Turkish Journal of Botany

http://journals.tubitak.gov.tr/botany/

Research Article

Turk J Bot
(2021) 45: 688-700

doi:10.3906/bot-2104-4

Habitat variation and vulnerability of *Quercus brantii* woodlands in the Zagros Mountains, Iran

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Received: 04.04.2021 • **Accepted/Published Online:** 17.11.2021 • **Final Version:** 28.12.2021

Abstract: During the past decades, extensive parts of the *Quercus brantii* woodlands in the Zagros Mountains declined in size and habitat quality. We aimed to explore the variation of oak woodlands in the southern Zagros Mountains and to assess the vulnerability. The following questions were addressed in the study: Which edaphic and physiographic parameters are most important in differentiating woodland vegetation? Which plant species express certain habitat quality and vulnerability characteristics? We examined 49 plots at different altitudes and aspects, recorded the vascular plant species for tree and herb-layer composition, and collected data on topographic and edaphic factors. TWINSPAN was applied to classify the plots. We identified three types of woodland plant communities that show differentiation associated with environmental factors. Most vulnerable types stand at lower altitudes, chiefly on southern aspects and with poor soil fertility. The highest tree-layer α diversity was observed at steeper slopes around the north at higher altitudes, on fertile fine soils rich in organic matter. Longitude, altitude, and slope were correlated with the soil factors and the vegetation composition. Soil erosion and the removal of fine organic soil resulted in forest degradation and loss of habitat quality. Facilitation of regeneration of *Quercus brantii* as keystone species in the forests of the Zagros mountain range is concluded as a crucial management objective to buffer the negative effects of climate change and overexploitation. The protection of larger areas of *Q. brantii* woodlands to conserve local-scale species and community diversity is imperative.

Key words: Ecosystem services, forest management, forest soil, Irano-Turanian, plant community, forest vegetation

1. Introduction

The biogeographical position and environmental factors such as climate, chemical and physical soil properties, topography, human interference, and management actions (frequency and intensity of grazing, fires, cultivation, etc.) contribute to the local plant community composition. Plant communities, sets of plants predictably occurring together in a habitat, can be used as indices of specific environmental conditions and habitat quality (Ellenberg et al., 1992). Therefore, vegetation classification and mapping are important preconditions to ecosystem management. Furthermore, plant species diversity and the occurrence of endemic and threatened plant species in plant communities can be used to identify the vulnerability and prioritize conservation actions (Mills et al., 1993).

The Zagros Mountains forest steppe, an ecoregion extending from north-west to south-west of Iran and beyond into eastern Turkey and northern Iraq, covers an area of almost 400,000 km^2, of which about 50% are wooded. The prevailing forest vegetation comprises Irano-Turanian oak woodlands of three native oak species (*Quercus brantii* Lindl., *Quercus infectoria* Oliv. and *Quercus libani* Oliv.), the latter two being widespread chiefly in northern Zagros forests (Valipour et al., 2014; Shakeri et al., 2021). In the southern Zagros Mountain range, pure open stands of the deciduous oak *Q. brantii* are usually found at low and mid-elevations but occur at elevations up to 2700 m (Sagheb-Talebi et al., 2014).

The xeric deciduous oak and open mixed forests, including those in the Zagros Mountain range, are exceptionally important in landscape ecology and provision of ecosystem services (water absorption and storage, reduction of soil erosion, biodiversity, wood resource, pastoralism, non-timber forest products, socio-cultural environment) (Jazirehi and Ebrahimi Rostaghi, 2003). In recent decades, the woodlands of the Zagros Mountains have experienced dramatic changes in cover and structure due to altered land use (cultivation, overgrazing, excessive collection of medicinal plants), especially in the southern part (Khalyani et al., 2012). Such anthropogenic impact,

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together with drought, leads to a decrease in soil organic matter, soil fertility, and moisture (Reichstein et al., 2013). Extensive forest habitats may partially compensate for such negative effects through better soil water holding capacity (Cianfrani et al., 2019).

Despite several local studies on the relationship between environmental factors and Zagros Forest types (Mirzaei et al., 2007; Mahdavi et al., 2010; Aghaei, 2011; Heydari et al., 2013), the *Q. brantii* woodlands of the south-western Zagros Mountains are an understudied research topic. With its high topographical and altitudinal variation, the southern Zagros range exhibits considerable endemic species richness (Mehrabian et al., 2020) and is, therefore, of high priority for biodiversity conservation (but only approximately 5% of the ecoregion are Protected Areas and Biosphere Reserves). As the southern Zagros is also most suitable for *Q. brantii* forest growth (Sagheb-Talebi et al., 2014), our study area is best suited for conducting research on xeric oak woodland. We collected plot data on the vascular plant species composition and measured soil and other environmental variables in different forest habitats to address the following questions: (1) What are the spatial distribution pattern of *Q. brantii* woodland plant communities? (2) Which edaphic and physiographic parameters are most important in differentiating oak woodland vegetation in the south Zagros? (3) Which plant species may serve as indicators expressing certain habitat quality and vulnerability characteristics? Furthermore, we aimed to reach a conclusion that identifies management objectives to retain ecosystem services and to improve the biodiversity and functional capacity of the *Q. brantii* woodlands.

2. Material and methods

2.1. Study area

Our study was conducted between 1800 m to 2700 m in the forest of Yasuj (Kohgiluyeh and Boyer-Ahmad province) in the southwest of Iran (30°41'-42'N and 51°34'-37'E). The annual rainfall is 791 mm ± 211 and the average temperature is 15.0 °C ± 0.7; the bioclimate according to Emberger's coefficient is semi-cold-dry. The average temperatures of the warmest and the coldest month are 27.2 and 2.5°C in July and January, respectively. The climate is Mediterranean-type, with a dry period of about six months, from April through October, with only 27 mm of total precipitation in the dry period (meteorological data by Yasuj station from 1987 to 2017). Prevailing rock types are Paleozoic, Mesozoic, and Tertiary limestones (Shearman et al., 1976), and the most common Mediterranean-type forest soils are red-brown, clayey-loamy, with pH value between 7.5 and 8.1 and usually thin organic layer (Dewan and Famouri, 1964; Sagheb-Talebi et al., 2014).

