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Comparison of plant species diversity, site index, and mean tree ring width values of different altitudinal zones in Turkish pine stands

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Abstract: Diversity and productivity have consistently been central topics in forestry research. With the advent of climate change, the need to better understand increasingly scarce natural resources has become critical for sustainable use. In this study, differences in alpha species diversity, site index, and tree-ring widths across three different altitudinal zones were analyzed. Additionally, the relationships between these parameters and environmental variables were analyzed. Initially, a normality test was applied to the data. Due to the failure to meet the normality assumption, non-parametric methods were preferred for data analysis. The Kruskal-Wallis test was applied to identify differences between groups. To determine the relationships of alpha species diversity, site index, and tree-ring width with environmental variables, Spearman correlation analysis was used, focusing on the Shannon and Simpson indices. Our results showed that Shannon and Simpson diversity differ across different altitudinal zones, while no differences were observed in terms of site index and annual ring growth. On the other hand, Bio1 and Bio12 were identified as the most influential variables on diversity. Additionally, there was a relatively low negative correlation between the site index and slope variable and between annual ring growth and the radiation index variable. The findings obtained from this study provided important insights for forestry management. In particular, understanding the effects of altitude-dependent abiotic factors on species diversity and tree ring growth will enable more accurate planning.
Keywords: Biodiversity, Kruskal-Wallis test, *Pinus brutia*, Productivity, Tree ring growth

Farklı yükselti zonlarındaki kızılçam meşcerelerinde bitki türü çeşitliliği, bonitet indeksi ve yıllık halka genişliği değerlerinin karşılaştırılması

Öz: Çeşitlilik ve verimlilik konuları ormancılık alanında daima trend olarak araştırmacıların odağında olmuştur. Özellikle iklim değişikliği ile beraber kıt kaynak niteliğinde olan doğal kaynakların daha iyi bir şekilde anlaşılmasına olan ihtiyaç sürdürülebilir kullanımın temelini oluşturmaktadır. Bu kapsamda çalışmada üç farklı yükselti zonunda alfa tür çeşitliliği, bonitet indeksi ve yıllık halka genişlikleri arasındaki farklar analiz edilmiştir. Ayrıca bu parametrelerin çevresel değişkenler ile olan ilişkileri belirlenmiştir. Verilere ilk olarak normallik testi uygulanmıştır. Normallik varsayımının sağlanamamasından ötürü verilerin analiz edilmesinde non parametrik yöntemler tercih edilmiştir. Gruplar arasındaki farkların belirlenmesi için Kruskal-Wallis testi uygulanmıştır. Shannon ve Simpson indekslerine yönelik hesaplanan alfa tür çeşitlilikleri, bonitet indeksi ve yıllık halka büyümesinin çevresel değişkenler ile ilişkilerinin belirlenebilmesi için Spearman korelasyon analizi kullanılmıştır. Sonuç olarak farklı yükselti zonlarında Shanon ve Simpson çeşitlilikleri bakımından fark tespit edilirken, bonitet indeksi ve yıllık halka büyümesi bakımından fark olmadığı görülmüştür. Diğer yandan çeşitlilikler üzerinde en etkili değişkenler olarak Bio1 ve Bio12 tespit edilmiştir. Ayrıca bonitet indeksi ile eğim değişkeni, yıllık halka büyümesi ile de radyasyon indeksi değişkeni arasında nispeten yüksek olmayan negatif korelasyon olduğu görülmüştür. Bu çalışmadan elde edilen bulgular ormancılık yönetimi için önemli öngörüler sunmuştur. Özellikle, yüksekliğe bağlı abiyotik faktörlerin tür çeşitliliği ve yıllık halka büyümesi üzerindeki etkisinin anlaşılması daha doğru planlamaların yapılmasına olanak sağlayacaktır.
Anahtar kelimeler: Biyolojik çeşitlilik, Kruskal-Wallis testi, *Pinus brutia*, Verimlilik, Yıllık halka büyümesi

1. Introduction

Climate change is one of the most important factors affecting ecosystems (Tekin et al., 2018; Acarer, 2024a). The anthropogenic acceleration of climate change over the last century has led to irreversible consequences for ecosystems (Özdemir et al., 2020). The consequences that we are forced to face often manifest themselves in the form of changes, restrictions or complete eradication of the distribution areas of plant and animal species.

