Dominant height (h_0) of each sample plot was determined by averaging the heights of the 100 tallest trees per hectare (e.g., 4 trees in 400 m^2, 8 trees in 800 m^2). The site index model by Seki and Sakici (2022) was used to estimate site index value of each sample plot, using dominant height and stand age. Then, sample plots were divided into three site index classes (low, moderate and high) based on the range of estimated site index values.

In each sample plot, soil samples were taken at 0-15 cm soil depth. Then, the soil samples were air dried and sieved through 2 mm screen. Soil properties including soil acidity (pH), electric conductivity (EC), hygroscopic moisture (HM), organic matter (OM), sand%, silt% and clay% were determined in laboratory studies.

Topographic features such as altitude, slope aspect and slope angle of the investigated stands were identified using the digital elevation model (DEM) in the ArcGIS® software. Aspect values were converted to radiation index (RI) using the following formula (Eq. 1) (Moisen and Frescino, 2002; Özel et al., 2021).

$$RI = \frac{[1-cos((\pi/180)(\text{aspect}-30))]}{2} \quad (1)$$

The data on the climatic features the stands were obtained by using the data of the meteorology station closest to each sample plot (Turkish Meteorological Service, TMS). In order to interpolate the data of these meteorological stations to the sample points, the assumption is adopted that the temperature decreases by 0.5 ℃ and the precipitation increases by 54 mm per 100 m in altitude as recommended by Schreiber. The climatic variables investigated in this study were annual precipitation, precipitation in spring (from March to May), precipitation in summer (from June to August), precipitation in the driest month, mean annual temperature and mean temperature of the coldest month.

Relationships between site index and ecological variables (topographic, edaphic and climatic) were investigated separately, using partial correlation analysis (controlling altitude) to avoid possible spurious correlations.

Since all data did not satisfy the assumptions of parametric tests (Shapiro-Wilk test, p-value < 0.05), they were described by medians and mean absolute deviations. Differences in these variables among site classes were investigated by Kruskal-Wallis test and applying the Mann-Whitney U post-doc test. Ecological (topographic, edaphic and climatic) variables that are thought to affect the site productivity (site index class) were also examined using principal component analysis (PCA). The PCA provides uncorrelated variables, called principal components (PCs), transforming correlated variables. So, this technique has been commonly used such of studies examining various variables which are thought to be correlated with each other. Statistical analyses were performed using R studio version 4.0.2.

Results

Descriptive statistics of the sample plots and ecological variables are given in Table 1. A total of 36 sample plots were taken from the study area, 8 from the high site index class (SI=24.5-30.0 m), 16 from the moderate site index class (SI=19.0-24.5 m), and 12 from the low site index class (SI=13.5-19.0 m). The sample plots were taken from the study area to represent the available range of site classes and ecological factors including altitude. As seen in the table, altitudes of the sample plots vary from 836 to 1452 m, and slope ranges between 5% and 51%. Depending on the altitude, the climatic values also varied considerably.

Kruskal-Wallis test and Mann-Whitney U post-doc tests (Table 1) revealed significant differences in the climatic variables among site index classes. While, it also revealed no significant differences in the topographic and edaphic variables among the site classes. Significant differences of climatic variables were between low and high-moderate sites, except mean annual temperature which differed only between high and low productive sites. According to these results, poor sites in terms of site productivity are easily distinguished from the moderate and high classes by having lower precipitation rates and a cold climate. It's also seen from the table that radiation index changed considerably from high to low site classes, however, this difference was not found significant at the 0.05 level.

Partial correlation analysis (Figure 2) revealed that climatic variables and altitude were significantly (p<0.01) correlated with site index. As seen from the figure, precipitation and altitude showed positive correlation, meaning site index as an indicator of site productivity increased with increase of altitude and precipitation. And, negative significant correlations were found between temperature and site productivity. Besides, there was no significant relationships were detected between site index and edaphic and topographic variables except altitude.

The results of the PCA analyses (Figure 3) are as follows: the first two components account for a total of (PC1: 37.2%, PC2: 31.5%) 68.7% of the total variance (Figure

3a and Figure 3b). The first PC was consisted of climatic variables except C6 (Figure 3c), while the second PC was consisted of the other variables including C6 (Figure 3d). Besides, it’s seen that low and high site index classes were separated with each other, except a few sample plots (Figure 3e). This discrimination was mainly due to the PC1 which consisted of climatic factors. These results also support partial correlation analysis and Kruskal-Wallis test.