Woody species locally associated with oak include *Acer monspessulanum* L., *Amygdalus elaeagnifolia* Spach, *Crataegus pontica* K. Koch, *Colutea persica* Pers., *Cotoneaster nummularius* Fisch. & C. A. Mey., *Daphne mucronate* Royle, *Fraxinus angustifolia* Vahl, *Lonicera nummulariifolia* Jaub. & Spach, *Pistacia atlantica* Desf., *Pistacia khinjuk* Stocks, and *Prunus mahaleb* L. Due to the proximity to the city and being located near traditional nomad routes, anthropogenic pressures are significant and include livestock grazing, coppicing, collecting fuel wood and medical plants, charcoal production, recreation, and tourism.

2.2. Sampling of vegetation

A systematic 250 × 500 m grid was used to cover 800 ha of oak forest (Figure 1), stratified to comprise diverse habitats and ecological gradients (elevations, slopes, and aspects). The data were collected on 49 plots of 15 × 30 m (located in the lower right corner of the grid). The plots (each 450 m^2) were distributed in two main aspects (facing north and south) and different elevations (1800–2700 m). Geographical coordinates (latitude, longitude) and topographical data (elevation, aspect) were recorded by GPS, and the slope was measured with a Suunto clinometer. The aspect was converted into a continuous north-south gradient (northness) by the following equation: Northness = (Cos θ) +1, where θ = aspect in degrees (Gusian et al., 1999). The range of aspects was between 0 = south and 2 = north.

The presence and abundance of all vascular plants, woody and herbaceous, were recorded during spring 2014 at a time when almost all herbaceous species were identifiable. The taxonomy of plants follows Flora Iranica (Rechinger, 1963) and Flora of Iran (Assadi et al., 1988-2002). The life forms based on the position of the overwintering buds in relation to the soil surface were determined using field observations and other studies. Chorological type spectra of species were determined based on Zohary et al. (1980-1993). The total cover of ground vegetation (all herbaceous species) and all tree species (%) or canopy closure were visually estimated and separately recorded in each plot. The canopy cover of living trees of ≥ 2.5 cm dbh (diameter at breast height) was calculated by measuring and averaging two crown diameters (the widest crown diameter and the diameter perpendicular to the widest crown diameters) for each tree and summing up all trees in the plot. The frequency of each herbaceous plant species in each plot was estimated in five micro-plots (0.5 × 2 m).

Traces of human activities in each plot (livestock grazing, cutting of trees, charcoal production) were recorded as nominal scale values present (1) or absent (0). They, as well as landform (1 = valley, 2 = hillside, 3 = hilltop), were analyzed as dummy explanatory variables.

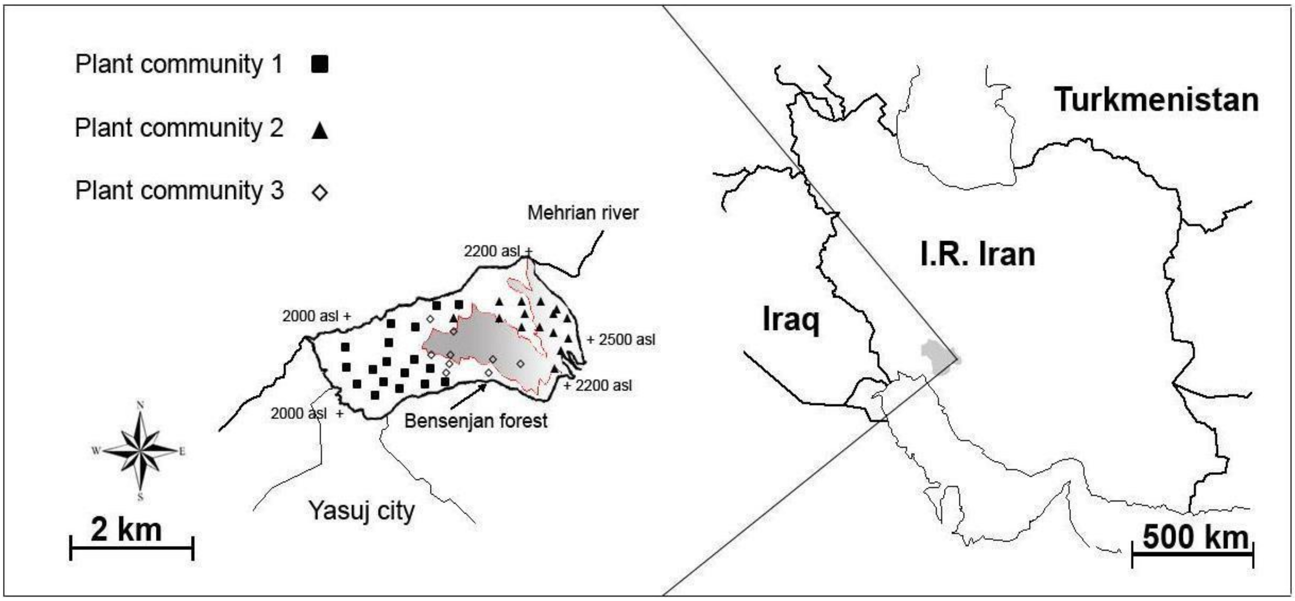

Figure 1. Location of the study area and sample plots (plant communities defined after data analysis). The grey area in the map is ≥ 2200 m a.s.l.

Humus depth was scaled as very poor (1) to rich (4). Stone, bare soil, and litter were visually estimated as the percent of the whole sampling plot.