In other words, climate change is known to have a direct impact on biodiversity (Mert and Acarer, 2018). This dominant behavior of climate change on species also affects the systems in which these species play an economic role (Acarer, 2024b). Primary forest tree species are particularly important in this respect. Primary forest trees perform many ecological and economic functions. Among them, the most widespread species in Türkiye is the Turkish pine (*Pinus brutia* Ten.) (Özdemir et al., 2022; Özdemir and Çınar, 2023). The Turkish pine is found in the Aegean and Mediterranean regions, where the Mediterranean climate prevails, as well as

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in the coastal areas of the western Black Sea region (Keten and Gülsoy, 2020). There are studies that show the potential distribution areas and potential production areas of the Turkish pine (Özdemir, 2022; Negiz et al., 2024). In these studies, it was stated that Turkish pine is distributed in wide areas in the Mediterranean and Aegean regions, is mostly the dominant species in stands where it is mixed with other species, and its productivity is relatively high in areas up to 1000 m above sea level. In some studies, it has been stated that dendrochronological findings can also reveal important findings regarding productivity (Lo et al., 2013; Salehnia and Ahn, 2022). However, dendrochronology studies on this species are limited. Among these, dendroclimatology studies that reveal the relationship between annual rings and climate are notably insufficient (Reis et al., 2018; Mechergui et al., 2021). These studies have particularly revealed a negative correlation between temperature increase and annual ring growth. As understood, climate change affects both species diversity and tree ring growth. On the other hand, the relationship between species diversity and tree ring growth should not be overlooked (Negiz et al., 2024). For this purpose, species diversity was calculated in the study and correlated with both environmental parameters and tree ring growth. In order to observe the indirect effects of climate change, sampling was carried out at three different altitudinal levels to determine whether there were statistically significant differences between the altitudinal groups.

Based on the information provided, within the scope of this study, the relationships between climatic parameters, diversity indices, and tree ring growth were determined and suggestions that could be useful for ecosystem-based multi-purpose planning studies were presented.

2. Material and method

2.1. Study area

The study was carried out in the Sütçüler district of Isparta province. Sütçüler is located in the Lake District of the Mediterranean Region. The study area covers approximately 128000 hectares, with altitudes ranging from 250 to 2500 meters. The total annual rainfall is 950 mm, and the average annual temperature is 12.1°C. The most common bedrock types are conglomerate, limestone, and sandstone, while the dominant forest tree species is Turkish pine (Özdemir et al., 2017; Baş et al., 2020).

2.2. Data collection and diversity estimation

Field studies were conducted in sample plots at three different altitudinal levels: below 750 meters (minimum elevation: 288 m), between 750 and 1250 meters, and above 1250 meters (maximum elevation: 1295 m). Data were collected for a total of 30 sample areas, each measuring 20 m x 20 m, with 10 different sample plots at each altitudinal zone. To avoid any variability due to aspect, only sample plots with a southern aspect were selected. The cover values of plant species in the sample plots were recorded according to the Braun-Blanquet scale. These values were then converted according to Westhoff and Maarel (1973) by assigning a value between 1 and 9 to each coverage area. Species diversity is determined through calculations performed for the alpha, beta, and gamma components. Alpha represents the diversity of sample areas, beta represents the dissimilarity between sample areas, and gamma represents the total diversity (Özdemir et al., 2017; Negiz and Aygül, 2019). In the present study Shannon-Wiener (H') (Shannon, 1948) and Simpson (D) (Simpson, 1949) alpha diversity values were calculated using the transformed values by BİÇEB software (Özkan et al., 2020).

$$H' = -\sum p_i \ln p_i \quad (1)$$

$$\mathrm{D} = 1 - \sum_{i=1}^{s} p_i^{\,2} \quad (2)$$

Where H' is the Shannon-Wiener diversity index (1), D is the Simpson diversity index (2), and p_i is the proportional values of species (Shannon, 1948; Simpson, 1949; Özdemir et al., 2017).