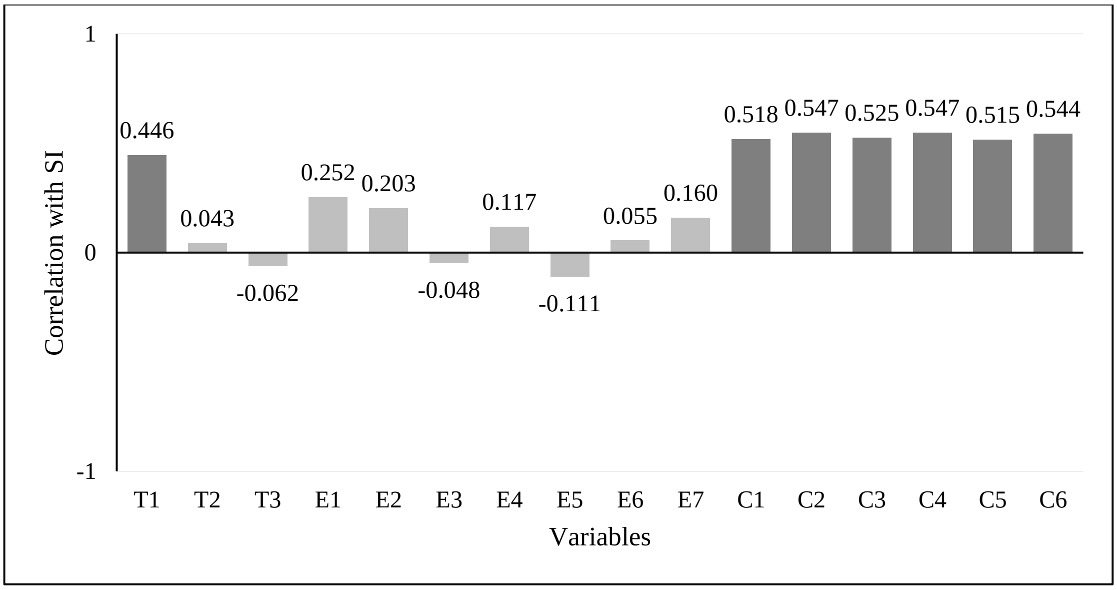

Figure 2. Relationships between site index (SI) and ecological variables including altitude (T1), radiation index (RI), slope (T3), pH (E1), EC (E2), hygroscopic moisture (E3), organic matter (E4), sand% (E5), silt% (E6), clay% (E7), annual precipitation (C1), precipitation in spring (C2), precipitation in summer (C3), precipitation in the driest month (C4), mean annual temperature (C5) and mean temperature of the coldest month (C6). Correlation coefficients are presented above the columns. Bold column indicates significant correlation at the 0.01 level.

