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Spatial Patterns of Species Diversity in the Saline Vegetation of Central Anatolia, Türkiye

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Abstract: Vegetation on saline soils thrives under extreme conditions. The saline vegetation of Central Anatolia is a key component of the Irano-Anatolian Biodiversity Hotspot, notable for its high habitat and species diversity. However, there has been a lack of quantitative assessments of plant diversity in these areas. To address this gap, this study aims to calculate and compare: 1) local species diversity (alpha diversity) across five vegetation alliances, 2) regional diversity (gamma diversity) for each alliance, and 3) the spatial variation in species diversity within alliances (beta diversity). Data from 101 plots representing five alliances, collected from Burdur Lake, Acıgöl, Salt Lake, Seyfe Lake, and Sultansazlığı were compiled from relevant publications. The results showed high species diversity in areas with high variation in salinity or humidity due to ecotone characteristics at all spatial scales. Notably, diversity was highest in salt steppes (*Achilleo wilhelmsii-Artemision santonici*) and in slightly saline, summer-dry marshes (*Lepidio caespitosi-Limonion iconici* and *Inulo aucheranae-Elymion salsi*). Conversely, diversity was lower in non-saline steppes typical of gypsum soils (*Astragalo karamasici-Gypsophilion eriocalycis*) and in communities found on hypersaline soils (*Salicornion fruticosae*). Overall, beta diversity was high, reflecting significant species turnover. These findings numerically support existing literature, which suggests that plant community composition can change drastically over short distances in saline areas. The results highlight the conservation priority of saline areas with ecotone characteristics.

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Türkiye'nin İç Anadolu Bölgesi'ndeki Tuzlu Bitki Topluluklarının Tür Çeşitliliğinin Mekansal Desenleri

Anahtar Kelimeler
Beta çeşitlilik,
Biyolojik çeşitlilik,
Bozkır,
Halofit,
Sazlık

Öz: Tuzlu alanlardaki bitki örtüsü ekstrem koşullar altında gelişir. İç Anadolu'nun tuzlu bitki örtüsü, yüksek habitat ve tür çeşitliliği ile İran-Anadolu Biyoçeşitlilik Sıcak Noktası' nın öne çıkan habitatlarını barındırır. Ancak, bu alanların tür çeşitliliğine yönelik nicel çalışma yapılmamıştır. Bu çalışmada 1) tuzlu alanlarda gelişen beş alyansın yerel tür çeşitliliği (alfa çeşitlilik), 2) her alyansın bölgesel çeşitliliği (gama çeşitlilik) ve 3) her alyansa ait parsellerde çeşitlilik farkları (beta çeşitlilik) hesaplanmıştır. Bu amaçla, bugüne kadar Burdur Gölü, Acıgöl, Tuz Gölü, Seyfe Gölü ve Sultan Sazlığı' nda yapılan çalışmalarda tespit edilen beş alyansa ait 101 parselin verileri kullanılmıştır. Her alansal ölçekte tür çeşitliliğinin yüksek çıktığı alyanslar tuz oranı ya da nemlilik açısından geçiş özelliğindeki yerlerde gözlenir. Çeşitlilik tuza dayanıklı bozkırlar (*Achilleo wilhelmsii-Artemision santonici*) ve tuzluluk oranı düşük, yazın kuruyan bataklıklarda (*Lepidio caespitosi-Limonion iconici* ve *Inulo aucheranae-Elymion salsi*) yüksek çıkmıştır. Tuzcul alan temsiliyeti düşük, jipsli bozkırları temsil eden kurak bozkırlarda (*Astragalo karamasici-Gypsophilion eriocalycis*) ve tuz oranı yüksek topraklarda gelişen topluluklarda (*Salicornion fruticosae*) çeşitlilik düşük çıkmıştır. Genel anlamda beta çeşitlilik değerleri yüksektir ve bunun nedeni yüksek tür devridir. Bu bulgu, tuzlu alanlarda bitki örtüsünün kısa mesafelerde ciddi değişimler gösterdiğini belirten literatür bilgisini sayısal olarak desteklemektedir. Bulgular toprak özellikleri açısından geçiş özelliğinde, ekoton oluşturan tuzcul alanların koruma açısından öncelikli olduğunu ortaya koymaktadır.

1. INTRODUCTION

Saline vegetation covers large areas around inland lakes in arid lands [1]. Many of Türkiye's saline areas are assigned as conservation priority sites with many endemic plants, migrant or resident bird populations [2]. They are also worth attention in terms of interesting and unique adaptations developed under high-stress conditions [3, 4]. Sadly, those precious areas have been either destroyed or degraded because of climate change, uncontrolled groundwater use in agriculture, cropland expansion, salt extraction, and tourism developments [2]. Therefore, it is crucial to understand biodiversity patterns of saline areas and guide conservation activities with ecological evidence. This would contribute to keep saline areas on the agenda of nature conservation.