Following the vegetation sampling, two increment cores were taken from each plus tree at an angle of 90 degrees. We selected plus trees since these are less affected by silvicultural processes, are more resistant to diseases, are an indicator of growth and development, and represent the yield strength of the forest stand (Clark and Wilson, 2005; Özdemir and Çınar, 2023). The upper height values of plus trees may differ according to the age of the stands. After the increment cores were collected, they were digitized and compared to identify missing or incorrect rings. This eliminated the measurement errors.

The winDENDRO software was used to measure the increment cores. First, the increment cores were scanned with a high-resolution scanner, and the images were saved in “tif” format at 600 dpi. The images were then processed in the winDENDRO software to determine the width of the annual rings and the ages of the trees. The scanning image of one of the sampled trees core is presented in Figure 1.

Figure 1. Scanning image of tree ring widths.

Once the increment core samples had been scanned and imported into the software, the outermost part of the tree ring was initially marked, and the value for the year of measurement was assigned. Subsequently, each tree ring was precisely marked by zooming in on the automatically identified and marked tree rings by the software. The measured tree ring widths were saved in txt format and then transferred to MS Excel. By comparing the tree ring widths measured from two different angles for each tree, false and missing rings were identified. This process allowed for the determination of the average tree ring widths for the relevant tree using the validated data.

Using the calculated diameter at breast height and tree height values, the upper heights of the Turkish pines were indexed to 75 years (Kalıpsız, 1963), and site index values were also calculated. "Upper height" in the context of forestry, particularly in relation to site index calculations, typically refers to the dominant height of the tallest trees in a stand. It is often defined as the average height of the tallest trees (often the top 20% in height) in a particular area. These trees are usually not suppressed by competition and are used as indicators of the site's productivity (Kalıpsız, 1963).

After calculating the diversity indices, annual ring widths, and site index values, the topographic and climatic variables for the sample areas were created. The topographic variables included altitude, slope, radiation index (Radind), heat index (Heatind), and topographic position index (Topind). The climatic variables included the mean annual temperature (Bio1) and total annual precipitation (Bio12). Altitude map covering the study area was first downloaded from the EarthExplorer database (EarthExplorer, 2024) at 30 m resolution. Then slope and Topind maps were created using “3D Analyst” and “Topography” tools, respectively. The Radind variable was obtained using the "raster calculator" tool based on the approach proposed by Roberts and Cooper (1989), while Heating was derived according to the method suggested by Geiger (1966). Bio1 and Bio12 variables were downloaded from WorldClim database at 30 arc second (~1 km) resolution (Fick and Hijmans, 2017). After all the variables were created, they were all imported into the ArcMap program. Finally, the "Extract Multi Values to Point" tool was used to assign the corresponding values to the attribute table of each variable.

2.3. Statistical analysis

As the normality assumption was not met, the Kruskal-Wallis method, a non-parametric approach, was used to examine the differences in diversity, productivity and tree ring width between the different altitudinal zones. Subsequently, Spearman correlation analysis was applied to identify the relationships between environmental variables, site index, tree ring growth, and diversity values. All statistical analyses were carried out using the R programming language (R Core Team, 2024).

3. Results and discussion

3.1. Results of diversity calculations

Simpson and Shannon-Wiener diversity indices were calculated based on coverage area values (Table 1).

As seen in Table 1, alpha diversities were calculated using the coverage area values of a total of 30 samples. Diversity values for Shannon range from 1.672 to 3.096, with an average value of 2.268. For Simpson, diversity values range from 0.803 to 0.95, with an average value of 0.886.

3.2. Results of tree ring widths, site index and diversity indices

Tree ring widths calculated in WinDendro software and site index values calculated according to Kalıpsız (1963) are given in Table 2. According to these results, average tree ring widths vary between 0.9805 and 4.5669, and site index values vary between 11 and 28.5455.

