

Spatial Distribution of Vascular Plant Species in the Sultan Mountains Based on Alpha and Beta Diversity

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Sultan Dağları Damarlı Bitki Türlerinin Alfa ve Beta Çeşitliliğine Göre Mekânsal Dağılımı

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Abstract

Mountainous regions stand out as areas where biological diversity is concentrated. In this study, the Sultan Mountains, which have been designated as both an Important Natural Area and an Important Plant Area in Turkey but currently lack any protection status, were investigated to determine plant species richness and diversity, thereby revealing the level of biodiversity in a mountainous area at a local scale. The alpha (α -diversity) and beta (β -diversity) diversity indices were utilised to ascertain the plant species richness and diversity in the Sultan Mountains. The mountainous region was subdivided into 95 main sample and 380 sub-sample plots for the study. In this study, the Menhinick and Shannon-Weiner (H') diversity index from alpha diversity indices and the βc index from beta diversity indices were used. As a result of the field study, 414 plant taxa were identified. The most prevalent plant taxa were identified within the Asteraceae, Lamiaceae and Fabaceae families. The genera with the highest number of taxa are *Astragalus*, *Hypericum* and *Linum*. Among the index values, the Menhinick index values vary between 0.43 and 1.61, while the Shannon-Weiner index (H') varies between 1.92 and 3.65. According to the βc analysis, the beta values vary between 2.5 and 31. However, it was found that the northern and eastern parts of the mountainous area exhibited a significantly higher level of diversity compared to the other areas.

Keywords: Biodiversity; Species Diversity; Alpha diversity; Beta diversity; Sultan Mountains

1. Introduction

Mountain areas, due to their topographic complexity and isolated biogeography, provide favourable environmental conditions for the presence, maintenance and distribution of biodiversity. Mountain regions host nearly half of the world's most critical biodiversity-rich areas. (Körner 2004, Vetaas and Grytnes 2002). The diversity of plant species growing in mountainous areas has drawn attention to biodiversity studies in these areas. These areas provide unique habitats for plant species due to high altitudes and diverse microclimates. In addition, as

Öz

Dağlık bölgeler biyolojik çeşitliliğin yoğunlaştığı yerler olarak dikkat çekmektedir. Bu çalışmada, Türkiye'de Önemli Doğa Alanı ve Önemli Bitki Alanı olarak tanımlanmasına rağmen herhangi bir koruma statüsüne sahip olmayan Sultan Dağları'nda, bitki türü zenginliği ve çeşitliliği ölçülerek yerel ölçekte bir dağlık alanın biyolojik çeşitlilik düzeyi ortaya konulmuştur. Sultan Dağları'ndaki bitki türü zenginliğini ve çeşitliliğini belirlemek için hem alfa (α -çeşitlilik) hem de beta (β -çeşitlilik) çeşitlilik indisleri kullanılmıştır. Araştırmanın gerçekleştirilmesi için dağlık bölgede 95 ana örnek 380 alt örnek alan belirlenmiştir. Bu çalışmada alfa çeşitlilik indislerinden Menhinick ve Shannon-Weiner (H') çeşitlilik indisi ile beta çeşitlilik indislerinden βc indisi kullanılmıştır. Arazi çalışması sonucunda 414 bitki taksonu tespit edilmiştir. En yaygın bitki taksonları Asteraceae, Lamiaceae ve Fabaceae familyaları içinde tespit edilmiştir. En fazla taksona sahip cinsler *Astragalus*, *Hypericum* ve *Linum*'dur. İndis değerleri arasında Menhinick indis değerleri 0,43 ile 1,61 arasında değişirken, Shannon-Weiner indisi (H') 1,92 ile 3,65 arasında değişmektedir. βc analizine göre beta değerleri 2,5 ile 31 arasında değişmektedir. Bununla birlikte, dağlık alanın kuzey ve doğu bölgelerinin diğer alanlara kıyasla önemli ölçüde daha yüksek bir çeşitlilik düzeyi sergilediği tespit edilmiştir.

Keywords: Biyoçeşitlilik; Tür Çeşitliliği; Alfa çeşitlilik; Beta çeşitlilik; Sultan Dağları

mountain areas are generally subject to less human intervention, biodiversity in these regions has been preserved and has become areas of high local endemism (Körner 2004, Körner et al. 2021). Therefore, biodiversity studies in these areas can provide basic information for the prioritisation of these regions.

The assessment of species composition, diversity and structure is one of the foundations of ecological studies (Bhat et al. 2020). In addition to numerical results, diversity calculations are utilised to evaluate ecosystems and elucidate disparities (Türkiş and Elmas 2018,

Whittaker 1960, Whittaker and Levin 1977). Such diversity calculations are typically conducted at three distinct levels, utilising alpha, beta and gamma diversity measurements to assess the diversity within a designated area (Jurasiński et al. 2009, Whittaker 1960, 1972). Alpha diversity (α -diversity) is used to measure local diversity within a single area, beta diversity (β -diversity) is used to measure diversity between habitats, i.e. species composition and dissimilarity between communities, and gamma diversity (γ) is used to measure diversity at a larger scale (Whittaker 1960, 1972; Whittaker et al. 2001). Determining the values of alpha and beta diversity in an area is an important reference for developing conservation strategies and adopting a more holistic approach to ecosystem management (Anderson et al. 2011, Socolar et al. 2016). Understanding the mechanisms that drive alpha and beta diversity is important for regional biodiversity (Jamoneau et al. 2018). The diverse topography and isolated biogeography of mountains are ideal conditions for hosting biodiversity (Gebrehiwot et al. 2019).

Türkiye's strategic location in terms of biodiversity is evidenced by its position at the intersection of the Mediterranean, Irano-Turanian and Euro-Siberian phytogeographic regions (Avcı 1993). Furthermore, it is the sole nation that encompasses three of the world's 34 biodiversity hotspots: the Caucasus, Irano-Anatolian and the Mediterranean (Mittermeier 2005). The country is home to a rich variety of flora, with more than 12000 plant taxa thriving within its borders, of which over 3600 are endemic (Güner et al. 2012). The formation of this biodiversity has been influenced by numerous ecological and evolutionary factors, including geological evolution, topographical diversity, climatic characteristics, soil structure and the country's geographical location (Atalay 2014, Şenkul and Kaya 2017). The rich plant diversity and unique ecological characteristics of Türkiye underscore the importance of research in biodiversity conservation. The identification and assessment of species diversity, in conjunction with the development of appropriate conservation strategies, are imperative for the continuity of ecosystems and the sustainability of biodiversity. Research conducted at various spatial scales and within different regions of Türkiye is contributing to the advancement of knowledge in this domain. Local data, generated in diverse regions, serve as invaluable resources for the conservation and sustainable management of biodiversity. The unique ecological and evolutionary characteristics of each region are best understood by utilizing local data. Moreover, the generation of local ecological data facilitates the

development of adaptation strategies to address challenges posed by climate change, habitat destruction and other anthropogenic impacts. Furthermore, regional studies facilitate the formulation of global conservation policy by offering insights into global trends and threats to biodiversity. The importance of local knowledge production for the conservation and sustainability of biodiversity at both local and global levels is therefore paramount. In the context of the Sustainable Development Goals, particularly Goal 15 - Terrestrial Life, the production of data and information to protect, restore and promote the sustainable use of terrestrial ecosystems is of critical importance (URL 1).