There are several saline areas in Central Anatolia [5]. The flora and plant community composition have been under research since 1960s [6]. Studies on vegetation have been carried out since 1970s with a classical phytosociological approach, aiming classification in which expert evaluations play a substantial role. As a result of those studies, the following vegetation hierarchy was proposed: two vegetation alliances and their associations under the ASTRAGALO-BROMETEA Quézel, 1973 steppe class, and seven alliances and several associations under SALICORNIETEA Br.-Bl. & Tüxen 1931 class [5]. In none of those studies, hovewer, an objective and qualitative evaluation of biodiversity patterns was provided, which remains a gap in saline biodiversity studies. Notwithstanding, the commonest measure of biodiversity is the species diversity and there are many methods available to measure it [7, 8]. The only study which applied quantitative methods to saline vegetation in Türkiye was conducted in Çukurova Plain, Adana, and analyzed alpha and beta diversity along humidity and salinity gradients [9]. Yet, to date, there have been no such quantitative studies targeting saline areas in Central Anatolia, which is at the heart of the Irano-Anatolian biodiversity hotspot [10]. This research gap results in shortcomings related to providing quantitative evidence for nature conservation value of the saline vegetation.

Species diversity can be measured and evaluated at three different spatial scales: alpha, beta and gamma [11]. Alpha diversity represents the local species diversity on a single site and it is the most commonly used scale of the species diversity [12]. The common measures of the alpha diversity are the species richness, i.e., the number of different species in a site, Shannon's and Simpson's indices which account for both species richness and abundances [13]. Gamma diversity represents the regional diversity of a community resulting from synthesis of local diversities sampled in several sites [8]. Beta diversity is expressed as the difference or proportion of alpha and gamma diversities and can be calculated with various approaches and formula [14]. The patterns of those three species diversity measures can be different as a result of different drivers. For example, a community can have high alpha but low beta diversity. The reason of that may be that the compositions of species-rich communities in all sites are very similar due to limited environmental variation which would otherwise support different species at different sites. On the contrary, in sites with high levels of environmental stress and variation one can expect low alpha diversity but high beta diversity. In the first case it may be sufficient to conserve a few representative sites to conserve communities but in the second case it is essential to conserve many sites within the distribution range of communities. Consequently, to guide conservation activities, it is of vital importance to measure species diversity at different spatial scales.

In this study, alpha, beta and gamma diversities of plant communities along humidity and aridity gradients in saline areas were calculated and compared. The study tested four hypotheses: 1) On hypersaline soils, low levels of alpha diversity were expected because extremely saline soils prevent growth of many plant species but allow only few ones well-adapted to those conditions. 2) In humid areas, by contrast, lack of aridity and salt stress would enable a high level of alpha diversity. 3) In ecotone areas -transitions of different habitat types or soil attributes (i.e., sub-humid or slightly-saline environments)- high levels of beta diversity were expected as environmental heterogeneity supports many different species. 4) Gamma diversity is highest in plant communities covering largest areas because species turnover would be high and there is high probability of including a many species in a large area.

2. MATERIAL AND METHOD

2.1. Materials

In this study the datasets collected in 25 m² or 40 m²-sized plots sampled in central Anatolia, published in four articles [15-18], were compiled for analysis. The five vegetation alliances previously identified by those studies were accepted as target plant communities (Table 1). Three other studies that did not include a phytosociological classification were excluded [19-21]. Alpha, beta and gamma diversities of each alliance were calculated for each alliance based on the corresponding dataset and subsequently compared. Some alliances were identified in more than one study area; therefore, a regional comparison was not conducted.

Plot size can influence the alpha, beta and gamma diversity results [22]. Using data from plots of widely varying sizes may lead to inconsistencies. To avoid this, plots with very small or large areas were excluded, and only data from plots sized 25 m² or 40 m²—commonly used and moderate sizes in phytosociological studies [15–18]—were retained. Specifically, 24 plots with sizes of 4, 8, 16, or 100 m² representing *Thero-Salicornion* Br.-Bl. 1933 in Yurdakulol et al. 1996 [15] were excluded. The data of a non-saline but adjacent steppe alliance, *Astragalo karamasici-Gypsophilion eriocalycis* Ketenoğlu et al. 1983, were included as a reference outlier group to support better interpretation of results. In total, data of 101 plots representing five vegetation alliances were used in the analyses:

Table 1. Vegetation alliances included in the study. Only data from plots of 25 m^2 or 40 m^2 sizes were used. For class and ordo names, syntaxonomic names in the source publications were used. Some names and higher-level classifications differ in Mucina et al. 2016 and FloraVeg. EU. * In Aydoğdu et al. 2002, no alliance was defined for one association.