Table 1. Variables used in forest site productivity evaluation

Variables	The code	Site index class High (SI=24.5-30.0 m) median (MAD) min – max	Moderate (SI=19.0-24.5 m) median (MAD) min – max	Low (SI=13.5-19.0 m) median (MAD) min – max
Stand				
Site index (m)	SI	27.2 (1.3) 24.8 – 30.0	20.4 (1.4) 19.5 – 24.0	16.3 (1.1) 13.5 – 18.6
Topographic				
Altitude (m)	T1	1297.5 (125.6) A 1000 – 1452	1188.5 (115.3) A 988 – 1434	1120.0 (97.5) A 836 – 1283
Radiation index	T2	0.84 (0.36) A 0.00 – 1.00	0.59 (0.37) A 0.00 – 0.98	0.28 (0.36) A 0.02 – 0.98
Slope (%)	T3	20 (7) A 5 – 35	16 (9) A 5 – 39	25 (8) A 13 – 51
Edaphic				
pH	E1	5.99 (0.62) A 5.25 – 7.34	5.94 (0.55) A 5.31 – 7.35	5.92 (0.80) A 5.21 – 7.41
EC	E2	62.2 (40.6) A 30.6 – 141.9	85.6 (45.71) A 26.8 – 172.4	85.8 (54.69) A 29.8 – 195.1
Hygroscopic moisture	E3	0.74 (0.25) A 0.40 – 1.18	1.18 (0.36) A 0.45 – 2.35	1.18 (0.42) A 0.58 – 1.92
Organic matter	E4	4.60 (1.38) A 2.73 – 7.52	5.63 (1.80) A 2.68 – 9.61	5.65 (2.00) A 2.28 – 9.31
Sand (%)	E5	75.3 (10.59) A 61.9 – 80.5	70.5 (8.00) A 43.6 – 84.4	73.5 (7.41) A 43.7 – 80.8
Silt (%)	E6	10.7 (1.88) A 9.1 – 15.8	11.8 (3.71) A 6.0 – 19.7	10.6 (2.05) A 7.9 – 16.5
Clay (%)	E7	11.6 (9.81) A 8.6 – 25.0	20.9 (6.51) A 9.6 – 38.8	14.1 (6.99) A 9.8 – 39.9
Climatic				
Annual precipitation (mm)	C1	777.5 (39.2) A 702.8 – 848.6	732.4 (31.8) A 628.9 – 816.2	651.8 (41.6) B 588.4 – 741.1
Precipitation in spring (March+April+May) (mm)	C2	393.3 (47.6) A 282.7 – 428.5	321.3 (38.3) A 227.4 – 402.6	250.3 (35.6) B 186.9 – 321.0
Precipitation in summer (June+July+August) (mm)	C3	377.8 (37.8) A 310.1 – 455.9	337.7 (33.9) A 223.5 – 423.5	246.4 (45.6) B 183.0 – 348.4
Precipitation in the driest month (mm)	C4	250.3 (51.8) A 133.2 – 288.0	169.7 (42.4) A 58.8 – 268.6	81.7 (41.7) B 18.3 – 171.5
Mean annual temperature (°C)	C5	13.4 (1.4) A 9.8 – 14.4	11.8 (1.5) AB 8.3 – 14.2	8.8 (1.5) B 8.0 – 11.9
Mean temperature of the coldest month (°C)	C6	1.3 (0.6) A -0.9 – 2.7	1.3 (1.4) A -2.4 – 2.4	-2.0 (1.7) A -2.7 – 1.7

Superscript letters of A, B and C are homogeneous subsets of post-hoc test results following Kruskal-Wallis test ($p<0.05$). If ecological variables have the same letter A, it means no significant difference among the site classes ($p>0.05$).