Along with the plant data, two mixed soil samples of five subsamples were collected per plot at 0–15 and 15–30 cm depth. The soil samples were air-dried at room temperature and sieved by a 2 mm mesh. Soil pH value and electrical conductivity (EC) were determined by pH and conductivity meters (ratio used for soil water pH and EC was 1:2 and 1:5, respectively). Soil texture (sand, silt, and clay percentages) was determined by the hydrometric method (Day, 1965). Organic matter (OM) was measured by chromic acid titration (Jackson, 1975). Available P was determined using Olsen et al. (1954). Exchangeable potassium was extracted with sodium acetate and determined by flame photometry (Alison and Richard, 1954).

2.3. Data analysis

The hierarchical divisive two-way indicator species analysis (TWINSPAN) was used to classify 47 sample plots (two plots were identified as outliers and removed) into groups differing in their plant species composition (Adel et al., 2014). Indicator species, defined as species differentiating a plant community, were tested by the Monte Carlo algorithm. The indirect ordination method DCA (detrended correspondence analysis) was also performed to underpin the TWINSPAN results. Linear redundancy analysis (RDA) was used to examine relationships between environmental variables and species composition. Only the significant explanatory variables ($p < 0.05$) by 999 Monte Carlo permutations were retained in the analysis. All analyses were performed using PC-ORD vs.5 (Mc Cune and Mefford, 2006). Moreover, stepwise discriminant analysis (DA) was applied to assess and recognize the most important predictor of environmental variables in the TWINSPAN-generated plant communities. The dissimilarity of the plant communities was calculated by Wilk's lambda. The classification accuracy between the predicted (according to DA) and identified plant community (based on TWINSPAN) was evaluated by cross-validation as described by Lachenbruch and Mickey (1968). Diversity indices (species richness, evenness, Shannon index, and Simpson index) were calculated for each sample plot using PC-ORD.

All assumptions like normality and homogeneity of covariance were examined by the Kolmogorov–Smirnov and Levene's tests. The relation between soil variables and these with indicator species and other environmental variables was assessed by Pearson and Spearman correlation coefficients, respectively. Also, one-way ANOVA and Tukey tests were used to compare the plant communities in terms of environmental variables and biodiversity indices. For parameters not normally distributed, the non-parametric Kruskal–Wallis test was used. All correlation analyses were conducted by SPSS vs. 16.

3. Results

3.1. Diversity and plant communities

A total number of 153 vascular plant species were identified in the 49 sampling plots (mean species richness = 33) (Appendix Table 1A). The prevailing life form was hemicryptophytes (63 species, 41%), followed by therophytes (31%). By far most species belong to the Irano-Turanian phytogeographic element (103 species, 67.3%), followed by bi-regional species of the Irano-Turanian/Mediterranean (7.8%) and Irano-Turanian/Euro-Siberian (7.3%) elements. TWINSPAN classified the vegetation plots at the level of two divisions into three types of plant communities (PC1: *Quercus brantii-Taeniatherum crinitum*; PC2: *Quercus brantii-Astragalus susianus*; PC3: *Quercus brantii-Thalictrum isopyroides*) all dominated by *Quercus brantii* (Figure 2). The cover percentage values of *Q. brantii* were45.1, 29.6, and 60.6 for PC1, PC2, and PC3, respectively (Table 1). PC1 was found mostly at lower altitudes, chiefly on southern aspects and with poor soil fertility. We observed the highest mean herb layer cover in PC1. In contrast, PC2, with the highest α-diversity of woody and tree-layer species, was found at higher altitudes, mostly on steep slopes around the north and with high soil fertility. PC3, with the highest oak dominance, was generally intermediate between PC1 and PC2 (Table 1). DCA analyses (eigenvalue = 3.54) confirmed the results of TWINSPAN (Appendix Figure 1A). The DCA diagram showed that the plots of PC1 were located in the negative part of the first axis of the diagram and those of PC2 in the positive part. The plot scores of PC3 were located in the central part of the coordinate axis inclined towards the negative section of the first axis and the positive section of the second axis (Figure 2). Sørensen's index of similarity was high between PC1 and PC3 (S= 0.774) and between PC2 and PC3 (S = 0.743) and lowest between PC1 and PC2 (S = 0.546).

The comparison of herb- and tree-layer α-diversity by analysis of variance revealed that all diversity parameters except richness differed significantly in the three plant communities (Table 2). The highest values of evenness, Shannon and Simpson indexes of trees were observed in PC2, while the lowest values of the herb layer occurred in PC1 (Table 2). ANOVA results demonstrated that hemicryptophyte, therophyte, and geophyte proportions were significantly different in the three plant communities. The highest hemicryptophyte values were associated with PC2 and the lowest with PC3. The lowest therophyte values occurred in PC2, and the highest and lowest values of geophytes were observed in PC3 and PC1, respectively (Table 2). The one-way ANOVA results for environmental variables showed that most of the variables except for altitude, slope, herb-layer cover, OM, and fine silt in two different depths and C/N (15-30) were not significantly different in the three plant communities (Table 2). Average values for the topography variables altitude and slope demonstrated that PC1 had the lowest value minimum amount compared to the other two plant communities. Results from soil variables showed that OM in two depths of soil and C/N (15-30) had higher values for PC2 and lower for PC1. The lowest levels of fine silt values in both soil depths were observed in PC2 and the highest in PC3 (Table 2).