Mountainous areas in Türkiye cover more than half of the country (about 59%) (Erol 1991, Görüm 2019) and are of critical importance in terms of plant diversity. However, studies on plant richness and diversity in these areas are very limited and there is a lack of data and information in assessments specific to these areas. This study was carried out in the Sultan Mountains, one of the important mountainous areas of Türkiye. Sultan Mountains is one of the important mountainous areas of Türkiye in terms of plant taxa (Figure 1) (Eken et al. 2006, Kargioğlu 2018, Kargioğlu and Başhan 2023, Özhatay et al. 2005).

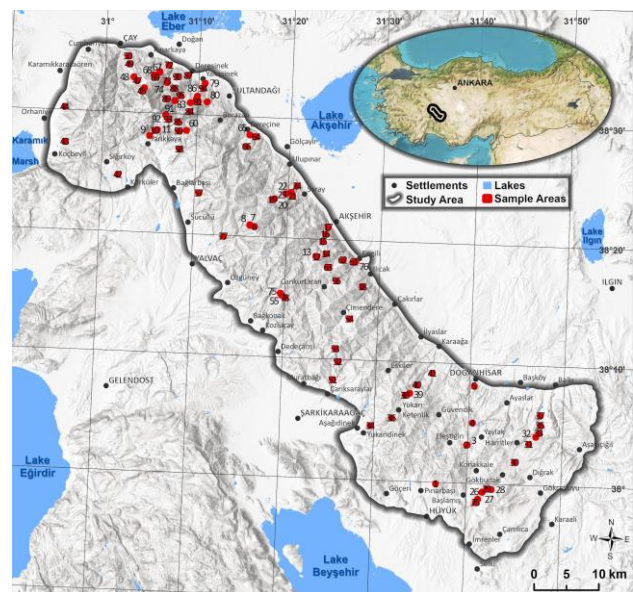


Figure 1. Location map and sampling design of the study area: 95 main plots and 380 sub-sample plots. The areas shown in red represent the sampling areas, and the numbers on these areas represent the sample codes.

Although the significance of the area in terms of plant taxa has been demonstrated by studies conducted in the Sultan Mountains (Atalay 1975a, Baytop and Dökmeci 1978, Gürbüz 2019, Kargioğlu 2018, Ocakverdi and Çetik 1982, Özçelik and Özhatay 2005), the region is not under any legal protection status. The present study aims to investigate the importance and impact of the subject in

terms of plant diversity in the local and regional area. In this context, the plant species growing in the mountain area were identified and the plant richness and diversity were evaluated with alpha and beta diversity indices. The analysis of the obtained data and information has enabled the creation of distribution maps, and the modelling of areas where plant species are either increasing or decreasing in number. The findings underscore the significance of the local mountainous region across diverse spatial scales, furnishing indispensable data for the conservation of biodiversity in this area.

2. Materials and Methods

2.1 Study Area

The Sultan Mountains are located at the intersection of the Central Anatolia and Mediterranean Regions (Figure 1). The mountainous area lies in the southwestern part of the Central Anatolia Region and constitutes an orographic branch of the Taurus Mountains range (Atalay 1975a, 1975b, 1977). The topographical features of the Sultan Mountains are contained within the drainage basins of the Akarçay, Antalya and Konya Closed Basins. The mountain range extends in a northwest-southeast direction between the Akşehir and Eber Lakes in the northern sector of the mountainous area and the Beyşehir Lake in the southern sector. The elevation values within this region range from approximately 1000 m at the base of the plain to 2610 m (Gelincikana peak). The region's present-day geomorphological characteristics have been shaped by tectonic movements and fluvial erosion (Atalay 1977). The annual average temperature of the mountainous region ranges from 4.2 to 11.7 °C (Fick and Hijmans 2017). The area falls within the B3 grid system, as delineated by Davis et al (1965-1985; Davis et al. 1988).

The geographical location of the Sultan Mountains, in conjunction with the influence of environmental factors (e.g. altitude, climate, soil characteristics), facilitates the coexistence of diverse plant species. The region's biodiversity is characterised by a diverse array of ecological niches, which are populated by plant species exhibiting a wide range of ecological requirements. The dispersal and diversification of plant species within this ecosystem are significantly influenced by altitude differences, microclimatic variations and soil heterogeneity. This renders the Sultan Mountains a rich and dynamic ecosystem in terms of biodiversity. The most prevalent plant species in the Sultan Mountains include *Quercus vulcanica*, *Q. infectoria*, *Q. cerris*, *Q. trojana* subsp. *trojana*, *Corylus avellana*, *Acer platanoides*, *A. hyrcanum* subsp. *sphaerocaryum*, *Juniperus communis*,

Juniperus excelsa, *Sorbus torminalis*, *Cedrus libani*, *Pinus nigra*, and *Cistus laurifolius*. In the mountainous area, plant species such as *Cedrus libani*, which is native to the Mediterranean phytogeographic regions, *Pinus nigra*, which is native to the Irano-Turanian phytogeographic regions, and *Coryllus avellana* var. *avellana* and *Coryllus colurna*, which are native to the Euro-Siberian phytogeographic regions, have been observed to co-occur. This observation indicates that the region possesses a rich and diverse flora structure in terms of plant species.

The Sultan Mountains are recognised as one of the most significant mountainous regions in Türkiye with regard to endemic plant taxa (Şenkul and Kaya 2017). This region is of particular interest due to its abundance of endemic plant taxa. Notable examples of endemic flora include *Quercus vulcanica*, *Genista burdurensis*, *Iris schachtii* and *Phlomis nissolii*, which thrive in the distinctive ecological milieu of the Sultan Mountains (Başhan 2019; Kargioğlu and Başhan 2023, Ketenci 2022).

2.2 Data Collection

The plant data utilised for the assessment of the plant species richness and diversity of the Sultan Mountains were obtained as a consequence of field studies conducted between 2019 and 2021. The plant taxa were recorded through the delineation of 95 main sample plots, each measuring 100 x 100 m, and 380 sub-sample plots, each measuring 20 x 20 m, employing a random sampling technique within the Sultan Mountains (Figure 1). The elevation (m) and coordinates of the sample plots were determined by Global Positioning System (GPS). During the field studies, data such as species information, abundance values, area covered and habitat structure of the plant taxa were recorded. Photographs of the plant species recorded during the field surveys were archived, and these visual data contributed to the scientific documentation of the study.