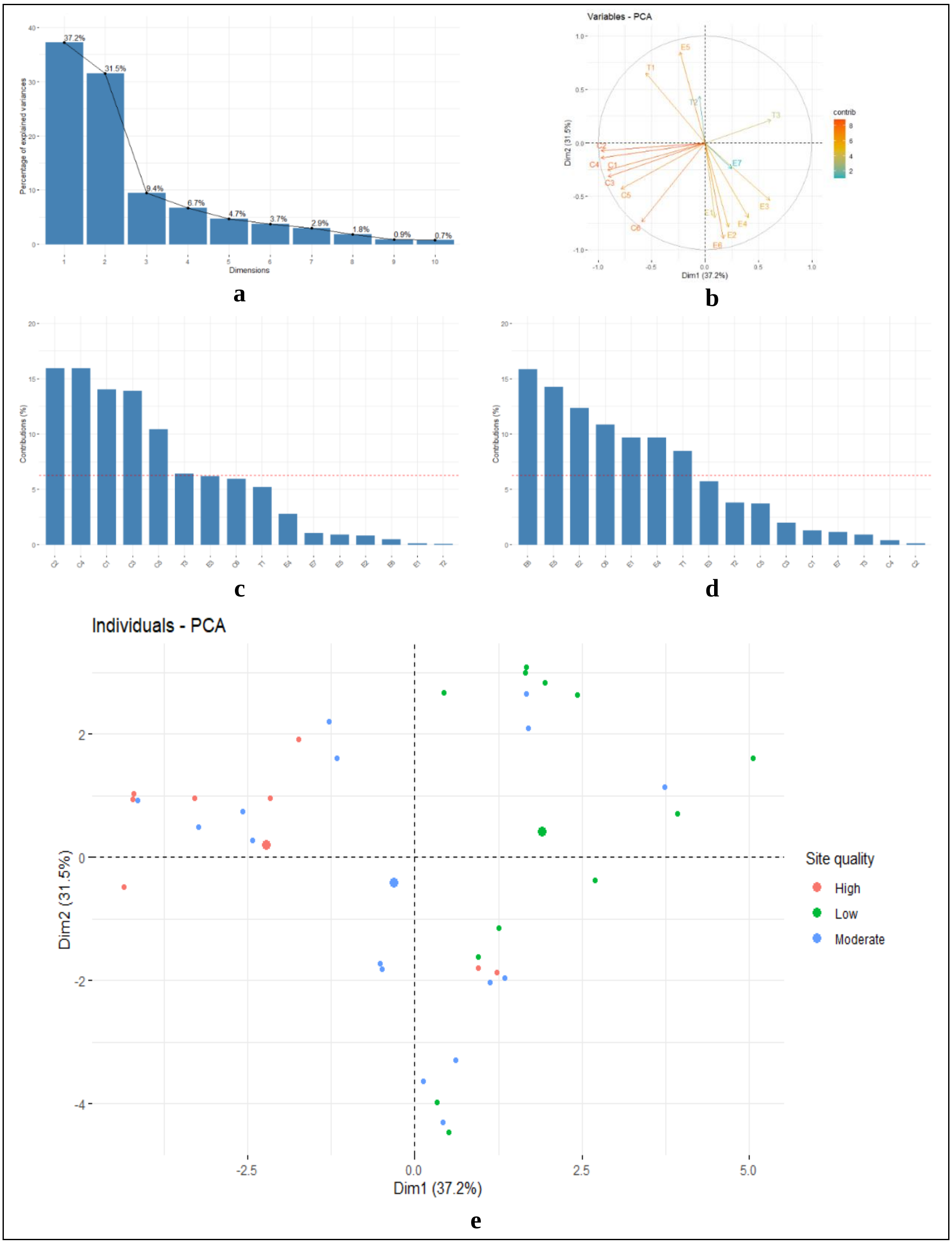

Figure 3. Results of PCA including; a) percentage of variances explained by each principal component, b) graph of variables: positive correlated variables point to the same side of the plot and negative correlated variables point to opposite sides of the graph., c) contribution of variables to PC1, d) contribution of variables to PC2, e) discrimination of sample plots based on the two PCs

Discussions

There was significant positive correlation (p<0.01) between altitude and site productivity of Crimean pine stands in this study. It was expected that an increase in altitude would cause an increase in precipitation, ensuring a humid habitat (Özel et al., 2021). Although altitude commonly shows positive correlation between site productivity of Crimean pine, various results for different species have been reported regarding relationship between altitude and site productivity. Our result supports previous studies conducted for *Pinus sylvestris* (Güner and Yücel, 2015) and *Pinus nigra* J.F. Arnold (Özkan et al., 2008; Gülsoy and Cinar, 2019), while negative correlations were reported for *Picea orientalis* (L.) (Ercanli et al., 2008), *Pinus pinaster* (Bravo-Oviedo et al., 2011) and *Pinus patula* (Nava-Nava et al., 2022). Besides, no significant relationship between site productivity and altitude for *Abies nordmanniana* (Stev.) Spach. subsp. *nordmanniana* (Yener and Duman, 2022), *Pinus pinaster* Ait. (Özel et al., 2021) and *Fagus orientalis* Lipsky (Guner, 2021) was indicated. Superscript letters of A, B and C are homogeneous subsets of post-hoc test results following Kruskal-Wallis test (p<0.05). If ecological variables have the same letter A, it means no significant difference among the site classes (p>0.05).

In this study, correlation between site productivity and slope (%) of the Crimean pine stands was insignificant at the 0.01 level. Opposite findings have been reported of this relationship. Some studies found negative correlations between slope% and site productivity of *Picea orientalis* (L.) (Ercanli et al., 2008), *Pinus brutia* Ten. (Özkan and Kuzugüdenli, 2010) and *Pinus patula* (Quichimbo et al., 2017). Besides, Atalay and Efe (2012) stated that *Pinus nigra* J.F. Arnold stands with high site productivity are more common in flat areas (well drained), and with low site productivity on steep slopes. However, positive correlations between slope% and site productivity of *Pinus nigra* J.F. Arnold (Ozkan and Gulsoy, 2009; Güner et al., 2016), *Pinus sylvestris* ssp. *hamata* (Güner and Yücel, 2015) and *Pinus pinaster* (Özel et al., 2021) were also reported. Our result supports findings of previous study by Guner (2021), which emphasized insignificant relationship between these variables. Actually, it is an expected situation that there will be a negative correlation between the degree of slope and site productivity, since it has a positive effect on soil water and nutrient conditions.