3.2. Relationships between environmental factors

Significant Pearson correlations were detected between environmental variables, i.e. soil and physiography characteristics (Appendix Table 2A). There is a positive relation between altitude and slope ($r = 0.33$, $p < 0.05$), K ($r = 0.57$, $p < 0.05$), N ($r = 0.57$, $p < 0.05$) and longitude ($r = 0.805$, $p < 0.01$). But longitude ($r = -0.35$, $p < 0.05$) and slope ($r = -0.46$, $p < 0.01$) showed negative correlations with grass cover. Moreover, slope had negative correlations with silt (15-30 cm depth) ($r = -0.48$, $p < 0.05$), clay (r

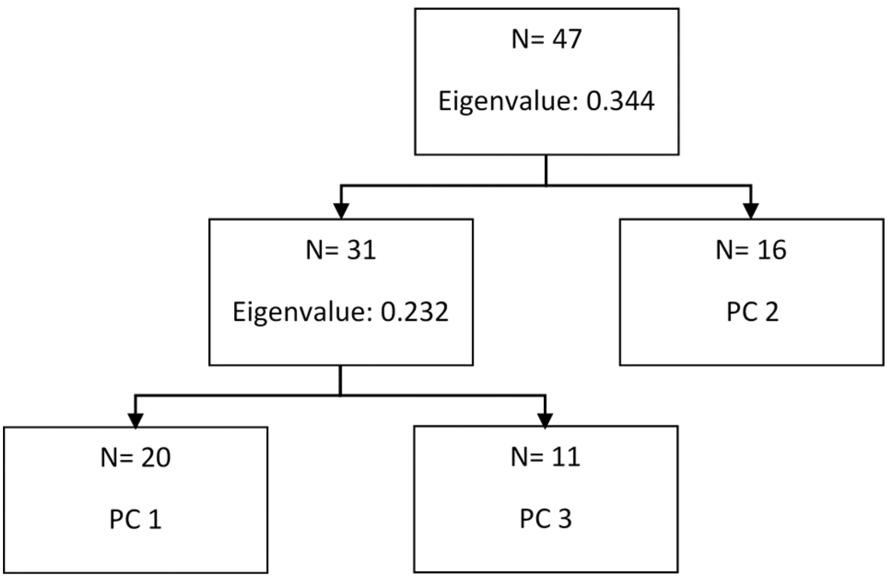

Figure 2. Hierarchy of the TWINSPAN classification.

Table 1. Woody species, geographical and vegetation information of the three plant communities (PC) of oak forest of the study area. Plant names in bold type indicate species confined to one plant community.

Variables	**PC1**	**PC2**	**PC3**
Elevation (m)	2010 (1883–2158)	2241 (2004–2459)	2173 (1932–2386)
Slope (%)	27.05 (2–50)	44.81 (17–80)	39 (20–55)
Prevailing aspect	35% N, 65% S	44% N, 56% S	54% N, 46% S
Organic matter (%)	0.96 (0–2.5)	3.55 (0.17–5.7)	2.58 (1.36–5.7)
Tree layer cover (%)	33.3 (0–60)	32.5 (0–60)	44.5 (25–60)
Herb layer cover (%)	72.5 (20–90)	54.4 (20–80)	64.0 (40–90)
Oak canopy cover (%)	45.1 (0–87)	29.6 (0–66)	60.6 (24–71)
Trees and shrubs	*Quercus brantii* *Pistacia atlantica* *Cerasus microcarpa* *Acer monspessulanum* *Daphne mucronata* *Fraxinus angustifolia* *Crataegus meyeri* ***Amygdalus orientalis*** ***Tamarix kotschyi***	*Quercus brantii* *Pistacia atlantica* *Cerasus microcarpa* *Acer monspessulanum* *Daphne mucronata* *Fraxinus angustifolia* *Lonicera nummulariifolia* ***Amygdalus haussknechtii*** ***Celtis caucasica*** ***Cerasus pseudoprostrata***	*Quercus brantii* *Pistacia atlantica* *Cerasus microcarpa* *Acer monspessulanum* *Daphne mucronata* *Crataegus meyeri* *Lonicera nummulariifolia*
Number oak trees per hectare	125	127	191

= –0.47, $p < 0.05$) and a positive with cation exchange capacity (CEC) ($r = 0.57$, $p < 0.05$). There was a positive correlation between latitude and human activity ($r = 0.32$, $p < 0.05$), OM ($r = 0.51$, $p < 0.05$) as well as silt ($r = 0.54$, $p < 0.05$) but a negative correlation with pH value ($r = -0.53$, $p < 0.05$). Tree cover showed a positive relation with K ($r = 0.48$, $p < 0.05$) and N ($r = 0.48$, $p < 0.05$), but grass cover had a positive correlation with longitude ($r = 0.334$, $p < 0.05$), litter ($r = 0.45$, $p < 0.05$), humus depth ($r = 0.295$, $p < 0.05$) and clay (15-30 cm depth) ($r = 0.53$, $p < 0.05$), but negative correlation with bare soil (r = –0.8, $p < 0.01$), stone ($r = -0.3$, $p < 0.05$), CEC ($r = -0.52$, $p < 0.05$) and EC (15–30 cm depth) ($r = -0.56$, $p < 0.05$). CEC had a positive correlation with slope ($r = 0.57$, $p < 0.05$), bare soil ($r = 0.49$, $p < 0.05$) and sand ($r = 0.86$, $p < 0.01$) but a negative correlation with clay ($r = -0.84$, $p < 0.01$) and silt ($r = -0.496$, $p < 0.05$).

Relations between soil variables were highly positive between CEC (15–30 cm depth) and sand (15–30 cm depth) ($r = 0.69$, $p < 0.01$) and negative between CEC and clay (15–30 cm depth) ($r = -0.68$, $p < 0.01$). Also, there was a positive correlation between silt (15–30 cm depth) and OM (15–30 cm depth) ($r = 0.46$, $p < 0.05$).

3.3. Relationships between environmental factors and indicator species

Relationships between species abundance and environmental variables by RDA analysis revealed that the indicator species of PC3, where the tree canopy was denser than in other plant communities, were positively correlated with coarse silt content. PC1 indicator species were negatively correlated with slope and elevation. The indicator species of PC2 increased in abundance in plots with lower silt content and higher altitude and longitude. Also, the indicator species of PC2 and PC3 were found on steeper slopes than those of PC1 (Figure 3).

RDA axis 1 was negatively correlated with grass cover ($r = -0.35$, $p < 0.05$) and positively with elevation ($r = 0.591$, $p < 0.01$), slope ($r = 0.449$, $p < 0.01$) and bare soil ($r = 0.30$, $p < 0.05$). Axis 2 showed positive correlation with tree cover ($r = 0.54$, $p < 0.01$), litter ($r = 0.47$, $p < 0.01$), organic matter ($r = 0.55$, $p < 0.05$) and silt ($r = 0.63$, $p < 0.01$), and negative correlation with longitude ($r = -0.42$, $p < 0.01$). Monte Carlo tested indicator species of the tree plant communities are given in Table 3 and Figure 3.