2.3 Species identification

The identification of the plant taxa of the Sultan Mountains was conducted using the "Flora of Turkey and the East Aegean Islands" and "Resimli Türkiye Florası 2" (Davis et al. 1965-1985; Davis et al. 1988; Güner et al. 2018). In the nomenclature of plants, the "Türkiye Bitki Listesi (Damarlı Bitkiler)" (Güner et al. 2012) was used. The plant data identified during field studies were then converted into data matrices and analysed. This methodological approach ensured that the analyses on plant diversity and richness were based on a solid scientific basis.

2.4 Analysis of α and β diversity patterns

The plant species richness and diversity of the area were calculated using the number of individuals recorded for each species, and the diversity index was calculated for each sample plot. For α -diversity, species richness (S), Menhinick index (Whittaker and Levin 1977), Shannon diversity index (H') (Shannon 1948) were evaluated. Beta diversity analyses β_c (Cody 1975) were used to calculate the dissimilarity between communities. Within the scope of the study, α and β diversity patterns were evaluated using only descriptive statistical analyses and were limited to this scope. The values of the species data obtained from the field studies were converted into data matrices and analysed using BiÇEB software (Özkan et al. 2020) to determine the α (Menhinick and Shannon index) and β diversity (β_c) values of the Sultan Mountains.

A frequency analysis was conducted to determine the recurrence of species within the sampling plots. For each species, the number of plots in which it was observed was identified, and these values were used to assess the level of species distribution and commonness across the study area. The index values presented in the manuscript were calculated separately for each sampling plot, and the resulting data were illustrated graphically.

The study utilised Kernel Density analysis to evaluate plant species richness and diversity, and to ascertain areas where they are concentrated. The Kernel Density analysis is a process which calculates the density of point features around each output raster cell (URL-2). This analysis is a tool utilised in plant species richness and diversity studies to ascertain the spatial distribution and visualise how species densities are distributed across the geographical area. In the context of plant species studies, Kernel Density analysis facilitates the extraction of information regarding regions exhibiting high diversity and those demonstrating changes in species density. The ArcGIS Pro software enabled the implementation of spatial analysis.

3. Results

3.1 Floristic composition

62 families, 216 genera and 414 plant taxa were recorded. 86 of these species are endemic. In the sample plots, *Cedrus libani* A. Rich. var. *libani*, *Pinus nigra* J. F. Arnold. subsp. *pallasiana* (Lamb.) Holmboe var. *pallasiana*, *Quercus cerris* L., *Quercus pubescens* Willd. subsp. *pubescens*, *Juniperus excelsa* M. Bieb. subsp. *excelsa*, *Sorbus torminalis* (L.) Crantz. tree species *Cistus laurifolius* L., *Rosa canina* L., shrub species, herbaceous taxa such as *Dianthus zonatus* Fenzl var. *zonatus*, *Sedum album* L.,

Astragalus angustifolius Lam. Among the plant species recorded in the sample plots, *Verbascum*, *Pinus nigra*, *Rosa canina*, *Hypericum* and *Eryngium campestre* L. have the highest frequency. The species with the lowest frequency are generally endemic plant species. These species include *Rorippa amphibia* (L.) Bess., *Rhamnus thymifolia* Bornm., *Phleum montanum* K.Koch., *Onosma armena* DC. and *Myosotis arvensis* (L.) Hill (Figure 4).

In the Sultan Mountains, the families Asteraceae (33 genera), Rosaceae (19 genera), Lamiaceae (18 genera), Fabaceae (17 genera) and Poaceae (10 genera) have the highest genera distributions according to plant families. The number of taxa in the families is Asteraceae (53 taxa), Lamiaceae (46 taxa), Fabaceae (42 taxa), Rosaceae (28 taxa) and Caryophyllaceae (16 taxa) (Figure 2). The distribution of plant taxa according to the number of genera is as follows: *Astragalus* (12 taxa), *Hypericum* (8 taxa), *Linum* (7 taxa), *Marrubium* (7 taxa) and *Quercus* (7 taxa) (Figure 3). The sample plots with the highest species richness are SA61, SA74 and SA87 (Figure 3).

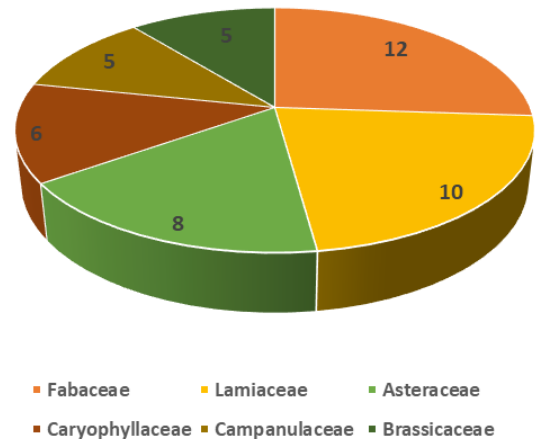


Figure 2. Distribution of plant taxa of Sultan Mountains according to families

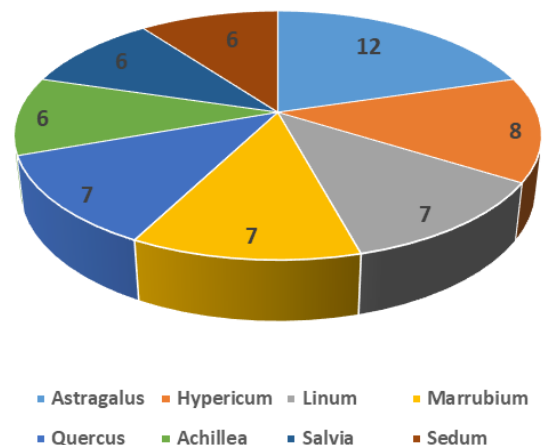


Figure 3. Distribution of plant taxa of Sultan Mountains according to genera

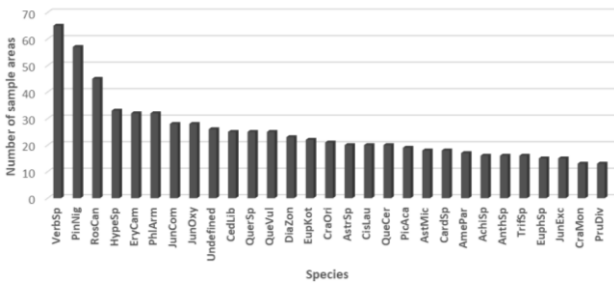


Figure 4. Frequency values of plant species identified in the sample plots during field studies in Sultan Mountains

3.2 Species Richness and Diversity

The data obtained from field studies conducted in the Sultan Mountains indicates that species richness values range from 9 to 52 (Figure 5). The Menhinick index values range from 0.43 to 1.61 (Figure 6). According to these indices, among the sample plots the highest richness levels were observed in SA61 (Menhinick index: 1.61), SA74 (Menhinick index: 1.32), and SA69 (Menhinick index: 1.13) (Figure 6).