Table 1. Alpha diversity values calculated for sample plots (sp)

sp	Simpson	Shannon	sp	Simpson	Shannon	sp	Simpson	Shannon
sp1	0.8034	1.672	sp11	0.9487	3.096	sp21	0.9047	2.338
sp2	0.8230	1.756	sp12	0.9391	2.814	sp22	0.9047	2.338
sp3	0.8360	1.798	sp13	0.9391	2.814	sp23	0.8840	2.282
sp4	0.8555	1.983	sp14	0.8796	2.221	sp24	0.8796	2.149
sp5	0.8810	2.102	sp15	0.8796	2.221	sp25	0.9071	2.342
sp6	0.8796	2.149	sp16	0.8473	1.903	sp26	0.9071	2.342
sp7	0.8796	2.149	sp17	0.8731	2.083	sp27	0.9355	2.835
sp8	0.8796	2.149	sp18	0.8704	2.141	sp28	0.8793	2.235
sp9	0.8522	1.931	sp19	0.8704	2.141	sp29	0.9281	2.622
sp10	0.9501	2.918	sp20	0.8930	2.360	sp30	0.8796	2.149

Table 2. Mean tree ring widths

Tree	Mean tree ring	Site index value	Tree	Mean tree ring	Site index value	Tree	Mean tree ring	Site index value
Tree1	1.7037	15.3103	Tree11	1.7034	12.8571	Tree21	2.4740	16.9333
Tree2	2.7465	15.8261	Tree12	1.3505	11.2727	Tree22	2.4740	16.9333
Tree3	1.2309	14.9655	Tree13	1.3505	11.2727	Tree23	2.2642	14.7619
Tree4	2.3697	15.5200	Tree14	2.3592	15.6842	Tree24	2.6867	19.4286
Tree5	2.6454	11.0000	Tree15	2.3592	15.6842	Tree25	4.3557	28.5455
Tree6	2.5642	17.5200	Tree16	2.8895	19.1667	Tree26	4.3557	28.5455
Tree7	1.2978	11.8182	Tree17	3.2072	16.6667	Tree27	3.3147	17.3846
Tree8	2.7312	16.6923	Tree18	1.8394	14.2963	Tree28	1.7813	13.2727
Tree9	3.8879	20.3636	Tree19	1.8394	14.2963	Tree29	4.5669	17.5000
Tree10	0.9805	14.9333	Tree20	2.0045	14.5455	Tree30	2.8472	20.8889

3.3. Environmental variables

Environmental variable values corresponding to each sample area are given in Table 3. In addition, the minimum, maximum and average values of each variable are presented at the bottom of the table.

3.4. Statistical analysis

The Shapiro-Wilk normality test was used to select the appropriate method for correlating the data, and it was found that the assumption of normality was not met ($p<0.05$). Therefore, a logarithmic transformation was applied to the data and the normality test was repeated. However, even after this transformation, the assumption of normality was still not met ($p<0.05$). Therefore, non-parametric methods were chosen for the statistical analyses. The Kruskal-Wallis test was used to determine whether there were statistically significant differences in diversity, site index, and mean tree ring widths among the three different altitudinal levels. The results of the analyses regarding diversity, site index, and mean tree ring widths across the altitudinal zones are presented in Table 4.

As can be seen in Table 4, there are significant differences between the altitudinal zones in terms of both the Shannon and Simpson diversity index values. However, no differences were found for mean tree ring widths and site index values.