Spearman correlations between indicator species and environmental variables showed that all indicator species of PC1 located in the third quarter of the RDA biplot had a negative correlation with slope, in contrast to the indicator species of PC2 in the second quarter, such as *Ornithogalum persicum*, *Silene chlorifolia*, *Rubia albicaulis*, *Linum strictum, Fritillaria imperialis* and *Sameraria stylophora*. Indicator species of PC2 in the fourth quarter, including those mainly established in the southern aspect, e.g., *Asperula setosa*, *Scandix iberica*, *Veronica orientalis*

Table 2. Descriptive statistics of woody and herb-layer diversity parameters and environmental variables in three plant communities of the oak forest of the Zagros Mountains. Different letters in each row indicate statistical differences among the plant communities by Tukey test. *F* and *p* values in the one-way ANOVAs are listed and *p* values < 0.05 are shown by bold letters. [Ch] indicates Mann–Whitney analysis. Data are mean ± standard error of the mean.

Environmental variables	PC1	PC2	PC3	F	P
Tree-layer richness	3.6 ± 0.26 a	4 ± 0.55 a	4.2 ± 0.39 a	0.435	0.65
Tree-layer Species Evenness Index	0.22 ± 0.04 ab	0.41 ± 0.09 a	0.11 ± 0.03 b	3.32	**0.045**
Tree-layer Shannon–Wiener	0.3 ± 0.05 ab	0.62 ± 0.14 a	0.17 ± 0.06 b	3.34	**0.045**
Tree-layer Simpson	0.15 ± 0.03 ab	0.32 ± 0.08 a	0.08 ± 0.03 b	3.5	**0.037**
Herb-layer richness	31 ± 1.77 a	27 ± 1.14 a	28 ± 1.92 a	1.65	0.2
Herb-layer Species Evenness Index	0.62 ± 0.03 b	0.77 ± 0.019 a	0.76 ± 0.04 a	8.89	**0.001**
Herb-layer Shannon-Wiener	2.1 ± 0.11 b	2.53 ± 0.07 a	2.53 ± 0.16 a	4.74	**0.014**
Herb-layer Simpson	0.77 ± 0.022 b	0.87 ± 0.01 a	0.8 ± 0.03 ab	1.43	0.25
Hemicryptophyte%	35.11 ± 0.82 ab	41.3 ± 0.85 a	31.99 ± 1.16 b	4.056	**0.024**
Phanerophyte%	6.83 ± 0.27 a	9.37 ± 0.55 a	8.99 ± 0.46 a	1.3	0.281
Therophyte%	34.9 ± 0.83 a	26 ± 0.85 b	29.16 ± 0.86 a	14.6	**0.001**
Chamephyte%	6.39 ± 0.22 a	6.46 ± 0.26 a	5.52 ± 0.23 a	0.328	0.72
Geophyte%	17.16 ± 0.37 b	22.4 ± 0.48 ab	24.41 ± 0.47 a	4.5	**0.016**
Longitude	556540 ± 190 c	560486 ± 37 a	558196 ± 298 b	57.5	0.**000**
Latitude	3396202 ± 105 a	3396427 ± 72 a	3396427 ± 118 a	2.06	0.14
altitude (m)	2010 ± 17.31 b	2241 ± 35.7 a	2173 ± 41.6 a	21.423	0.**000**
Slope (%)	27.05 ± 3.45 b	44.81 ± 4.88 a	39 ± 3.31 ab	6.618	0.**003**
Slope aspect (northness)	0.99 ± 0.17 a	0.85 ± 0.27 a	0.89 ± 0.22 a	0.1400	0.870
Human activities	0.65 ± 0.4 a	0.69 ± 0.47 a	0.60 ± 0.49 a	0.20 [Ch]	0.9
Valley	0.25 ± 0.15 a	0.18 ± 0.4 a	0.20 ± 0.3 a	0.21 [Ch]	0.89
Hillside	0.55 ± 0.29 a	0.64 ± 0.49 a	0.70 ± 0.45 a	0.65 [Ch]	0.71
Hilltop	0.20 ± 0.13 a	0.18 ± 0.1 a	0.10 ± 0.05 a	0.47 [Ch]	0.79
Woody-layer cover (%)	33.25 ± 3.52 a	32.50 ± 4.78 a	44.50 ± 3.02 a	2.143	0.130
Herb-layer cover (%)	72.50 ± 0.04 a	54.38 ± 7.26 b	64.00 ± 5.41 ab	7.01 [Ch]	0.**030**
Stone (%)	52.50 ± 5.27 a	57.86 ± 7.84 a	55.00 ± 8.97 a	0.182	.834
Bare soil (%)	24.25 ± 3.63 a	33.75 ± 5.57 a	29.00 ± 3.48 a	1.620	0.210
Litter (%)	38.95 ± 4.45 ab	34.38 ± 8.05 b	56.00 ± 5.81 a	2.822	.071
Humus depth	2.29 ± 0.22 a	2.54 ± 0.377 a	2.75 ± 0.36 a	0.99	0.6
OM% (0–15)	0.96 ± 0.26 b	3.55 ± 1.71 a	2.58 ± 0.68 ab	4.181	**.035**
pH value (0–15)	7.81 ± 0.06 a	7.79 ± 0.085 a	7.86 ± 0.08a	0.178	0.8390
EC (μscm^{-1}) (0–15)	100.6 ± 5.01 a	92.16 ± 4.79 a	110.51 ± 8.65 a	1.275	0.306
CEC% (0–15)	41.41 ± 7.42 a	46.12 ± 16.43 a	41.95 ± 5.25 a	0.057	0.945000
K (gkg–1) (0–15)	36.75 ± 5.2 a	51.59 ± 13.79 a	45.04 ± 6.3 a	1.016	.384
Total N% (0–15)	51.45 ± 7.28 a	72.23 ± 19.3 a	63.06 ± 8.85 a	1.016	0.38400
C/N (0–15)	0.02 ± 0.004 a	0.05 ± 0.002 a	0.04 ± 0.002 a	1.79	0.19
P (0–15) (gkg^{-1})	9.50 ± 3.88 a	5.40 ± 2.13 a	7.02 ± 2.06 a	0.256	0.777
Sand (0–15)	35.2 ± 4.58 a	31.6 ± 12.4 a	33.8 ± 3.87 a	.078	0.925
Fine Silt (0–15)	4.02 ± 0.49 b	2.6 ± 1.26 b	6.3 ± 0.54 a	6.496	**0.009**
Coarse Silt (0–15)	23.6 ± 1.82 a	28.3 ± 4.63 a	22.1 ± 2.15 a	1.101	0.357