In the Sultan Mountains, the Menhinick index revealed a high species richness in the sample plots above Lake Eber, Saray and Engili. The northern and eastern slopes of the mountainous area are the areas with higher species richness compared to other areas. Conversely, the areas of Körküler, Aşağıdinek, Ilıcak, Kozluçay, Karamık, Yarikkaya and Pınarkaya, which are mountainous, exhibited the lowest species richness, as indicated by the Menhinick indices. The distribution of the sample plots indicates that species richness values are elevated in areas between 1300 and 1800 m.

In the Sultan Mountains, the Shannon-Weiner index (H') ranges from 1.92 to 3.65. The areas with the highest H' value are SA61 (3.65), SA74 (3.59), and SA87 (3.38). SA61, which has the highest H' value, has the highest number of taxa compared to the other sample plots (Figure 7). Conversely, among the sample plots, the lowest diversity values were observed in SA43 (1.92), SA42 (1.93), SA51 (1.94), SA38 (1.95), and SA91 (1.96).

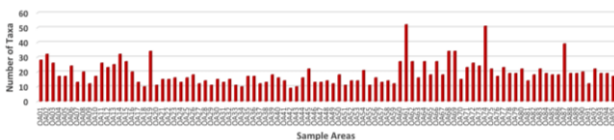


Figure 5. Distribution of species richness numbers in the sample plots in Sultan Mountains

The Shannon index indicates that the areas above Engili, the valley above Eber and the area above Deresineke are significant in terms of species diversity. Conversely, the areas above Karamık, Çarıkсарайlar, Eskiler, and Gökбудak exhibited lower species richness.

According to the beta diversity values carried out to determine the uniqueness between the sample plots, it varies between 2.5 and 31 values (Figure 8). These beta diversity values indicate environmental variability.

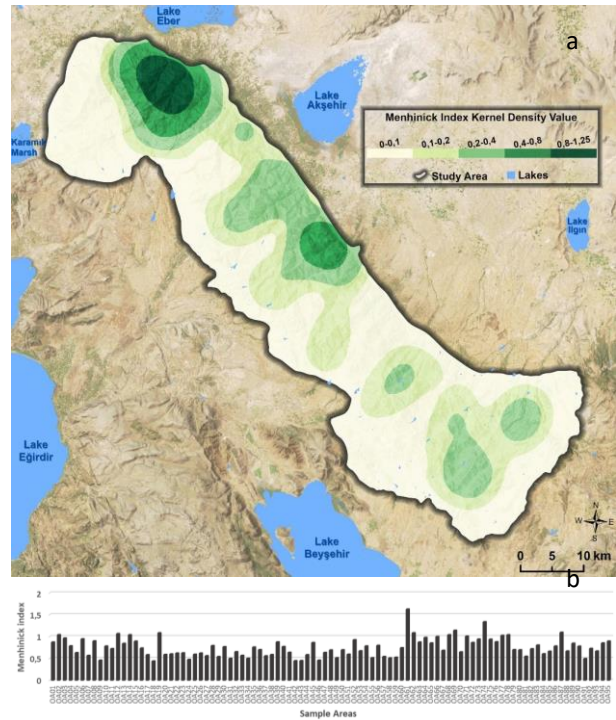


Figure 6. Sultan Mountains values according to Menhinick index a) Distribution according to Kernel Density analysis b) distribution according to sample plots

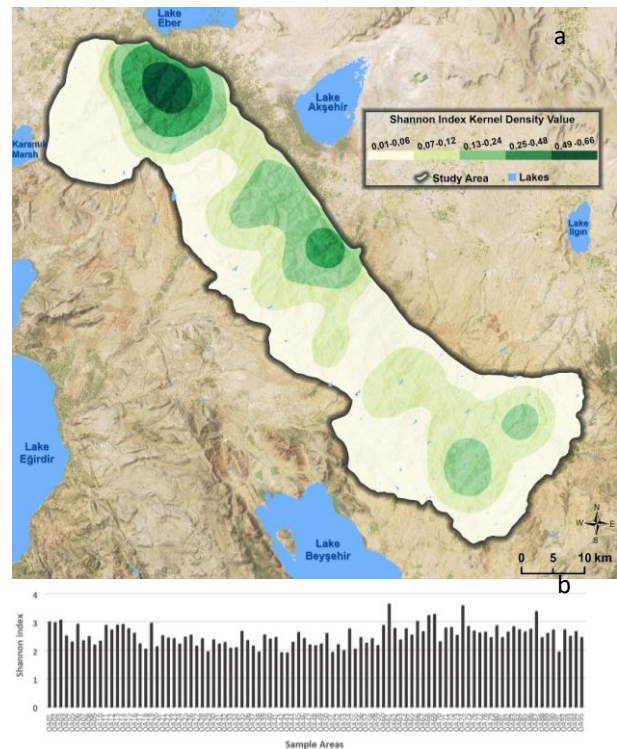


Figure 7. Sultan Mountains species diversity values according to Shannon index a) Distribution according to Kernel Density analysis b) distribution according to sample plots

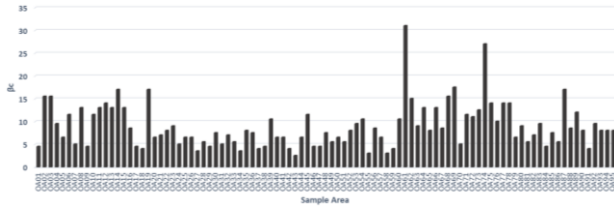


Figure 8. Distribution of β_c values according to sample plots of the Sultan Mountains

4. Discussion

4.1 Distribution and Species Pattern of Plant Richness and Diversity

In this study, conducted in the Sultan Mountains, alpha and beta indices of floristic diversity were utilised. The utilisation of these indices is pivotal in quantitatively determining the diversity values in a given area, in understanding the mechanisms driving diversity, and in comprehending regional diversity (Jamoneau et al. 2018). The environmental and evolutionary mechanisms that operate in the formation of plant diversity in a region are effective in shaping plant composition over time. The study of plant diversity in mountainous regions continues to increase worldwide in different regions and scales (e.g. Antonelli et al. 2018, Arslan et al. 2019, Aydınözü 2002, Ferrari 2018; Fontaine et al. 2007, Kaya Köse and Şenkul 2023, Keser 2013, Körner 2004, Körner et al. 2021, Marini et al. 2013, Mert and Özkan 2017, Özdemir et al. 2017, Şentürk et al. 2013, Sherman et al. 2008, Zhang et al. 2009). In Türkiye, the importance of biodiversity studies in mountainous regions is increasing. In this context, the Sultan Mountains are of particular interest due to their environmental diversity, plant diversity and endemic plant species (Eken et al. 2006, Kaya Köse and Şenkul 2023, Özhatay et al. 2005, Şenkul and Kaya, 2017).