Vegetation type and location	Class and ordo	Alliance, associations, plot number and size	Source
Steppes Burdur Lake and Acıgöl	ASTRAGALO-BROMETEA Quézel 1973, ONOBRYCHIDO ARMENI-THYMETALIA LEUCOSTOMI Akman, Ketenoğlu, Quézel 1985	*Astragalo karamasici-Gypsophilion eriocalycis* Ketenoğlu, Quezel, Akman, Aydoğdu 1983: *Artemisetum santonici* Çetik 1981, 7 plots, 25 m^2	[15]
Salt steppes Salt Lake and Seyfe Lake	ASTRAGALO-BROMETEA Quézel 1973, ONOBRYCHIDO ARMENI-THYMETALIA LEUCOSTOMI Akman, Ketenoğlu, Quézel 1985	*Achilleo wilhelmsii- Artemision santonici* Aydoğdu, Hamzaoğlu, Kurt 2004: *Achilleo wilhelmsii-Artemisietum santonici* Aydoğdu, Hamzaoğlu, Kurt 2004, *Artemisio scopariae-Peganetum harmalae* Aydoğdu, Hamzaoğlu, Kurt 2004, 25 plots, 25 m^2 and 40 m^2	[17]
Salt marshes Burdur Lake and Acıgöl	Salicornietea Br.-Bl. Ex Tx (Puccinellio-Salicornietea Topa 1938), JUNCETALIA MARITIMI Braun-Blanq. ex Horvatić 1934	*Salicornion fruticosae* Br.-Bl. 1933: *Cresso creticae-Halocnemetum strobilacei* Yurdakulol Öcel, Demirörs, Yıldız, Keleş 1996, 4 plots, 25 m^2*	[15]
Salt marshes Salt Lake and Seyfe Lake	Salicornietea Br.-Bl. Ex Tx (Puccinellio-Salicornietea Topa 1938), HALOSTACHETALIA (Grossheim) E.Topa. 1938	*Lepidio caespitosi-Limonion iconici* Aydoğdu, Hamzaoğlu, Kurt 2002: *Lepidio caespitosi-Limonietum iconici, Limonio tamaricoidis-Puccinellietum convolutae, Sphenopodo divaricati-Halocnemetum strobilacei, Suaedo anatolicae-Salsoletum nitrariae,* 27 plots, 25 m^2	[16]
Salt marshes Salt Lake and Seyfe Lake	Salicornietea Br.-Bl. Ex Tx (Puccinellio-Salicornietea Topa 1938), JUNCETALIA MARITIMI Braun-Blanq. ex Horvatić 1934	*Inulo aucheranae-Elymion salsi* Aydoğdu, Hamzaoğlu, Kurt 2002: *Inulo aucheranae-Elymetum salsi, Eragrostio collinae-Puccinellietum anatolicae,* 19 plots, 40 m^2	[16]
Salt marshes Sultansazlığı, Kayseri	SALICORNIETEA FRUTICOSAE Br.-Bl. 1931, HALOSTACHETALIA (Grossheim) E.Topa. 1938	*Lepidio caespitosi-Limonion iconici* Aydoğdu, Hamzaoğlu & Kurt 2002*: Halocnemetum strobilacei* (B.Keller) Topa 1938, *Lepidio caespitosi-Limonietum iconici* Aydoğdu, Hamzaoğlu ve Kurt 2002, *Halocnemetum strobilacei* (B.Keller) Topa 1938, 9 plots, 25 m^2	[18]
Salt marshes Sultansazlığı, Kayseri	SALICORNIETEA FRUTICOSAE Br.-Bl. 1931, JUNCETALIA MARITIMI Braun-Blanq. ex Horvatić 1934	*Inulo aucheranae-Elymion salsi* Aydoğdu, Hamzaoğlu ve Kurt 2002: *Inulo aucheranae-Elymetum salsi* Aydoğdu, Hamzaoğlu ve Kurt 2002, *Tamaricetum parviflorae-tetrandrae* Hamzaoğlu ve Aksoy 2006, 11 plots, 25 m^2	[18]

Achilleo wilhelmsii-Artemision santonici Aydoğdu, Kurt, Hamzaoglu, Ketenoglu & Cansaran 2004*, Astragalo karamasici-Gypsophilion eriocalycis* Ketenoğlu, Quezel, Akman, Aydoğdu 1983*, Inulo aucheranae-Elymion salsi* Aydoğdu, Hamzaoğlu, Kurt 2002*, Lepidio caespitosi-Limonion iconici* Aydoğdu, Hamzaoğlu, Kurt 2002, and *Salicornion fruticosae* Br.-Bl. 1933. These alliances were included in the most recent synthesis of Türkiye's vegetation [23], although some names and higher-level classifications differ in Mucina's list of European vegetation [24] and in the Database of European Vegetation, Habitats and Flora (FloraVeg.eu). Saline vegetation changes along the gradients of aridity and salinity from center towards periphery of each saline lake, resulting in environmental, not regional, differentiation of vegetation types [23]. Consequently, similar vegetation zonation is observed around each lake [25]. Since salt marshes and salt steppes across central Anatolia share comparable floristic and environmental characteristics, the compiled dataset represents the region's saline vegetation overall [5].

Astragalo karamasici-Gypsophilion eriocalycis, a non-saline steppe alliance, was first described on the gypsum bedrocks around Çankırı [26]. A sub-alliance was later identified on gypsiferous soils between Sivas and Erzincan [27]. It is mainly found on gypsum-rich soils with many endemic and gypsophile species. Characteristic species include *Astragalus karamasicus, A. aduncus, Thymus leucostomus*, *Linum mucronatum* subsp. *gypsicola, Gypsophila eriocalyx, G.parva, Lappula barbata, Ziziphora tenuior* and *Z. taurica, Centaurea patula, Allium flavum* subsp. *tauricum* var. *pilosum (Allium flavum* var. *pilosum* in the original publication)*, Bupleurum boissieri, Silene supina* subsp. *pruinosa* [28]. In the dataset from Burdur Lake, *Artemisia santonicum* was the dominant species, while the frequency and cover values of the alliance's diagnostic species were relatively low [15].

Figure 1. Map of the study area. Google Earth layer is the base of the map [35]. Saline areas appear white. The studied areas are labeled and shown in red ellipses. The map was prepared using the QGIS program [36].