Table 2. (Continued).

Clay (0–15)	37.08 ± 3.6 a	37.4 ± 9.45 a	37.6 ± 2.64 a	0.005	0.995
OM% (15–30)	2.85 ± 0.6 b	7.08 ± 1.25 a	4.96 ± 0.7 ab	6.527	**0.008**
pH (15–30)	7.76 ± 0.05 a	7.55 ± 0.1 a	7.74 ± 0.07 a	1.917	0.179
EC (µscm^{-1}) (15–30)	119.9 ± 11.7 a	151.9 ± 41.24 a	136.5 ± 10.2 a	0.848	0.446
CEC % (15–30)	38.18 ± 6.31 a	29.58 ± 17.91 a	20.68 ± 3.38 a	1.582	0.236
K (gkg–1) (15–30)	51.4 ± 3.881 a	52.4 ± 5.69 a	59.5 ± 7 a	0.676	0.523
Total N% (15–30)	72.04 ± 5.43 a	73.55 ± 7.97 a	83.38 ± 9.81 a	0.676	0.523
C/N (15–30)	0.04 ± 0.003 b	0.1 ± 0.001 a	0.06 ± 0.002 ab	3.92	**0.04**
P (gkg–1) (15–30)	10.49 ± 3.16 a	15.80 ± 0.94 a	7.95 ± 1.28 a	1.032	0.379
Sand (15–30)	7.95 ± 4.43 a	31.41 ± 12.64 a	32.42 ± 3.57 a	0.050	0.952
Fine Silt (15–30)	4.71 ± 0.55 ab	3.09 ± 1.09 b	6.57 ± 0.67 a	4.347	**0.031**
Coarse Silt (15–30)	32.42 ± 1.85 a	32.42 ± 2.24 a	26.51 ± 2.84 a	0.06100	0.941
Clay (15–30)	34.34 ± 3.56 a	39.92 ± 11.37 a	34.49 ± 2.97 a	0.282	0.758

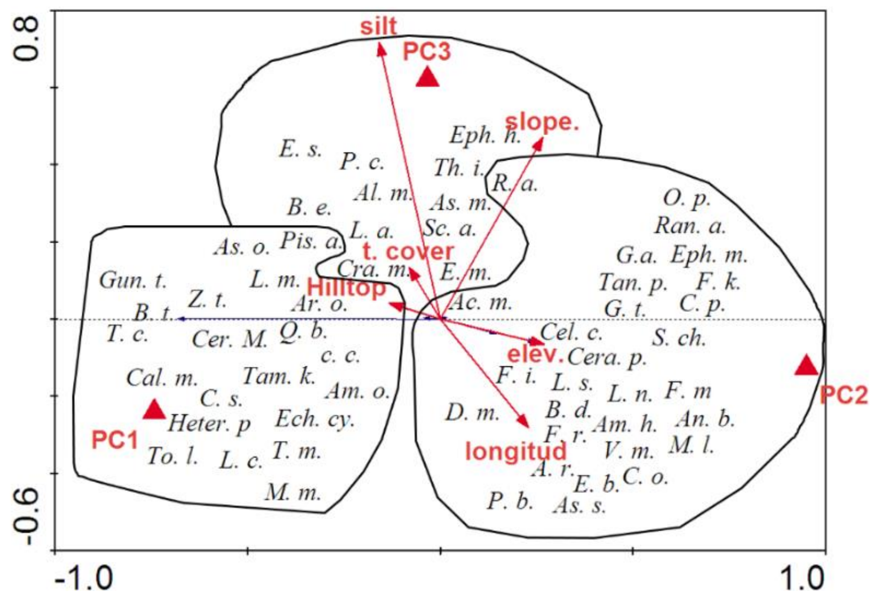

Figure 3. Species-environment biplot of RDA for significant explanatory variables (slope, tree cover, elevation, longitude, silt, and hilltop) on the first two ordination axes (ax1 = 45.5% and ax2 = 17%). Triangles indicate the position of the plant communities 1, 2, and 3 in ordination space. Only indicator species of each community are presented. Abbreviations of species names are given in Table 3.

and *Amygdalus haussknechtii*, consequently showed negative correlation with aspect while *Eremostachys laevigata* of PC1 showed a positive correlation with aspect. Most indicator species of PC1, in contrast to PC2, had a negative correlation with longitude and latitude. *Callipeltis microstegia* and *Gundelia tehranica* of PC1 showed a positive correlation with pH (15–30 cm in soil depth), and *Fibigia macrocarpa* and *Rubia albicaulis* of PC2 showed a negative correlation. Also, *Cerasus microcarpa, Bromus tectorum, Eremostachys laevigata* of PC1 showed a positive correlation with pH value (0–15 cm in soil depth). Results of soil fertility showed that some indicator species of PC2 such as *Astragalus susianus, Matthiola longipetala, Ornithogalum persicum,* and *Ranunculus arvensis,* and *Quercus brantii* had a positive correlation with organic matter (OM) and *Ficaria kochii* with N and K content, whereas indicator species of PC1 such as *Gundelia tehranica* and *Heteranthelium piliferum* showed an inverse

Table 3. Synoptic table of the TWINSPAN classification (division level 2). Values are mean cover % (woody plant species) and mean frequencies (herbaceous plant species) in each community. The bold values refer to differential species of plant communities (PC) 1, 2, and 3. Woody species (trees and tall shrubs) are marked by (T). Both groups, woody, and non-woody indicator species, were sorted by indicator value of each plant community from high to low.