In local studies conducted within the borders of the Sultan Mountains, 458 plant taxa were recorded in the Deresinek Basin (Başhan 2019, Kargioğlu and Başhan 2023), 582 taxa in the Eber River Basin (Ketenci 2022), and 735 taxa in 122 important plant areas (Özçelik and Özhatay 2005). Asteraceae (54 taxa), Fabaceae (35 taxa), Brassicaceae (33 taxa) (Başhan 2019, Kargioğlu and Başhan 2023) in Deresinek Basin and Asteraceae (77 taxa), Fabaceae (56 taxa), Brassicaceae (39 taxa) in Eber River Basin. Among the plant families recorded as a result of the field surveys carried out within the framework of this study, Asteraceae (53 taxa), Lamiaceae (46 taxa) and Fabaceae (42 taxa) have the highest rates, and these results are consistent with other studies.

With respect to the plant species present in the region, the Sultan Mountains are of particular interest as they represent an area that harbours plant species belonging

to three floristic regions in Türkiye. These regions encompass the Mediterranean, Irano-Turanian, and Euro-Siberian phytogeographic regions. Field studies have revealed that species belonging to the Irano-Turanian and Mediterranean phytogeographic regions are dominant in the Sultan Mountains. Notable tree species in this region include *Pinus nigra*, *Quercus* sp., *Cedrus libani* and *Juniperus* sp., which are commonly found in the mountainous terrain. In contrast, species such as *Corylus avellana* L. and *Taxus baccata* L., which are characteristic of the Euro-Siberian phytogeographic regions, are predominantly distributed in the mountainous terrain. These taxa were predominantly observed on the northern slopes of the mountainous area and in the microclimatic areas within the valleys. The higher humidity experienced on the northern slopes in comparison with other parts of the mountainous area is a key factor in the concentration, settlement and growth of plant species belonging to the Euro-Siberian phytogeographic regions. These microclimatic areas play a crucial role in preserving biodiversity by providing suitable habitats for a wide range of plant species with distinct ecological requirements.

The mountainous region is of significant importance in Türkiye due to its high plant species richness and endemism. Of the 94 endangered plant taxa within the Important Plant Area, 7 are endemic to the region (Özhatay et al. 2005). These endemic species include *Astragalus axcherensis*, *Astragalus scholerianus*, *Campanula iconia*, *Minuartia anatolica* var. *phrygia* and *Sideritis phrygia* (Özhatay et al. 2005). In other studies carried out in the Sultan Mountains, 58 endemic plants were identified in the Deresinek Basin (Başhan, 2019; Kargioğlu and Başhan 2023) and 67 endemic plant species were identified in the Eber River Basin (Ketenci 2022). In the field surveys conducted in this study, 86 out of 414 plant taxa were identified as endemic plant taxa in the sampling areas. The endemic plant richness of the Sultan Mountains indicates that the region possesses a distinctive biological and ecological importance. The presence of endemic flora in this region is indicative of its distinct evolutionary processes and ecological interactions, suggesting that local habitat conditions are conducive to the evolution and survival of these species.

4.2 Plant Diversity Distribution

The findings of the present study are in accordance with the Menhinick index and the Shannon index, which demonstrate that areas of high species richness are generally located on the northern and eastern slopes of mountainous areas. The present study utilised Kernel

Density analysis, a statistical technique employed for the estimation of density, in conjunction with diversity indices to ascertain the density of these areas. The application of Kernel Density analysis enabled the visualisation of the spatial distribution of species richness and diversity densities within a specified area. The Kernel Density analysis calculates the density of spatial data points and visually displays density differences on maps (URL-2). This approach facilitates a more profound comprehension of the impact of diverse ecological and environmental factors on the distribution of plant species. This method is an important tool for identifying areas of high species richness and diversity.

The concentration of plant species richness and diversity on the northern and eastern slopes of the Sultan Mountains is attributable to various environmental and anthropogenic factors. The mountainous area increases from south-east to north-west, creating opportunities for the formation of niche areas suitable for the growth of different plant species. Furthermore, the high levels of ruggedness in this area contribute to the emergence of different microhabitats and ecological niches, thereby increasing plant diversity. The higher humidity levels in these areas relative to other regions result in a concentration of plant species that prefer humid environments on these particular slopes. Furthermore, the northern and eastern slopes are less exposed to human influence, thereby allowing natural vegetation to be preserved and biodiversity to be observed at higher levels.

Beta diversity is comprised of two fundamental processes: (1) spatial turnover, which describes the movement of species from one region to another, and (2) nestedness, referring to the loss or gain of species within subsets (Baselga 2010; Baselga et al. 2007). Beta diversity, which reflects diversity patterns between habitats, species' adaptability, and diversity differences across ecosystems or regions, supports the perception of high species richness. The increase in differences and numbers among communities within a region is associated with the region's rising heterogeneity (Gould and Walker, 1999). The β_c diversity index in the Sultan Mountains highlights high species diversity, indicating the presence of different plant groups and unique species compositions in the area. In addition to spatial scale, within-species areas, topographical and microclimatic variations have been identified as contributing factors to this diversity.

In the Sultan Mountains, areas of high beta diversity are dominated by species such as *Alyssum* sp., *Hypericum* sp., *Achillea* sp., *Eryngium campestre* L., and *Cota austriaca*

(Jacq.) Sch.Bip., whereas species like *Acer platanoides* L., In contrast *Malus sylvestris* (L.) Mill., *Crataegus monogyna* Jacq. var. *monogyna*, *Juniperus oxycedrus* L. subsp. *oxycedrus* var. *oxycedrus* f. *oxycedrus*, *Cota tinctoria* (L.) J.Gay ex Guss. var. *tinctoria*, and *Genista aucheri* Boiss. are observed to be present in low numbers (SA78). Overall, herbaceous species are predominant in areas of high beta diversity in the Sultan Mountains, with species such as *Verbascum* sp., *Carduus* sp., *Phlomis armeniaca* Willd., and *Anthemis* sp. being commonly distributed.

A considerable proportion of the observed variation in species composition between areas can be attributed to micro-environmental variations. The geographical distance separating areas is found to influence environmental conditions and species composition, with closer areas exhibiting strong environmental and compositional similarity. Conversely, more distant areas characterised by greater environmental heterogeneity have been shown to support species with distinct niche preferences (Das et al. 2020, Thakur et al. 2022; Wani et al. 2023). This underscores the imperative for the conservation and sustainable management of the biodiversity of the Sultan Mountains.

4.3 Risk Factors and Conservation Approaches

It is widely accepted that plant diversity on a global scale is currently under threat and is considered to be endangered. Indeed, the risk to biodiversity has been a matter of concern for some time, and the importance of local plant research has become increasingly evident. Specifically, within the scope of the Sustainable Development Goals (SDGs) (Life on Land/Goal 15), studies conducted in mountainous regions to protect, restore, and sustainably utilise terrestrial ecosystems, as well as to prevent biodiversity loss, are of critical importance. The identification of species, diversity, and ecological characteristics of locally growing plants constitutes a fundamental step for conservation, management, and monitoring efforts in these areas. In this context, floristic research conducted in biodiversity-rich regions such as the Sultan Mountains plays a pivotal role in safeguarding ecosystem services and in efforts to conserve biodiversity. Furthermore, the assessment of endemic flora within this region is imperative for the conservation of biodiversity and the maintenance of ecosystem services. The Sultan Mountains are home to a rich variety of endemic plant species, thus significantly contributing to Türkiye's floristic diversity and supporting ecosystem health and sustainability. The presence of endemic species underscores the ecological uniqueness and

sensitivity of the region, and the conservation of these species is essential for maintaining the balance and functioning of local ecosystems. In this regard, botanical studies in the Sultan Mountains provide a scientific basis for the identification, conservation, and monitoring of endemic species, enabling the development of strategic measures to protect populations of these threatened species.