In the study, relationships between edaphic factors and Crimean pine site productivity were not significant ($p > 0.05$). Actually, this result is not surprising considering that Crimean pine is abstemious tree species with respect to soil requirements (Gülsoy and Cinar, 2019). The productivity of this species can vary depending on the weathering degree of the soil (Atalay and Efe, 2012). Similar to the results obtained in this study, there was a weak relationship between site productivity and edaphic factors, and a strong relationship between climate were obtained for *Pinus pinaster* (Bravo-Oviedo et al., 2011). As a result of our study, climatic factors (especially precipitation) were the main drivers of site productivity of Crimean pine stands located in the Kastamonu region. This is the most common result reported in previous studies. For example, Özel et al. (2021) underlined that the site index of *Pinus pinaster* plantations was highly positively correlated with precipitation. Besides, the study by Güner et al. (2016) also stated that annual precipitation and precipitation of the driest month had positive effect on site productivity of Crimean pine forests. However, Nava-Nava et al. (2022) did not found a significant correlation between mean annual precipitation and site index of *Pinus patula* stands.

As seen from the previous studies and the current one, diverse results have been obtained for different species and locations. The comparisons focused on the correlations between site productivity and individual ecological variables. However, as mentioned above, these ecological variables including edaphic, topographic and climatic factors have also integrated and complex effects on site productivity. Besides, ecological demands of each tree species stated above are different from each other. This truth can lead variations in the results. Crimean pine, investigated in this study, is an abstemious tree species with respect to ecological conditions such as edaphic factors. We therefore possibly resulted insignificant relationships between site productivity of this species and most of these factors including edaphic and topographic (except altitude). The datasets obtained in such studies are very important for the results to be achieved. In fact, the distribution and range of data obtained within the scope of the study on ecological factors and stand productivity have a direct effect on the results. For example; if this type of a study is carried out for a tree species with an optimal growth altitude and the sampled stands are generally obtained from above this altitude range, a positive correlation would be detected between site productivity and altitude, and in the opposite case, a negative correlation would be detected. Besides, the same will be true for climatic and edaphic factors that are directly and/or indirectly affected by altitude. The possible reasons for the above-mentioned and contradictory results of studies in different regions may also be due to this sampling design.

Conclusion

Crimean pine is a very conscientious species in terms of ecological demands. However, it still grows at higher potentials in humid environments with high rainfall. For these reasons, it is important to prefer Crimean pine in afforestation studies to be carried out in regions with these characteristics. Alternatively, it seems reasonable to manage the Crimean pine stands in areas with such characteristics for the purpose of wood production, and to establish other stands to purify drinkable water, stabilize inclined soil to erosion, improve air quality and recreational facility. Management strategies are very important here, as trees have low growth ability at low altitudes, and so they are vulnerable to other external pests. In these regions, it is crucial to prioritize forest management for ecological rather than economic purposes, and to take measures against other pests such as insects.

Forest scientists are in search of a solution to climate change, especially in the last few decades. The results of such studies will enable the development of alternative decision-making and management strategies in parallel with climate change forecasts.

In this study, site index values were obtained from the temporary sample plots. Besides, since there are no meteorological stations in the sampled stands, climate data were obtained by interpolating the nearest station data. Then, the relationships between the site index values and ecological variables including the meteorological variables were investigated. In order to obtain the most consistent results, permanent sample plots and meteorological stations established within these plots and obtaining continuous data are needed.

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Ethics Committee Approval

N/A

Peer-review

Externally peer-reviewed.

Author Contributions

Conceptualization: M.S., O.E.S.; Investigation: M.S., O.E.S.; Material and Methodology: M.S., O.E.S.; Visualization: M.S., O.E.S.; Writing-Original Draft: M.S., O.E.S.; Writing-review & Editing: M.S., O.E.S. All authors have read and agreed to the published version of manuscript

Conflict of Interest

The authors have no conflicts of interest to declare.

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References

Atalay, I. & Efe, R. (2012). Ecological attributes and distribution of Anatolian black pine [*Pinus nigra* Arnold. subsp. *pallasiana* Lamb.Holmboe] in Turkey. *Journal of Environmental Biology*, 33, 509-519.