Plant species name		PC1 N = 20	PC2 N = 16	PC3 N = 11	**Plant species name**		PC1 N = 20	PC2 N = 16	PC3 N = 11
Cerasus microcarpa (Cer. m.) (T)	**1**	0.93	0.18	0.2	*Minuartia meyeri* (M. m.)	**1**	0.13	0	0
Pistacia atlantica (Pis. A.) (T)	1	0.69	1.32	0.19	*Crupina crupinastrum* (C. c.)	**1**	0.18	0	0
Tamarix kotschyi (Tam. k.) (T)	1	0.03	0	0	*Fibigia macrocarpa* (F. m.)	**2**	0.05	0.97	0.05
Amygdalus orientalis (Am. O.) (T)	1	0.1	0	0	*Ornithogalum persicum* (O. p.)	**2**	0.23	1.69	0.65
Lonicera nummulariifolia (L. n.) (T)	**2**	0	1.69	0.43	*Astragalus susianus* (As. s.)	**2**	5.05	13.81	0.1
Amygdalus haussknechti i (Am. h.) (T)	**2**	0	1.06	0	*Silene chlorifolia* (S. ch.)	**2**	0	2.63	0
Fraxinus angustifolia (F. r.) (T)	**2**	0.95	2.04	0	*Scandix iberica* (S. i)	**2**	0.1	1.2	0.1
Acer monspessulanum (Ac. m.) (T)	2	1.16	2.19	0.5	*Tanacetum polycephalum* (Tan. P.)	**2**	0	0.88	0.05
Cerasus pseudoprostrata (Cera. P.) (T)	2	0	0.94	0	*Ficaria kochii* (F. k.)	**2**	0.08	2.88	0.91
Celtis caucasica (Cel. C.) (T)	2	0	0.17	0	*Galium aparine* (G. a.)	**2**	0.25	2.35	1.15
Daphne mucronata (D. m.) (T)	2	0.66	1.41	0.51	*Anemone biflora* (An. b)	**2**	0.05	0.66	0.05
Quercus brantii (Q. b.) (T)	3	45.11	29.59	60.64	*Euphorbia macrostegia** (Eph. m.)	**2**	1.23	4.94	4.41
Crataegus meyeri (Cra. m.) (T)	3	0.05	0	2	*Geranium tuberosum** (G. t.)	**2**	1.64	6.41	3.49
Taeniatherum crinitum (T. c.)	**1**	26.95	0.31	7.4	*Colchicum persicum* (C. p.)	**2**	0.18	5.56	3.4
Gundelia tehranica (Gun. t.)	**1**	1	0	0.2	*Ranunculus arvensis* (Ran. a.)	**2**	0.13	1.38	0.7
Heteranthelium piliferum (Heter. p.)	**1**	7.33	0.06	0.05	*Matthiola longipetala* (M. l.)	**2**	0	0.76	0.1
Alyssum linifolium (A. l.)	**1**	0.11	0	0	*Poa bulbosa* (P. b.)	**2**	5.03	8.69	0.6
Crepis sancta (C. s.)	**1**	0.57	0	0.3	*Asperula setosa* (A. s.)	**2**	0	1.06	0.7
Torilis leptophylla (To. l.)	**1**	2.54	0	0.1	*Bromus danthoniae* (B. d.)	**2**	0.5	9.06	0.2
Bromus tectorum (B. t.)	**1**	22.15	4	13.4	*Carthamus oxyacantha* (C. o.)	**2**	0.3	1.59	0.15
Ziziphora tenuior (Z. t.)	**1**	0.91	0	0.61	*Linum strictum* (L. s.)	**2**	0	0.13	0
Lens culinaris (L. c.)	**1**	0.51	0	0.1	*Veronica orientalis* (V. m.)	**2**	0	0.16	0
Callipeltis microstegia (Cal. m.)	**1**	1.22	0.01	0.45	*Rubia albicaulis* (R. a.)	**2**	0	0.1	0
Lasiopogon muscoides (L. m.)	**1**	0.11	0	0	*Fritillaria imperialis** (F. i.)	**2**	0	0.44	0
*Aristolochia olivieri** (Ar. o.)	**1**	0.13	0	0	*Eremurus spectabilis* (E. s.)	**3**	1.06	0.22	3.4
Eremostachys laevigata (E. l.)	**1**	0.5	0	0	*Thalictrum isopyroides* (Th. i.)	**3**	1	2	45
Trigonella monantha (T. m.)	**1**	0.15	0	0	*Euphorbia helioscopia* (Eph. h.)	**3**	0.05	0.29	0.65

relation with OM, and *Lens culinaris*, *Gundelia tehranica*, *Crupina crupinastrum* and *Echinophora cinerea* with N and K content. Correlations of indicator species with soil texture revealed that *Poa bulbosa*, *Fibigia macrocarpa*, and *Rubia albicaulis* of PC2 had a negative correlation with silt while *Bromus tectorum*, indicative of PC1, had a positive correlation with silt. Also, *Eremurus spectabilis*, *Ziziphora tenuior,* and *Gundelia tehranica* showed a negative correlation with clay.

Most of the threatened plant species and endemic species except for *Aristolochia olivieri* were more frequent at higher altitudes in PC2 and PC3 (Table 3; Appendix Table 1A).

Application of discriminate analysis (DA) to distinguish effective environmental variables indicated that the three plant communities were well separated by five predictive variables, namely slope, bare soil, CEC, OM, and silt (Wilks' Lambda = 0.565, p = 0.036) (Table 4). The rate of correct classification was 78.1% (100% for PC1 and PC3), and no significant difference was observed between predicted groups and the original classification (Kappa statistic value = < 0.0001). Results of stepwise DA for each function indicated that PC2 occurs on steeper slopes with higher amounts of bare soil and OM compared to PC1. Plots of PC3 had a higher percentage of fine silt than PC1 and PC2.