The Sultan Mountains have historically been subject to various human impacts. This mountainous region has been inhabited and traversed by various civilisations, including the Lydians, Phrygians, and the Roman Empire. Agricultural and livestock activities have had a long-term impact on the region, particularly in the lower southern elevations, and these activities continue to the present day. These anthropogenic impacts have been identified as significant factors contributing to the decline of biodiversity in the region. Calculations of plant richness and diversity have revealed lower species richness and diversity in these impacted areas.

Given Türkiye's ratification of the Convention on Biological Diversity and the Sustainable Development Goals (Life on Land/Goal 15), the necessity for further research in this field is increasingly apparent. Despite the absence of formal protected status, the Sultan Mountains are recognised as both an Important Plant Area and an Important Nature Area (Eken et al. 2006, Özhatay et al. 2005). This region is distinguished by its unique value in terms of plant diversity and endemic species diversity. The biodiversity of the region is further supported by nearby Important Nature Areas, including Akşehir and Eber Lakes, Beyşehir Lake, Eğirdir Lake, and Karamık Marsh. The Sultan Mountains, due to their location, serve as a refuge for plant species and stand out for their environmental and botanical diversity. Consequently, there is a compelling case for comprehensive studies encompassing the Sultan Mountains, which have the potential to make significant contributions to the conservation and sustainable management of the region's biodiversity. While a comprehensive conservation approach is imperative, there is also a need for more localised studies to provide cost-effective, practical, and ecologically meaningful insights.

5. Conclusion

Diversity indices represent a significant approach in ecological studies for conducting quantitative comparisons among the biological components of ecosystems (Heip et al. 1998). This study underscores the pivotal role of plant richness and diversity within a mountainous region. The diversity indices calculated for

each plot included the following: i) the Menhinick index (total species count for each sample) to determine species richness in the Sultan Mountains, ii) the Shannon Diversity Index to assess species diversity, iii) the β_c index to evaluate dissimilarity across regions, and iv) Kernel Density analysis to ascertain the distributions of species richness and diversity. A total of 414 plant taxa were recorded, and areas with high species richness and diversity within the mountainous region were identified. The study revealed that the Sultan Mountains harbour a variety of flora, with particular species richness on the northern and eastern slopes as determined by sample plots. While a comprehensive conservation strategy is imperative for the Sultan Mountains and adjacent regions, the utilisation of collected data to prioritise these areas is advantageous given the constraints on financial and temporal resources.

Research studies that determine plant richness and diversity, along with data repositories and assessments, are essential for monitoring changes in plant diversity within the area. These efforts are instrumental in preventing and mitigating adverse impacts on ecosystem dynamics, such as biodiversity loss, and support the sustainability of local biodiversity. The data obtained from this research are crucial for developing long-term management strategies for monitoring, conserving, and managing plant richness and diversity.

Declaration of Ethical Standards

This study is derived from the doctoral thesis entitled "Endemik bitki coğrafyaları: Sultan Dağları örneği" (thesis no. 854923), completed in 2024 by Seda KAYA KÖSE under the supervision of Assoc. Prof. Dr. Çetin ŞENKUL.

The author declares that she complies with all ethical standards.

Credit Authorship Contribution Statement

Author-1: Conceptualization, investigation, methodology and software, visualization and writing – original draft.

Author-2: Conceptualization, investigation, methodology, visualization and writing – original draft.

Authors-3: Conceptualization, investigation, methodology, visualization and writing – original draft.

Declaration of Competing Interest

The authors have no conflicts of interest to declare regarding the content of this article.

Data Availability Statement

Supplementary data materials can be shared upon request.