Achilleo wilhelmsii-Artemision santonici alliance represents salt steppes around Salt Lake and Seyfe Lake in the Konya basin and intertwoven with hypersaline vegetation [17]. Dominant species include *Artemisia santonicum* and *Achillea santolinoides* subsp. *wilhemsii*. Other common species of the alliance are *Allium pseudoflavum* and *Noaea mucronata*. Halophytes are frequently found.

Lepidio caespitosi-Limonion iconici is a salt marsh alliance occurring at ecotones between *Artemisia* steppes and submerged *Juncus* spp. swamps. The alliance is found on strongly-saline soils that remain wet except the driest summer months in Konya Basin [23]. Dominant species are *Halocnemum strobilaceum, Frankenia hirsuta, Petrosimonia brachiata, Limonium iconicum* and *Lepidium cartilagineum* subsp. *caespitosum* (published as *Lepidium caespitosum*).

Cresso creticae-Halocnemetum strobilacei plant association was identified in salt marshes around Burdur Lake and Acıgöl [15]. It shows the characteristics of two alliances, i.e. *Thero-Salicornion* Br.-Bl. 1933 and *Salicornion fruticosae* Br.-Bl. 1933. The former consists of annual succulent plants in tidal flats and irregularly inundated inland depressions in the Mediterranean and warm Atlantic zone, while the latter comprises dwarf chenopod shrubs under similar conditions [24]. In this study, the dataset was evaluated under the *Salicornion fruticosae* alliance, as the plant community composition was more consistent with this alliance. Dominant and common species included *Halocnemum strobilaceum, Cressa cretica* and *Salicornia perennans (*published as *Salicornia europea* subsp. *prostate*).

Inulo aucheranae-Elymion salsi salt marshes are found on south of Salt Lake in areas that dry between August and October but remain otherwise wet [16]. Soil salinity is relatively low. Most characteristic species are endemics. The common or dominant species included *Elymus elongatus* subsp. *salsus*, *Inula aucherana* and *Juncus maritimus*.

2.2. Study Sites

The data for this study were collected from four different sites within Konya Basin, located in Central Anatolia Region of Türkiye: i) Saline soils around Salt Lake (Tuz Gölü), spanning the provinces of Ankara, Konya and Aksaray, ii) saline areas around Seyfe Lake in Kırşehir province, iii) the Sultansazlığı marshes in Kayseri province, and iv) saline areas around Denizli Acıgöl and Burdur Lake (Figure 1). Although Burdur Lake and Acıgöl are not officially included in Central Anatolia, they were included in the study due to their proximity to the regional boundary and the similarity of their saline vegetation to that of the Central Anatolia. Environmental data from the original publications [15–18] indicate the following characteristics for these sites: Elevation ranges from 930 to 1140 meters above sea level, annual precipitation varies between 308 and 370 mm, and the highest average temperature during the warmest months can reach 33.3 °C. According to Emberger's classification system, two bioclimate types are present: the semi-arid lower very cold Mediterranean climate and the arid upper very cold Mediterranean climate.

All study areas feature saline hydromorphic alluvial soils, with salinity influenced by proximity to water bodies, salt accumulation, and humidity. In the salt marshes of Salt Lake and Seyfe Lake, pH ranges from 8.2 to 8.6, sodium ion (Na^+) concentrations from 38.1 to 853.1 me/L, and chloride ion (Cl^-) concentrations from 3 to 32.5 me/L. In the surrounding saline steppes, values are lower: pH 7.5–7.7, Na^+ 3–10.8 me/L, and Cl^- 11.0–11.2 me/L.

Sultansazlığı marshes are sodic, with pH values between 8.8 and 9.4, Na^+ concentrations from 2825 to 4475 ppm, and Cl^- concentrations from 1.1 to 9.4 ppm. In the steppes around Burdur Lake and Acıgöl, the pH is approximately 7.8, with Na^+ ranging from 12 to 20 me/L and Cl^- from 5.8 to 10.1 me/L; in salt marshes, these values are Na^+ 15–25 me/L and Cl^- 6.9–8.3 me/L, with a pH of 7.8

2.3. Data Processing, Calculations and Tests

Plant nomenclature followed the List of Plants of Turkey: Vascular Plants [29]. Taxonomic updates made since the publication of the original data sources were incorporated; synonymized names were replaced with currently accepted names, and any typographical errors in taxon names were corrected. Duplicate entries of the same species within syntaxonomic tables were consolidated. Species were used as the taxonomic unit for three reasons: (1) the study aimed to assess species-level diversity, (2) subspecies were not consistently identified or reported, and (3) retaining both species and subspecies data could distort species diversity calculations. Consequently, subspecies and varietal data were aggregated at the species level, and a few entries recorded only at the genus level were excluded. The final dataset comprised a species-by-site matrix of 191 species across 101 plots.