Table 3. Values of environmental variables of sample plots

	Altitude	Slope	Radind	Sicind	Topind	Bio1	Bio12
sp1	1287	17	0.5764	0.8311	-102.1870	11.180	1397.30
sp2	1271	14	0.5427	0.8233	-123.7030	11.180	1397.30
sp3	1292	15	0.3283	0.7933	-101.5360	11.180	1397.30
sp4	1271	14	0.5427	0.8233	-123.7030	11.180	1397.30
sp5	1041	18	0.2213	0.8132	-170.2890	11.994	1103.90
sp6	1295	3	0.9665	0.8199	26.0354	11.269	1123.40
sp7	1295	3	0.9665	0.8199	26.0354	11.269	1123.40
sp8	1295	3	0.9665	0.8199	26.0354	11.269	1123.40
sp9	934	7	0.4373	0.8249	-58.1422	13.147	1323.90
sp10	1049	3	0.5995	0.8143	41.1475	12.521	1019.20
sp11	1051	2	0.1076	0.8068	51.8647	12.521	1019.20
sp12	346	12	0.9574	0.8580	-293.2570	17.384	1001.29
sp13	346	12	0.9574	0.8580	-293.2570	17.384	1001.29
sp14	1295	3	0.9665	0.8199	26.0354	11.269	1123.40
sp15	288	8	0.9146	0.8409	-259.8020	17.492	1009.53
sp16	943	10	0.5698	0.8401	-60.8881	13.147	1323.90
sp17	943	10	0.5698	0.8401	-60.8881	13.147	1323.90
sp18	305	15	0.9137	0.8669	-250.2300	17.492	1009.53
sp19	305	15	0.9137	0.8669	-250.2300	17.492	1009.53
sp20	878	17	0.9984	0.8685	-19.2936	13.702	875.969
sp21	602	13	0.6696	0.8550	-88.9392	16.184	1113.240
sp22	602	13	0.6696	0.8550	-88.9392	16.184	1113.240
sp23	867	9	0.9640	0.8406	-28.0330	13.702	875.969
sp24	1295	3	0.9665	0.8199	26.0354	11.269	1123.400
sp25	648	10	0.0294	0.7659	-83.4317	15.298	1010.190
sp26	648	10	0.0294	0.7659	-83.4317	15.298	1010.190
sp27	930	17	0.8624	0.8765	-203.3940	12.906	1035.090
sp28	960	21	0.4062	0.8502	-95.4103	13.108	1134.970
sp29	678	13	0.4233	0.8079	-117.2230	14.895	944.150
sp30	1295	3	0.9665	0.8199	26.0354	11.269	1123.400
Minimum	288	2	0.0294	0.7659	-293.2570	11.180	875.969
Maximum	1295	21	0.9984	0.8765	51.8647	17.492	1397.300
Mean	908.5	10.433	0.6667	0.8302	-90.2327	13.577	1119.592

Table 4. Kruskal-Wallis test results

	Chi-squared	p value
Shannon	7.8521	0.0197
Simpson	7.3785	0.0249
Mean tree ring	0.2177	0.8969
Site index	0.9811	0.6123