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5. References

- Anderson, M.J., Crist, T.O., Chase, J.M., Vellend, M., Inouye, B.D., Freestone, A.L., Sanders, N.J., Cornell, H.V., Comita, L.S., Davies, K.F., Harrison, S.P., Kraft, N.J.B., Stegen, J.C., and Swenson, N.G., 2011. Navigating the multiple meanings of β diversity: A roadmap for the practicing ecologist. *Ecology Letters*, **14**(1), 19-28. <https://doi.org/10.1111/j.1461-0248.2010.01552.x>
- Antonelli, A., Kissling, W.D., Flantua, S.G.A., Bermúdez, M. A., Mulch, A., Muellner-Riehl, A.N., Kreft, H., Linder, H.P., Badgley, C., Fjeldså, J., Fritz, S.A., Rahbek, C., Herman, F., Hooghiemstra, H., and Hoorn, C., 2018. Geological and climatic influences on mountain biodiversity. *Nature Geoscience*, **11**, 718-725. <https://doi.org/10.1038/s41561-018-0236-z>
- Arslan, M., Gülsoy, S., Karataş, R., Koray, E.Ş., Kaptanoğlu, A.S., Mert, A., Kavgacı, A. and Özkan, K., 2019. Relationships among forest vegetation, plant diversity and some environmental factors in Türkmen Mountain (Eskişehir-Kütahya, Turkey). *Ormanlık Araştırma Dergisi*, **6**(2), 128-141. <https://doi.org/10.17568/ogmoad.507432>
- Atalay, İ., 1975a. Sultandağları'nda toprak erozyonu araştırmaları. *Türk Coğrafya Dergisi*, **26**, 48-72.
- Atalay, İ., 1975b. Tektonik hareketlerin Sultandağları'nın jeomorfolojisine olan etkileri. *Türkiye Jeoloji Bülteni*, **8**, 21-26.
- Atalay, İ., 1977. Sultandağları ile Akşehir ve Eber Gölleri havzalarının strüktürel, jeomorfolojik ve toprak erozyonu etüdü. Ph.D. thesis, Atatürk Üniversitesi Basımevi, Erzurum.
- Atalay, İ., 2014. Türkiye'nin Ekolojik Bölgeleri. Meta Basım, İzmir.
- Avcı, M., 1993. Türkiye'nin flora bölgeleri ve Anadolu Diagonalı'ne coğrafi bir yaklaşım. *Türk Coğrafya Dergisi*, **28**, 225-248.
- Aydınözü, D., 2002. Küre Dağları doğu kesiminin bitki coğrafyası. Ph.D. thesis. Istanbul University, Institute of Social Sciences, İstanbul, 249.
- Baselga, A., 2010. Partitioning the turnover and nestedness components of beta diversity. *Global Ecology and Biogeography*, **19**, 134-143. <https://doi.org/10.1111/j.1466-8238.2009.00490.x>
- Baselga, A., Jiménez-Valverde, A., and Niccolini, G., 2007. A multiple-site similarity measure independent of richness. *Biology Letters*, **3**(6), 642-645. <https://doi.org/10.1098/rsbl.2007.0449>
- Başhan, Ö.F., 2019. Deresine (Afyonkarahisar) Havzası florası. MSc Thesis, Afyon Kocatepe University, Institute of Science, Afyonkarahisar, 119.
- Baytop, A. and Dökmeci, G., 1978. A contribution to the flora of Sultandağları. *İstanbul Üniversitesi Eczacılık Fakültesi Mecmuası*, **14**, 144-156.
- Bhat, J.A., Kumar, M., Negi, A.K., Todaria, N.P., Malik, Z. A., Pala, N.A., Kumar, A. and Shukla, G., 2020. Species diversity of woody vegetation along altitudinal gradient of the Western Himalayas. *Global Ecology and Conservation*, **24**, e01302. <https://doi.org/10.1016/j.gecco.2020.e01302>
- Cody, M.L., 1975. Towards a theory of continental species diversities: bird distributions over Mediterranean habitat gradients Ecology and Evolution of Communities (eds M.L. Cody & J.M. Diamond), Belknap Press, Harvard, 214-257.
- Das, D.S., Rawat, D.S., Maity, D., Dash, S.S., and Sinha, B.K., 2020. Species richness patterns of different life-forms along altitudinal gradients in the great Himalayan National Park, Western Himalaya, India. *Taiwania*, **65**(2), 154-162. <https://doi.org/10.6165/tai.2020.65.154>
- Davis, P.H., 1965-1985. Flora of Turkey and the East Aegean Islands Vol. 1-9. Edinburgh University Press, Edinburgh.
- Davis, P.H., Mill, R.R. and Tan, K., 1988. Flora of Turkey and the East Aegean Islands Vol. 10. Edinburgh University Press, Edinburgh.
- Eken, G., Bozdoğan, M., İsfendiyoğlu, S., Kılıç, T. and Lise, Y., 2006. Türkiye'nin Önemli Doğa Alanları. Doğa Derneği, Ankara.
- Erol, O., 1991. Türkiye Jeomorfoloji Haritası. (1/1.000.000 Ölçekli. Maden Tetkik ve Arama Genel Müdürlüğü, Ankara.
- Ferrari, C., 2018. Timberline and Alpine Vegetation in the Northern Apennines: Bioclimate Scenery and Vegetation Diversity. F. Pedrotti (eds), Climate Gradients and Biodiversity in Mountains of Italy, Springer, Cham, 109-124. https://doi.org/10.1007/978-3-319-67967-9_6
- Fick, S.E. and Hijmans, R.J., 2017. WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. *International Journal of Climatology*, **37**(12), 4302-4315. <https://doi.org/10.1002/joc.5086>
- Fontaine, M., Aerts, R., Özkan, K., Mert, A., Gülsoy, S., Süel, H., Waelkens, M., and Muys, B., 2007. Elevation and exposition rather than soil types determine communities and site suitability in Mediterranean mountain forests of southern Anatolia, Turkey. *Forest Ecology and Management*, **247**, 18-25. <https://doi.org/10.1016/j.foreco.2007.04.021>
- Gebrehiwot, K., Demissew, S., Woldu, Z., Fekadu, M., Desalegn, T. and Teferi, E., 2019. Elevational changes in vascular plants richness, diversity, and

- distribution pattern in Abune Yosef mountain range, Northern Ethiopia. *Plant Diversity*, **41(4)**, 220-228. <https://doi.org/10.1016/j.pld.2019.06.005>
- Görüm, T., 2019. Tectonic, topographic and rock-type influences on large landslides at the northern margin of the Anatolian Plateau. *Landslides*, **16**, 333-346. <https://doi.org/10.1007/s10346-018-1097-7>
- Gould, W.A. and Walker, M.D., 1999. Plant communities and landscape diversity along a Canadian Arctic river. *Journal of Vegetation Science*, **10(4)**, 537-548. <https://doi.org/10.2307/3237188>
- Güner, A., Aslan, S., Ekim, T., Vural, M. and Babaç, M.T. (eds), 2012. Türkiye Bitkileri Listesi (Damarlı Bitkiler). Nezahat Gökyiğit Botanik Bahçesi ve Flora Araştırmaları Derneği Yayını, İstanbul.
- Güner A., Kandemir, A., Menemen, Y., Yıldırım, H., Aslan, S., Ekşi, G., Güner, I., and Çimen, A.Ö. (eds), 2018. Resimli Türkiye Florası Cilt 2. ANG Vakfı Nezahat Gökyiğit Botanik Bahçesi Yayınları, İstanbul.
- Gürbüz, N., 2019. Bolvadin, Çay ve Sultandağı'nda (Afyonkarahisar) yetişen doğal bitkilerin halk tarafından geleneksel kullanımı. MSc Thesis, Afyon Kocatepe University, Institute of Science, Afyonkarahisar, 248.
- Heip, C.H.R., Herman, P.M.J. and Soetaert, K., 1998. Indices of diversity and evenness. *Oceanis*, **24**, 61-87.
- Jamoneau, A., Passy, S.I., Soininen, J., Leboucher, T. and Tison-Rosebery, J., 2018. Beta diversity of diatom species and ecological guilds: Response to environmental and spatial mechanisms along the stream watercourse. *Freshwater Biology*, **63**, 62-73. <https://doi.org/10.1111/fwb.12980>
- Jurasinski, G., Retzer, V. and Beierkuhnlein, C., 2009. Inventory, differentiation, and proportional diversity: a consistent terminology for quantifying species diversity. *Oecologia*, **159**, 15-26. <https://doi.org/10.1007/s00442-008-1190-z>
- Kargioğlu, M., 2018. A Phytosociological investigation on endemic *Quercus vulcanica* Boiss. & Heldr. ex Kotschy at Sultan Mountains (Afyonkarahisar-Turkey). *Afyon Kocatepe Üniversitesi Fen ve Mühendislik Bilimleri Dergisi*, **18**, 412-419. <https://doi.org/10.5578/fmbd.66982>
- Kargioğlu, M. and Başhan, Ö.F., 2023. Deresinek (Afyonkarahisar) Basın flora. *Afyon Kocatepe Üniversitesi Fen ve Mühendislik Bilimleri Dergisi*, **23**, 1-26. <https://doi.org/10.35414/akufemubid.1141377>
- Kaya Köse, S. and Şenkul, Ç., 2023. Dağlık ekosistemlerde bitki tür zenginliği ve çeşitliliği: Sultan Dağları örneği. *Süleyman Demirel Üniversitesi Fen-Edebiyat Fakültesi Sosyal Bilimler Dergisi*, **60**, 190-201.
- Keser, N., 2013. Murat Dağı'nda endemizmde etki eden topoğrafik faktörler (İç Batı Anadolu). *Turkish Studies (Elektronik)*, **8(12)**, 711-736.
- Ketenci, H., 2022. Eber Deresi Havzası florası (Afyonkarahisar). MSc Thesis, Afyon Kocatepe University, Institute of Science, Afyonkarahisar, 121.
- Körner, C., 2004. Mountain biodiversity, its causes and function: An overview. Mountain Biodiversity: A Global Assessment, Ch. Körner and E.M. Spehn (eds), CRC Press, 3-20.
- Körner, C., Urbach, D. and Paulsen, J., 2021. Mountain definitions and their consequences. *Alpine Botany*, **131(2)**, 213-217. <https://doi.org/10.1007/s00035-021-00265-8>
- Marini, L., Bertolli, A., Bona, E., Federici, G., Martini, F., Prosser, F. and Bommarco, R., 2012. Beta-diversity patterns elucidate mechanisms of alien plant invasion in mountains. *Global Ecology and Biogeography*, **22**, 450-460. <https://doi.org/10.1111/geb.12006>
- Mert, A. and Özkan, K., 2017. Studies on taxonomic diversity of plant communities and modeling its potential distribution in Yazılı Canyon Nature Park, Turkey. *Journal of Environmental Biology*, **38**, 1267-1274. <https://doi.org/10.22438/jeb/38/6/MRN-282>
- Mittermeier, R.A., Gil, P.R., Hoffman, M., Pilgrim, J., Brooks, T., Mittermeier, J.C., Lamoreux, J., da Fonseca, G.A.B., 2005. Hotspots Revisited: Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions. CEMEX, Mexico City.
- Ocakverdi, H. and Çetik, A.R. 1982. Sultan Dağları-Doğanhisar bölgesinin (Konya) fitososyolojik yönden incelenmesi. *Selçuk Üniversitesi Fen Fakültesi Dergisi*, **2(B)**, 73-90.
- Özçelik, H. and Özhatay, N. 2005. Sultan Dağları. Özçelik, H. and Özhatay, N., 2005. Sultan Dağları. *Türkiye'nin 122 Önemli Bitki Alanı*, N. Özhatay, A. Byfield and S. Atay (eds), Mas Matbaacılık, İstanbul, 250-255.
- Özdemir, S., Negiz, M.G., Turhan, U.U., Şenol, A. and Arslan, M., 2017. Kuyucak Dağı yöresinde alfa çeşitliliğinin gösterge bitki türleri. *Türkiye Ormanlık Dergisi*, **18(2)**, 102-109. <https://doi.org/10.18182/tjf.289095>
- Özhatay, N., Byfield, A., Atay, S., Özhatay, N., Byfield, A., and Atay, S., 2005. Türkiye'nin 122 Önemli Bitki Alanı. In WWF-Türkiye (Doğal Hayatı Koruma Vakfı) Yayınları.
- Özkan, K., Küçüksille, E.U., Mert, A. and Gülsoy, S. 2020. Biyolojik çeşitlilik bileşen (BİÇEB) hesaplama yazılımı program kodu: 1005 Proje No: 1170983 Proje Yürütücüsü: Prof. Dr. Kürşad ÖZKAN.