Many studies targeting alpha and gamma diversity in plants have only used species richness and not used cover or abundance data [30]. However, abundance data are needed to calculate different measures of alpha diversity. In the vegetation datasets used in this study, species abundance was recorded using the Braun-Blanquet's cover-abundance scale [31], using one of seven categories: - (absent), r (cover < 5%, one individual or rare), + (cover < 5%, very few individuals), 1 (cover < 5%, individuals abundant with very low cover or not abundant but with higher cover), 2 (cover < 25%), 3 (cover 25% - 50%), 4 (cover 50% - 75%) and 5 (cover > 75%). Furthermore, categories of 1 and 2 were divided into subcategories [32]. To use these ordinal categories in diversity calculations, numerical transformations are required. According to Wildi [33], the Braun-Blanquet scale can be converted using rank values and the formula $x'=xy$, where x is the rank and y is an exponent selected by the researcher. For instance, using y=0.25 yields values between 1 and 1.7 for the entire scale, minimizing distinctions between rare and dominant species, which is unsuitable for this study's goals. Alternatively, using y=2.5 produces values more representative of actual cover (e.g., a "5" becomes 88.18), but this inflates gamma diversity. As a compromise, the study used y=1.5, producing the following transformation: – = 0; r = 1; + = 1.84; 1 = 2.83; 2 = 5.20; 3 = 8.00; 4 = 11.18; 5 = 14.7. A sensitivity analysis showed that alpha diversity values calculated using y=0.25 and y=2.5 showed no significant differences from the calculation with y=1.5. Therefore y=1.5 was chosen for its balance. Data were digitized using the JUICE software [34].

Hill numbers were used to quantify species diversity on both alpha and gamma scales [37], allowing for weighting based on species abundance [37, 38]. The following were calculated: species richness (qD = 0, equal weighting), Shannon diversity (qD = 1, abundance-weighted), inverse Simpson (qD = 2, greater weight to dominant species). Alpha diversity was calculated using the renyi function of the *vegan* package in R software [39]. Comparisons of diversity between alliances were conducted using the nonparametric Kruskal-Wallis test, followed by Wilcoxon pairwise comparisons. Statistical significance was set at $p < 0.05$, and results were visualized using the *ggpubr* package [40].

In the study, gamma diversity was calculated at the level of alliances, the lowest regional unit in the vegetation classification [41]. It groups associations with shared regional patterns but local differences and meets the gamma diversity level [42]. Gamma diversity was estimated using incidence-based rarefaction and extrapolation [43], with 95% coverage-based standardization [44]. This method can interpolate or extrapolate biodiversity using species accumulation curves. Bootstrap confidence intervals were used to assess statistical differences, where non-overlapping intervals indicate significance [7]. Incidence was adopted as the data type because cover-abundance scales converted to abundance data gave unreliable results in this calculation.

Beta diversity was assessed using three abundance-based metrics, i.e., Bray-Curtis dissimilarity index, balanced variation in species abundances and unidirectional abundance gradients. Analogous to species turnover [45], balanced variation in species abundances (beta.bray.bal) computes how much a decline of a species' abundance from one site to another is balanced with an increase in abundance of another species. Analogous to nestedness [45], unidirectional abundance gradients (beta.bray.gra) are calculated to measure how much sites are subsets of other sites with high abundances of each species. The widely used Bray-Curtis dissimilarity index is derived from the sum of these two sources of dissimilarity. Beta diversity calculations were performed using the *betapart* package in R software [46]. The data set was divided into alliances and for each alliance, abundance-based pair-wise dissimilarities of all plots were calculated. All calculations were performed with R software [48] in the R Studio environment [49].

3. RESULTS

3.1. Alpha Diversity

The mean species richness of saline vegetation based on data from 101 plots with 25 m² or 40 m² sizes, was 17.0 (standard error ± 0.464) with species richness ranging from 6 to 27. The average Shannon diversity was 14.5 (±0.438), and the inverse Simpson diversity was 12.0 (±0.414).

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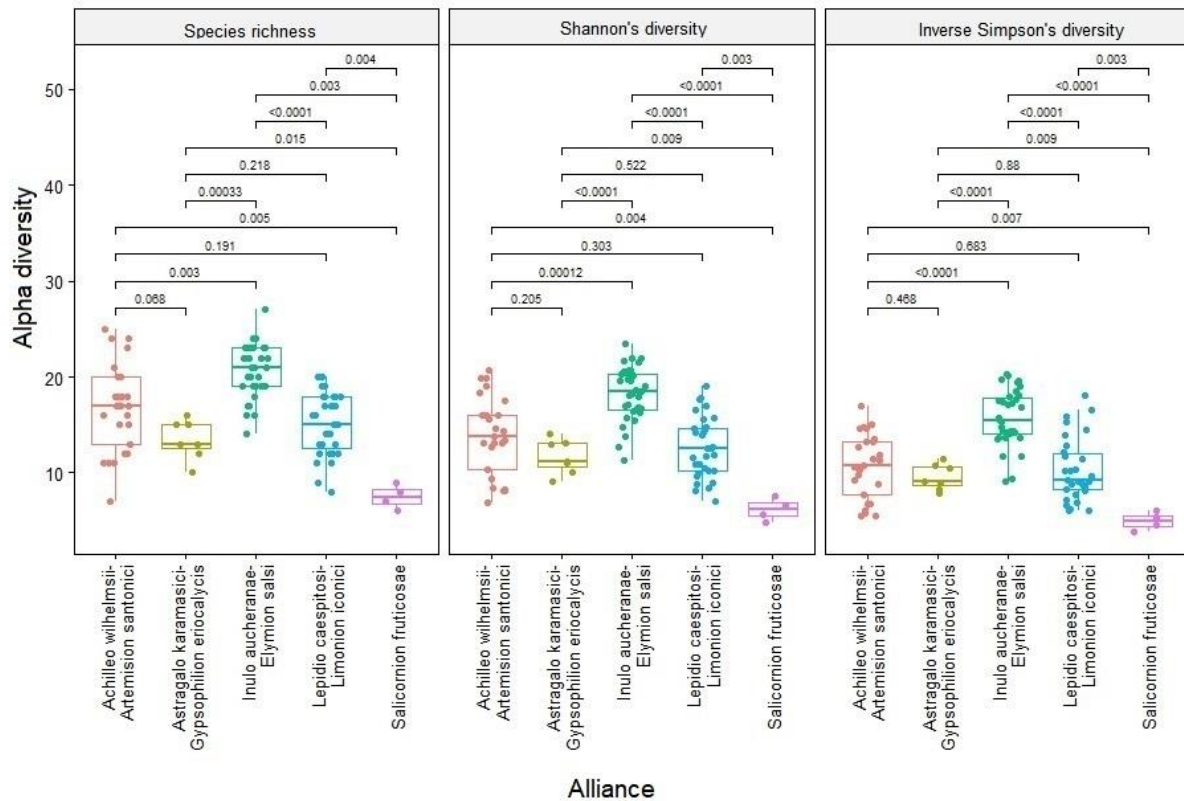
Figure 2. Boxplots showing the alpha level diversity of five alliances representing Central Anatolian saline vegetation. The alliances are shown in different colors. The graph was generated using the *ggpubr* package in R Studio [40]. The alpha diversity value of each plot is indicated with a dot using the "jitter" feature. Statistical significances between the alliances were indicated using *p* values of Wilcoxon tests.