Barrio-Anta, M. & Diéguez-Aranda, U. (2005). Site quality of pedunculate oak (*Quercus robur* L.) stands in Galicia (northwest Spain). *European Journal of Forest Research*, 124(1), 19-28.

Bolat, F., Ülker, O. & Günlü, A. (2022). Nonlinear height-diameter models for Hungarian oak (*Quercus frainetto* Ten.) in

Dumanlı Forest Planning Unit, Çanakkale/Turkey. *Austrian Journal of Forest Science*, 139(3), 199–220.

Bravo-Oviedo, A., Roig, S., Bravo, F., Montero, G. & Del Rio Gatelurrutia, M.G. (2011). Environmental variability and its relationship to site index in Mediterranean maritine pine. *Forest Systems*, 20(1), 50-64.

Çepel, N., Dündar, M. & Günel, A. (1977). *Türkiye'nin önemli yetişme bölgelerinde saf sarıçam ormanlarının gelişimi ile bazı edafik ve fizyografik etmenler arasındaki ilişkiler.* Tübitak, Tarım ve Ormancılık Araştırma Grubu, Proje No: TOVAG 154, Tübitak Publications No:354, TOVAG Seri No: 65, Ankara. (in Turkish)

Ercanli, I., Gunlu, A., Altun, L. & Baskent, E.Z. (2008). Relationship between site index of oriental spruce [*Picea orientalis* (L.) Link] and ecological variables in Maçka, Turkey. *Scandinavian Journal of Forest Research*, 23(4), 319-329.

GDF, (2021). Forestry statistics. Ankara (Turkey): General Directorate of Forestry Publications. (in Turkish)

Guner, S.T. (2021). Relationships between site index and ecological variables of oriental beech forest in the Marmara Region of Turkey. *Fresenius Environmental Bulletin*, 30, 6920-6927.

Gülsoy, S. & Cinar, T. (2019). The relationships between environmental factors and site index of Anatolian black pine (*Pinus nigra* Arn. subsp. *pallasiana* (Lamb.) Holmboe) stands in Demirci (Manisa) district, Turkey. *Applied Ecology and Environmental Research*, 17(1), 1235-1246.

Gülsoy, S., Süel, H., Çelik, H., Özdemir, S. & Özkan, K. (2014). Modelling site productivity of Anatolian black pine stands in response to site factors in Buldan District, Turkey. *Pakistan Journal of Botany*, 46(1), 213-220.

Güner, Ş.T. (2008). *Bozkıra geçiş bölgesindeki sarıçam (Pinus sylvestris L. subsp. hamata (Steven) Fomin) ormanlarının gelişimi ile bazı yetişme ortamı özellikleri arasındaki ilişkiler.* Çevre ve Orman Bakanlığı, Orman Toprak ve Ekoloji Araştırmaları Enstitüsü Müdürlüğü Publication, 358-3, 41s, Eskişehir. (in Turkish)

Güner, Ş.T. & Yücel, E. (2015). The relationships between growth of *Pinus sylvestris* ssp. *hamata* forests with ecological factors in Central Anatolia. *Biological Diversity and Conservation*, 8(3), 6-19.

Güner, Ş., Çömez, A., Özkan, K., Karataş, R. & Çelik, N. (2016). Modelling the productivity of Anatolian black pine plantations in Turkey. *Journal of the Faculty of Forestry Istanbul University*, 66(1), 159-172. (in Turkish)

Kahyaoğlu, N. & Güvendi, E. (2020). The relationships between the site index of Maritime pine planting areas and some ecological factors (case of Sinop-Bektaşa region). *Turkish Journal of Forest Science*, 4(1), 11-25. (in Turkish)

Moisen, G.G. & Frescino, T.S. (2002). Comparing five modelling techniques for predicting forest characteristics. *Ecological Modelling*, 157(2-3), 209-225.

Monserud, R.A. (1984). Height growth and site index curves for inland Douglas-fir based on stem analysis data and forest habitat type. *Forest Science*, 30(4), 943-965.

Nava-Nava, A., Santiago-García, W., Quiñonez-Barraza, G., Santos-Posadas, H.M.D.L., Valdez-Lazalde, J.R. & Ángeles-Pérez, G. (2022). Climatic and topographic variables improve estimation accuracy of Patula pine forest site productivity in Southern Mexico. *Forests*, 13(8), 1277.