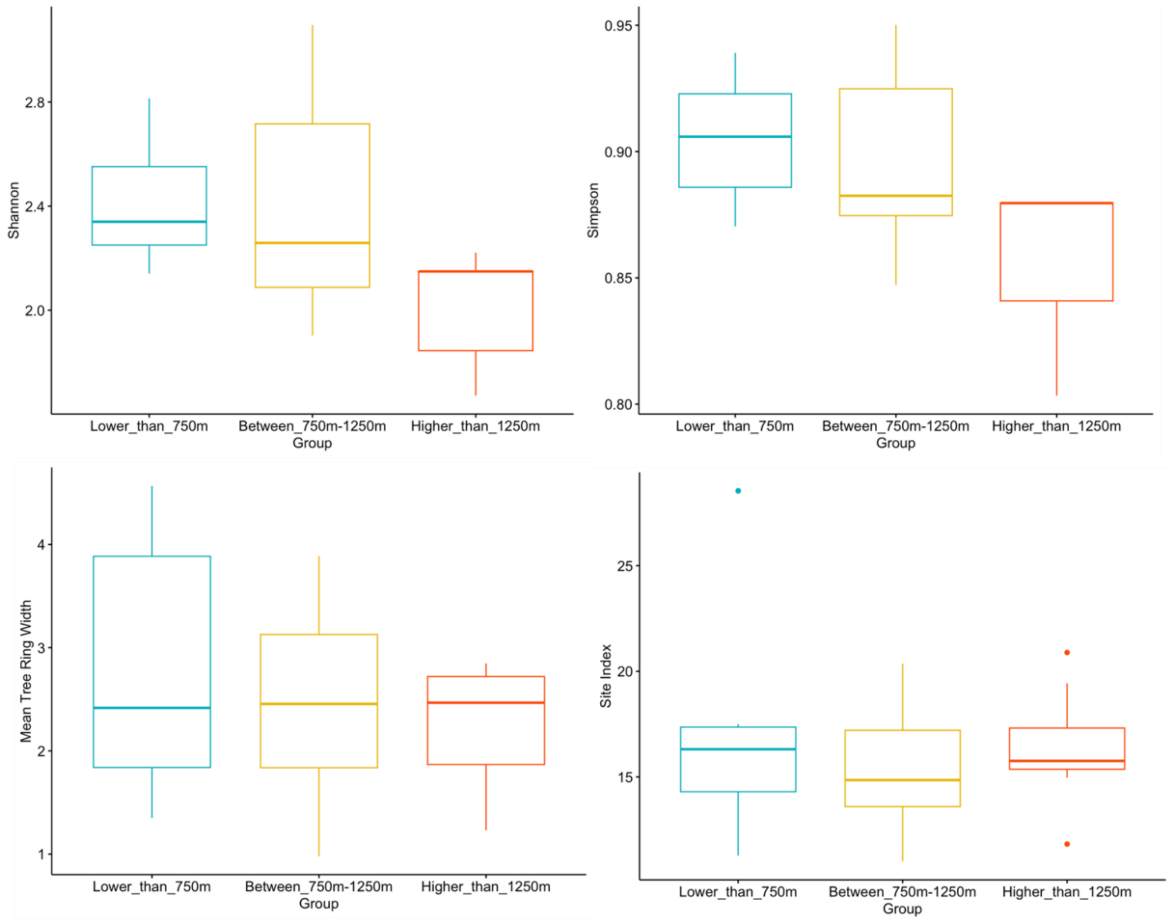

Figure 2. Results of the box plots for the Kruskal-Wallis test

According to Figure 2, it is evident that the Shannon and Simpson diversity values for sample areas corresponding to altitudinal zones above 1250 meters significantly differ from those of the other groups. However, it is clear that there is no difference in terms of mean tree ring widths and site index values.

There are several studies conducted on different species that show the variation in tree ring growth with elevation. For instance, Villalba et al. (1997) in their study on *Nothofagus pumilio* (Poepp. & Endl.) Krasser in Argentina, similar to our study, tree ring widths were examined across three different elevation zones. The study also suggested that the variation in mean tree ring width is primarily related to changes in temperature and precipitation during the spring and summer months. Furthermore, it also noted that the response to climate change could be influenced by local elevation differences. This was attributed to local conditions, such as topographic position and forest structure, which affect snow accumulation and persistence. In the study by Klippel et al. (2017), it was found that there could be differences related to elevation, and aspect could also make a significant difference. In our study, to isolate the effect of elevation more purely, sampling was conducted only from south-facing areas, avoiding any differences due to aspect. It was also found that there was no statistically significant difference between the elevation zones in terms of site index values.

Spearman correlation analysis was used to determine the relationships between diversity, site index, and tree ring widths with environmental variables.

As can be seen from the correlation analysis results (Figure 3), the Shannon and Simpson diversity index values have a positive relationship with Bio1 ($p<0.05$) and a negative relationship with Bio12 ($p<0.001$). Similar results regarding the relationship between elevation-dependent climate parameters and diversity were obtained by Moradi et al. (2020) that conducted to determine which function describes Species–area relationships (SARs) at different elevations and explored how variations in environmental characteristics influence SAR shape in Alborz Mountains (Iran). In their study, the researchers found a negative relationship between elevation and species richness. In our study, the negative and strong relationship between the Bio1 variable and elevation is consistent with the results of the aforementioned study. McCain and Grytnes (2010) also showed how elevation-dependent abiotic factors influence flora and fauna diversities. In their research, they identified four main trends in species richness with elevation: decreasing richness with increasing elevation, plateaus in richness at low elevations then decreasing with or without a mid-elevation peak and a unimodal pattern with a mid-elevational peak.

Tree ring growth was found to be highly correlated with the site index. It is well known that tree ring growth of species in productive areas is quite good (Taylor, 1981; Lopatin et al., 2006; Gea-Izquierdo et al., 2014). No other statistically significant variables were identified apart from mean tree ring width and site index, but there was a relatively high negative relationship with the variables Radind and Heatind.