- Şenkul, Ç. and Kaya, S., 2017. Türkiye Endemik bitkilerinin coğrafi dağılışları. *Türk Coğrafya Dergisi*, **69**, 109-120.
<https://doi.org/10.17211/tcd.322515>
- Şentürk, Ö., Uluşan, M.D., Eser, Y., Şenol, A. and Özkan, K., 2013. Investigation of Relationships between vegetation and environmental factors in the Çarıkisaraylar District of the Sultan Mountains. 3rd International Geography Symposium - GEOMED 2013, Antalya, 597-607.
- Shannon, C.E., 1948. A mathematical theory of communication. *The Bell System Technical Journal*, **27**, 379-423.
- Sherman, R., Mullen, R., Haomin, L., Zhendong, F. and Yi, W., 2008. Spatial patterns of plant diversity and communities in Alpine ecosystems of the Hengduan Mountains, northwest Yunnan, China. *Journal of Plant Ecology*, **1**, 117-136.
<https://doi.org/10.1093/jpe/rtn012>
- Socolar, J.B., Gilroy, J.J., Kunin, W.E. and Edwards, D.P., 2016. How should beta-diversity inform biodiversity conservation?. *Trends in Ecology & Evolution*, **31**, 67-80.
- Thakur, S., Negi, V.S., Dhyani, R., Bhatt, I.D. and Yadava, A.K., 2022. Influence of environmental factors on tree species diversity and composition in the Indian western Himalaya. *Forest Ecology and Management*, **503**, 119746.
<https://doi.org/10.1016/j.foreco.2021.119746>
- Türkış, S. and Elmas, E., 2018. Effect of environmental factors on species diversity of the Yenice Hot Spot Forests in Turkey. *Journal of Forestry Research*, **29**, 1719-1730.
<https://doi.org/10.1007/s11676-018-0595-8>
- Vetaas, O.R. and Grytnes, J.A., 2002. Distribution of vascular plant species richness and endemic richness along the Himalayan elevation gradient in Nepal. *Global Ecology and Biogeography*, **11**, 291-301.
<https://doi.org/10.1046/j.1466-822X.2002.00297.x>
- Wani, Z.A., Akhter, F., Ridwan, Q., Rawat, Y.S., Ahmad, Z. and Pant, S., 2023. A bibliometric analysis of studies on plant endemism during the period of 1991-2022. *Journal of Zoological and Botanical Gardens*, **4**, 692-710.
<https://doi.org/10.3390/jzbg4040049>
- Whittaker, R.H., 1960. Vegetation of the Siskiyou Mountains, Oregon and California. *Ecological Monographs*, **30**, 279-338.
<https://doi.org/10.2307/1943563>
- Whittaker, R.H., 1972. Evolution and Measurement of species diversity. *Taxon*, **21**, 213-251.
<https://doi.org/10.2307/1218190>
- Whittaker, R.H. and Levin, S.A., 1977. The role of mosaic phenomena in natural communities. *Theoretical Population Biology*, **12(2)**, 117-139.
[https://doi.org/10.1016/0040-5809\(77\)90039-9](https://doi.org/10.1016/0040-5809(77)90039-9)
- Whittaker, R.J., Willis, K.J. and Field, R., 2001. Scale and species richness: Towards a general, hierarchical theory of species diversity. *Journal of Biogeography*, **28(4)**, 453-470.
<https://doi.org/10.1046/j.1365-2699.2001.00563.x>
- Zhang, D.C., Zhang, Y.H., Boufford, D.E. and Sun, H., 2009. Elevational patterns of species richness and endemism for some important taxa in the Hengduan Mountains, southwestern China. *Biodiversity and Conservation*, **18(3)**, 699-716.
<https://doi.org/10.1007/s10531-008-9534-x>

Internet References

1-<https://www.kureselamaclar.org/> (05.01.2025)

2-<https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/how-kernel-density-works.htm> (01.01.2025)