Statistically significant differences in alpha diversity were observed among the alliances, according to the nonparametric Kruskal-Wallis test ($p < 0.0001$). Pairwise comparisons using the Wilcoxon test revealed significant differences between several alliances (Figure 2). The *Inulo aucheranae–Elymion salsi alliance*, representing slightly saline, summer-dry marshes, exhibited the highest species richness. This was followed by the *Achilleo wilhelmsii–Artemision santonici* salt steppes and the *Lepidio caespitosi–Limonion iconici* transitional salt marshes. Conversely, the alliances with the lowest species richness were the *Astragalo karamasici–Gypsophilion eriocalycis* steppes and the *Salicornion fruticosae* hypersaline vegetation with succulent Chenopods. Notably, these two alliances were represented by a small number of plots in the dataset.

The patterns observed for Shannon and inverse Simpson diversity indices mirrored those of species richness in terms of statistical significance and diversity ranking. Importantly, using different transformation values (y = 0.25 and y = 2.5) for Braun-Blanquet cover categories did not alter the results in terms of statistical significance or the order of diversity rankings—only the p-values of the Wilcoxon tests varied slightly.
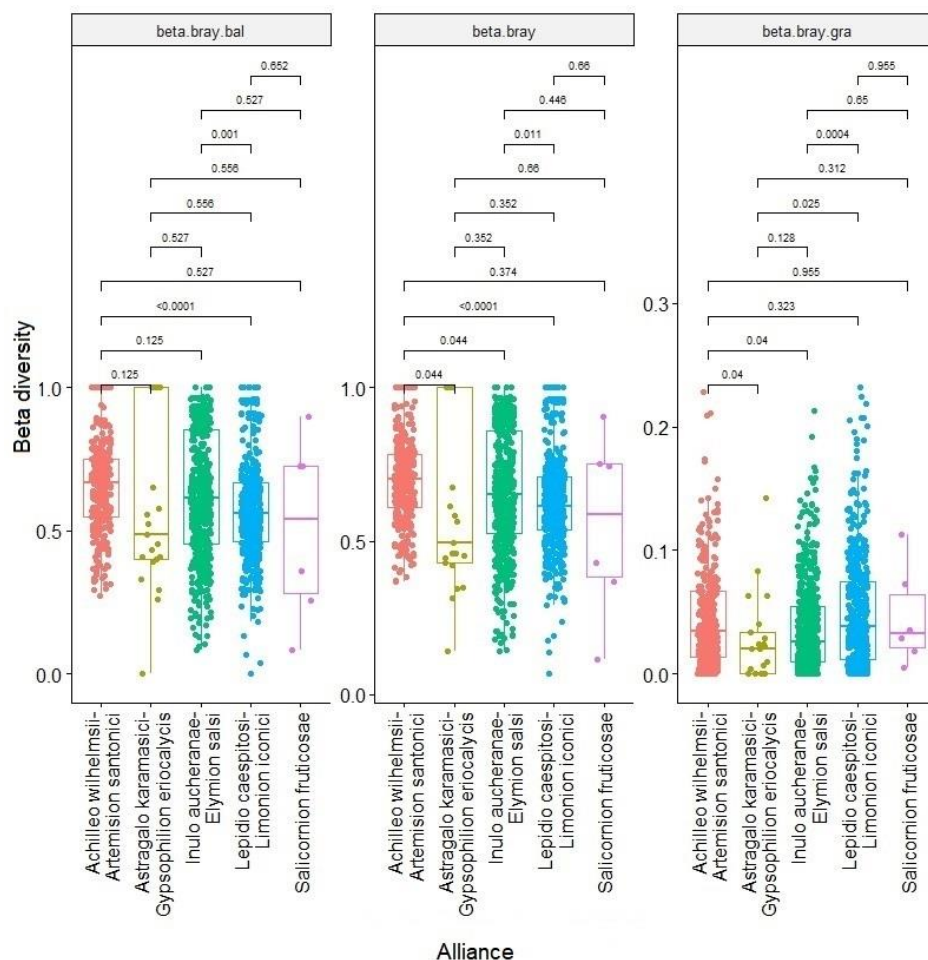
3.2. Beta Diversity

Bray-Curtis dissimilarity index (beta.bray) results indicated that within most alliances, plots were either highly similar or very dissimilar in species composition. The *Achilleo wilhelmsii–Artemision santonici* salt steppes

exhibited relatively high beta diversity, whereas the *Astragalo karamasici–Gypsophilion eriocalycis* steppes displayed relatively low Bray-Curtis values (Figure 3). The median dissimilarity values for the remaining three alliances were close to each other and to the overall mean. Despite being represented by only four plots, the *Salicornion fruticosae* alliance showed a wide range of Bray-Curtis values.