Oğuzoğlu, Ş. & Özkan, K. (2015). Productivity distribution modelling of Anatolian Black Pine (*Pinus nigra* subsp. *pallasiana* var. *pallasiana*) in the Türkmen Mountain, Eskişehir. *Biyolojik Çeşitlilik ve Koruma*, 8(2), 134-140. (in Turkish)

Ozkan, K. & Gulsoy, S. (2009). Effect of environmental factors on the productivity of crimean pine (*Pinus nigra* ssp. *pallasiana*) in Sutculer, Turkey. *Journal of Environmental Biology*, 30(6), 965-970.

Özçelik, R., Cao, Q.V., Gómez-García, E., Crecente-Campo, F. & Eler, Ü. (2019). Modeling dominant height growth of cedar (*Cedrus libani* A. Rich) stands in Turkey. *Forest Science,* 65(6), 725-733.

Özel, C., Güner, Ş.T., Türkkan, M., Akgül, S. & Şentürk, Ö. (2021). Modelling the site index of *Pinus pinaster* plantations in Turkey using ecological variables. *Journal of Forestry Research,* 32(2), 589-598.

Özkan, K. (2013). Modeling productivity of Crimean pine by using fuzzy logic applications. *Eurasian Journal of Forest Science,* 1(1), 51-59.

Özkan, K. & Kuzugüdenli, E. (2010). The relations between site index of brutian pine (*Pinus brutia* Ten.) and ecological site factors in Sütçüler district from the Mediterranean region. *Turkish Journal of Forestry,* 11(1), 16-29. (in Turkish)

Özkan, K., Gülsoy, S. & Mert, A. (2008). Interrelations between height growth and site characteristics of *Pinus nigra* Arn. ssp. *pallasiana* (Lamb.) Holmboe. *The Malaysian Forester*, 71, 9-16.

Payandeh, B. & Wang, Y. (1994). Relative accuracy of a new base-age invariant site index model. *Forest Science,* 40(2), 341-348.

Quichimbo, P., Jiménez, L., Veintimilla, D., Tischer, A., Günter, S., Mosandl, R. & Hamer, U. (2017). Forest site classification in the Southern Andean region of Ecuador: A case study of pine plantations to collect a base of soil attributes. *Forests,* 8(12), 473.

Raptis, D.I., Papadopoulou, D., Psarra, A., Fallias, A.A., Tsitsanis, A.G. & Kazana, V. (2024). Height-diameter models for King Boris fir (*Abies borisii regis* Mattf.) and Scots pine (*Pinus sylvestris* L.) in Olympus and Pieria Mountains, Greece. *Journal of Mountain Science*, 21(5), 1475-1490.

Seki, M. & Sakici, O.E. (2017). Dominant height growth and dynamic site index models for Crimean pine in the Kastamonu–Taşköprü region of Turkey. *Canadian Journal of Forest Research,* 47(11), 1441-1449.

Seki, M. & Sakici, O.E. (2022). Ecoregional variation of Crimean pine (*Pinus nigra* subspecies *pallasiana* [Lamb.] Holmboe) stand growth. *Forest Science*, 68(5-6), 452-463.

Skovsgaard, J.A. & Vanclay, J.K. (2008). Forest site productivity: a review of the evolution of dendrometric concepts for even-aged stands. *Forestry: An International Journal of Forest Research,* 81(1), 13-31.

Vanclay, J.K. & Henry, N.B. (1988). Assessing site productivity of indigenous cypress pine forest in southern Queensland. *The Commonwealth Forestry Review,* 67(1), 53-64.

Wang, G.G. & Klinka, K. (1996). Use of synoptic variables in predicting white spruce site index. *Forest Ecology and management,* 80(1-3), 95-105.

Weiskittel, A.R., Hann, D.W., Kershaw Jr, J.A. & Vanclay, J.K. (2011). *Forest growth and yield modeling*. John Wiley and Sons.

Yener, I. & Duman, A. (2022). The relationships between some site characteristics and site index of Caucasian fir (*Abies nordmanniana* (Stev.) Spach. subsp. *nordmanniana*) stands: A case study from Şavşat Forest Enterprise Directorate. *Artvin Coruh University Journal of Forestry Faculty*, 23(1), 113-126. (in Turkish).