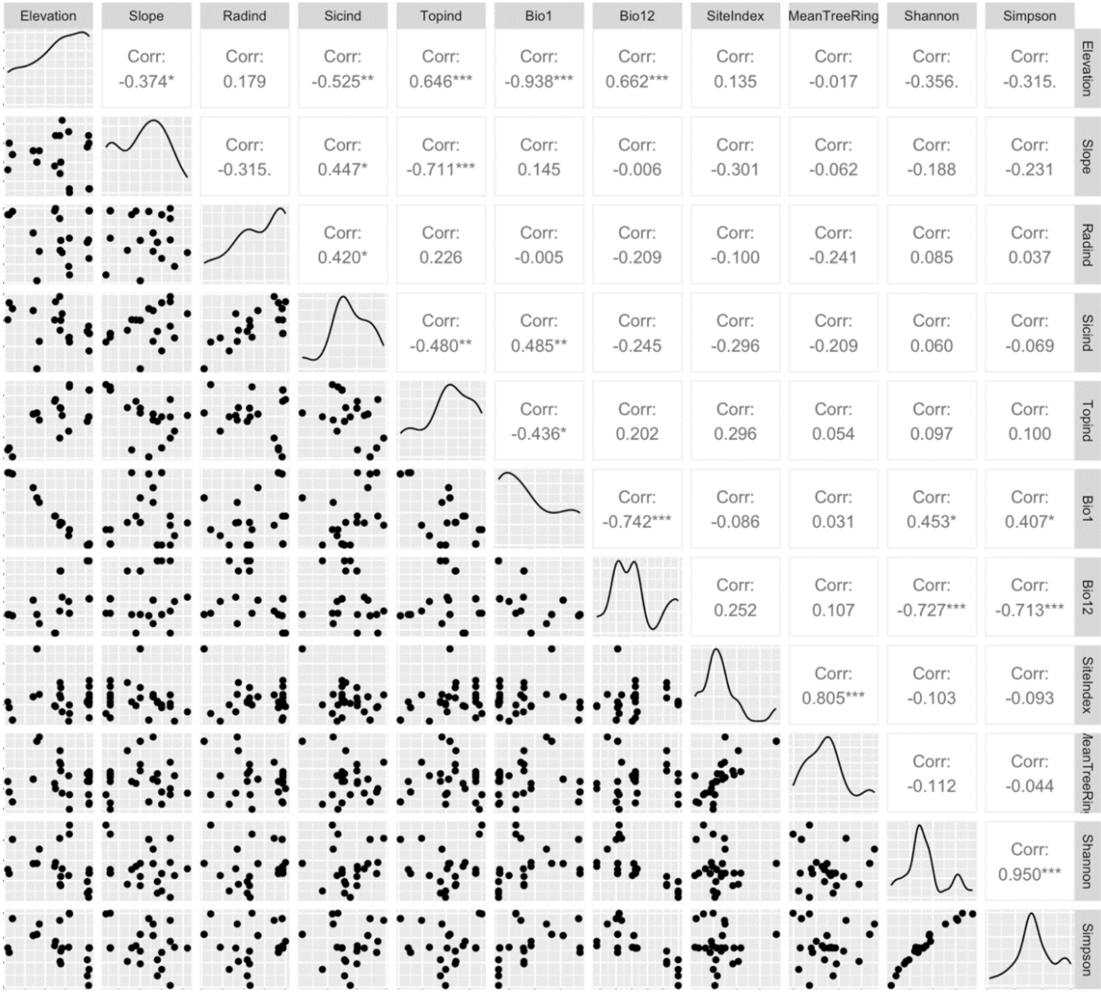

Figure 3. Spearman correlation analysis results

4. Conclusions

There was a significant relationship between altitude-dependent abiotic factors, such as Bio1 (annual mean temperature) and Bio12 (annual precipitation), and species diversity. However, in areas where the altitudinal range for Turkish pine is narrow, altitude alone may not cause significant differences in site index or tree-ring width unless the aspect is considered. In such cases, aspect could play a crucial role in influencing site index and tree growth.

For future planning, it is important to note that examining tree-ring growth and productivity across different aspect groups, within the same altitudinal range, may yield valuable insights. This could be particularly useful for predicting site productivity and understanding the spatial variation in growth patterns. For example, we expect that variations in temperature, summer drought intensity, and winter precipitation, as influenced by aspect at higher altitudes, may result in substantial differences in annual ring width and overall growth rates of Turkish pine.

Turkish pine, being a dominant species in Mediterranean ecosystems, is essential for forest management. Therefore, incorporating both site index data and detailed information on species diversity and average tree-ring growth in Turkish pine habitats will enhance ecosystem-based, multiple-use forest management planning. Specifically, this information can guide silvicultural interventions by targeting aspects with higher productivity potential and by adapting management strategies to mitigate the effects of temperature fluctuations and drought on tree growth.

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