In contrast to alpha diversity, beta diversity comparisons revealed fewer statistically significant differences among alliances. Specifically, the *Lepidio caespitosi–Limonion iconici* transitional salt marshes exhibited significantly lower dissimilarity values than the *Achilleo wilhelmsii–Artemision santonici* salt steppes, while the *Inulo aucheranae–Elymion salsi* alliance had significantly higher values compared to other salt marshes. Species turnover values (beta.bray.bal) were similar to the Bray-Curtis index and reflected comparable patterns in inter-alliance differences. In contrast, values for nestedness (beta.bray.gra) were generally low across alliances (Figure 3). Nonetheless, based on this metric, most alliances were significantly different from each other.

Figure 3. Boxplots showing the beta diversity of five alliances representing Central Anatolian saline vegetation with three different measures. The alliances are shown in different colors. Each point indicates the dissimilarity value of two different plots within an alliance. For clarity, overlapping points were shifted slightly using the "jitter" feature. Values for the first two measures of beta diversity ranged from 0 to 1, while the beta.bray.gra axis ranged from 0 to 0.5.
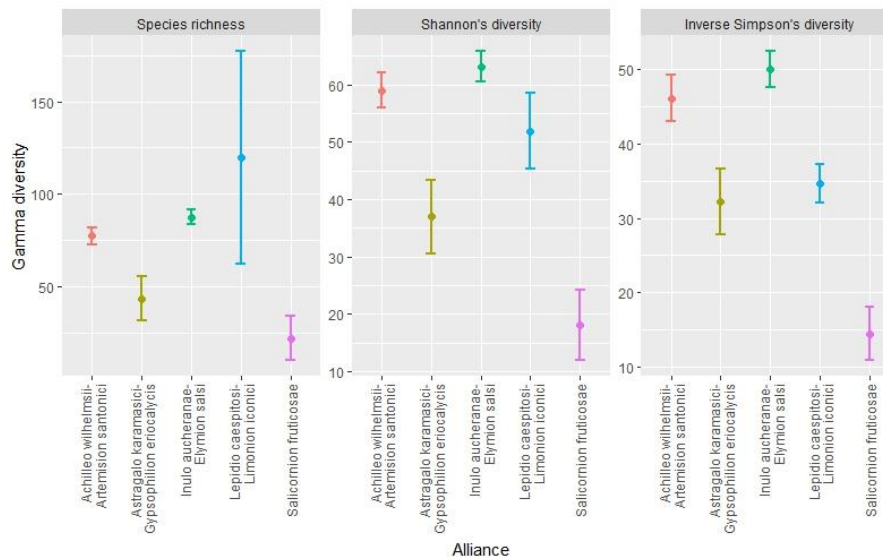
3.3. Gamma Diversity

The average species richness at the gamma (regional) level was estimated at 70.1±17.1. Significant differences in gamma diversity were observed among the alliances (Figure 4). The highest species richness was recorded in two salt marsh alliances: *Lepidio caespitosi–Limonion iconici* and *Inulo aucheranae–Elymion salsi*, followed by the salt steppes of *Achilleo wilhelmsii–Artemision santonici*. The lowest values were found in the *Astragalo karamasici–Gypsophilion eriocalycis* steppes and the hypersaline *Salicornion fruticosae* vegetation. However, this ranking changed when species frequency was considered using Shannon and inverse Simpson diversity indices. In particular, the diversity of *Lepidio caespitosi–Limonion iconici* decreased relative to other highly diverse alliances, approaching the values of the *Astragalo karamasici–Gypsophilion eriocalycis* steppes. By contrast, the *Inulo aucheranae–Elymion salsi* and *Achilleo wilhelmsii–Artemision santonici* alliances maintained high values, indicating more even distribution of species.

4. DISCUSSION AND CONCLUSION

Saline habitats are typically considered species-poor [5]. However, this study found an average of 17 species per 25 or 40 m² plot, which is relatively high given the stressful conditions associated with salinity. For comparison, the European Grassland Database reports an average of 35 species per 100 m² plot for *Astragalo-Brometea* steppes ($n = 3$) and 10 species for *Juncetea maritimi* marshes ($n = 78$) [50]. The Central Anatolian saline plots demonstrate comparable species richness, especially considering their smaller size.

Among the alliances, *Inulo aucheranae–Elymion salsi* slightly saline, summer-dry marshes had the highest alpha diversity. These habitats feature moderate salinity and humidity levels—conditions that are neither as harsh as hypersaline environments nor as dry as typical steppes. This finding supports the second hypothesis: intermediate environmental stress fosters higher species richness [51, 52]. A similar pattern was observed in Mongolian grasslands, where diversity increased with humidity [53]. On the other hand, the lowest alpha diversity was observed in the *Salicornion fruticosae* hypersaline vegetation, in line with the first hypothesis and existing literature indicating that extreme conditions (e.g. hypersalinity) significantly limit species establishment [54]. Previous research from Çukurova similarly showed increased alpha and beta diversity with decreasing salinity and increasing humidity [9], further supporting these results.

Figure 4. Gamma diversity of five alliances representing Central Anatolian saline vegetation. The alliances are shown in different colors. Diversity estimates are shown with dots and confidence intervals with lines.

The beta diversity across alliances was generally high. This suggests that plots within the same alliance can be markedly different in species composition. The high dissimilarity was largely driven by species turnover (beta.bray.bal), rather than nestedness (beta.bray.gra). In Central Anatolia, microhabitat variability is high—even across short distances—leading to complete species replacement in nearby plots. These findings are consistent with the presence of beta diversity values approaching 1 in Figure 3 and confirm substantial small-scale compositional changes [42]. This supports the argument that regional diversity in saline habitats, though modest at the plot level, is significantly enhanced by spatial heterogeneity. Conservation efforts should therefore prioritize multiple representative sites rather than focusing on single locations.

The *Achilleo wilhelmsii–Artemision santonici* salt steppes exhibited the highest beta diversity and were also among the most diverse in terms of alpha and gamma diversity. These communities occur at the transition between steppe and saline zones and may be classified as ecotones [17]. Similar findings have shown ecotones to be high in beta diversity and critical in conservation prioritization [55]. Additionally, their high gamma diversity likely results from combining species pools from two different ecosystems [5, 56]. These transitional areas should therefore be focal points for biodiversity conservation in Central Anatolia.

Salt marsh communities also demonstrated high beta diversity, second only to salt steppes. This may be attributed to two additional factors: (i) salt marsh plots were located in two distinct regions (Salt Lake and Sultansazlığı), separated by over 100 km, and (ii) a greater number of plots were included. This wide geographic range and larger sampling effort naturally lead to higher species turnover and thus elevated beta diversity [57].

The highest gamma diversity was observed in *Achilleo wilhelmsii–Artemision santonici* salt steppes and *Inulo aucheranae–Elymion salsi* low-saline marshes. These results reaffirm the value of ecotones and moderately saline habitats for conserving regional species richness, partially supporting the fourth hypothesis. In contrast, the *Astragalo karamasici–Gypsophilion eriocalycis* steppes had low diversity at both alpha and gamma levels. The data used for this alliance originated from plots around Lake Burdur, where the habitat is both saline and arid—non-optimal for this community type, which typically occurs on gypsiferous soils such as those in Çankırı, Ankara, and Erzincan [15, 26, 27]. Including plots from those core regions in future studies would likely improve gamma diversity estimates for the alliance. Currently, these data suggest that gypsophilous vegetation is not a major component of Central Anatolia's saline habitats. The *Salicornion fruticosae* alliance also showed low alpha and gamma diversity, in line with its ecological characteristics. Hypersaline environments support only a few specialized species [5], but even within this limited group, there was some variation, as indicated by a few plots with high beta high beta diversity values.

This study relied on vegetation data collected between 1996 and 2006. Since then, saline ecosystems in Central Anatolia have been increasingly impacted by climate change and anthropogenic activities. Saline lakes have contracted due to reduced precipitation, groundwater depletion, and agricultural expansion [58–60]. These changes likely influence both the composition and extent of saline vegetation, making updated fieldwork essential.

The data sources of this study had different plot sizes calculated with minimal area method. Very small and very large plots were excluded from the analysis as numerical comparison of the species data from those plots may lead to erroneous results. But two commonest and closer sizes were kept to make maximum use of available data. In future studies, if standardized data can be collected from each plant community with equal size and number of plots, comparisons can be made with smaller confidence interval estimates. With a similar approach, studies with nested plots are thought to provide the most useful data in terms of numerical analysis [61].

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Conducting new vegetation studies in the same areas but with standardized methods will provide up-to-date and precise results.

Studies of syntaxonomic classification have advanced with new quantitative and objective methods in delimitation of the syntaxonomic units [62]. As a result, vegetation classifications of different regions around world have been revised and new classifications were proposed (e.g. see [63] for forests of Japan). Syntaxonomic classification of the saline steppes requires such quantitative analyses and revisions. Before that, collecting data from under-represented parts of central Anatolia such as Palas Lake in Kayseri is a must. I hope this study will be a motivation for such further studies. After a comprehensive revision, similar analyses of biodiversity patterns can provide the complete picture of the spatial biodiversity patterns.

This study provides the first quantitative comparison of species diversity in saline habitats across Central Anatolia, analyzing five major vegetation alliances across alpha, beta, and gamma levels. Each diversity component revealed a different pattern, emphasizing the need for multi-scalar approaches in biodiversity assessments. Alliances thriving under moderate conditions (e.g., ecotones) are crucial for conserving high local and regional diversity. However, low-diversity habitats, including those with extreme conditions or limited sampling, may still host rare or endemic species and warrant conservation.

In conclusion, conserving the biodiversity of Central Anatolian saline ecosystems requires a dual strategy: protecting both moderately stressful ecotone habitats and preserving the unique, harsh environments that support specialized flora. This work underscores the ecological complexity of these habitats and the importance of updated, standardized research for effective conservation planning.

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