Table 4. Test of stepwise discriminate functions analysis (DA) by Wilk's lambda test for the three plant communities and environmental variables. Wilks' Lambda = 0.565, p = 0.036.

Variables in model	Function 1	Function 2
Slope %	**1.579**	–0.116
Bare soil	**1.133**	–0.105
CEC %	**–1.975**	–0.106
OM %	**1.267**	–.073
Fine silt	0.111	**0.94**

4. Discussion

We identified three types of plant communities of *Quercus brantii* woodland (PC1-3), differing in floristics, physiographic, and edaphic factors. The results showed that PC1 plots were located in habitats of lower altitude, less steep slope, and less organic matter (OM) than PC2 and PC3. Life form results confirmed the higher rate of hemicryptophytes and a lower rate of therophytes in higher altitude, as repeatedly observed in elevation gradients of Mediterranean-type climate (Bergmeier, 1995; Vogiatzakis et al., 2003). The highest values of α biodiversity, as observed in PC2, follow increasing humidity (Shen et al., 2012; Erdős et al., 2018) and higher rates of OM (Rubio and Escudero, 2005). Also Klimek et al. (2008) found that local species diversity increased with steep slopes due to occurrences of infrequent plants.

According to our DA results, CEC and OM of soil were important in the separation of PC1, located on soils with higher CEC and lower OM. OM can remove soil calcium carbonate due to absorbing and holding water by OM (Stevenson, 1994; Jobbagy and Jackson, 2000) and Mediterranean forest soils on limestone decarbonate faster in wetter environments (Rubio and Escudero, 2005). Other studies in the Zagros forests also showed that the rate of CEC in the soil is higher at lower altitudes, whereas nitrogen, potassium, and clay rates are lower (Zamani and Zolfaghari, 2013; Mirzaei et al., 2007). Also, soil texture was found to be a relevant factor for *Q. brantii* woodlands in our study. In general, water storage capacity is better in finely textured soil (Maestre et al., 2003) such as in PC3 in this study. This community showed a high canopy cover and leaf litter rate resulting in higher preservation of soil moisture. Further, litterfall accelerates the N cycle (Vesterdal et al., 2008) and accordingly oak rejuvenation and growth.

Relations between soil and physiography features such as aspect, altitude, and longitude show the effect of micro-topography on soil moisture and consequently on nutrient availability and soil texture (Penna et al., 2009). In the study area, latitude and longitude are closely related to elevation and signalize a climatic gradient (temperature, annual sunshine hours). OM, K, N, and silt content increased with elevation and latitude, while pH value decreased (Table 2A). Slope steepness was associated with coarse soil particles (sand, gravel) and CEC. These results are in accordance with other studies that found a positive relationship between altitude, OM, K, and N (Sebastiá, 2004; Penna et al., 2009). Decreasing of silt and clay with slope due to soil erosion and runoff at higher slopes was observed in several studies (Demelash and Stahr, 2010; Nabiollahi et al., 2018; Manrique et al., 1991). We found a reverse relation between CEC and clay, and a direct relation between K and clay ($r= 0.42$, $p< 0.05$). Soil K has a positive charge and can be absorbed by the negative charge of soil clay, then clay has a positive effect on K content (Nabiollahy et al., 2006). Also, Moore et al. (1993) found that soil texture is an important factor in a number of soil chemical properties such as OM, quite as we observed a positive correlation between OM with the fine soil particle content.

Gundelia tehranica, an indicator species of PC1, grows on poor soils with low organic matter, nitrogen, and potassium content, in coincidence with the results of Heydari et al. (2010). This species as well as *Alyssum linifolium, Bromus tectorum, and Taeniatherum crinitum* of PC1 are adapted to drought and alkaline soil with high grazing pressure (Vitek and Noroozi, 2017; Mirdavoodi et al., 2013). Our results showed that PC1 woodland plots are associated with lower habitat quality and a high degree of human activities, confirming once more that sites at lower elevations exhibit deforestation earlier than those situated at the highest elevations (Rubiales et al., 2012). Extreme climatic events together with human activities can accelerate negative changes in Mediterranean oak forests (Benito-Garzón et al., 2013; García-Valdés et al., 2013). A characteristic tree species of PC1 is *Cerasus microcarpa*, also in other studies on forests of Zagros, were found to occur more frequently at lower elevations and around the south aspect with high soil pH value and sparse tree cover (Arekhi et al., 2010; Khanhasani et al., 2016). In montane PC2, tree indicator species are *Lonicera nummulariifolia*, *Amygdalus haussknechtii,* and *Fraxinus angustifolia* supported by several herb-layer species (Table 3). A study on the Saverz mountain southwest of Yasuj showed that these species were associated with two medical plant species *Ferulago angulata* and *Dorema aucheri* (Jafari and Zarifian, 2015). These endemic umbellifers (Apiaceae) are threatened due to illegal over-exploitation. The habitat of PC2 may be suitable for the regeneration of these species. Also, *Lonicera nummulariifolia* and *Acer monspessulanum* as well as the nitrogen-fixing *Celtis caucasica* and *Astragalus* have been reported in high-elevation areas on silty soils with high nitrogen and potassium content

(Zamani and Zolfaghari, 2013; Dehnavi et al., 2014; Al-Fredan, 2011). One of the indicator herb species of PC2 was *Rubia albicaulis*, found in sloped high-altitude sites on soils with high P content (Zamani and Zolfaghari, 2013). A positive relation between frequency of *Q. brantii*, *Viola odorata*, and *Astragalus murinus* (endemic species) with tree cover, organic matter, and litterfall showed the essential role of *Q. brantii* litterfall in the formation of soil humus and organic matter. *Q. brantii* can contribute to the preservation and regeneration of threatened plants. The diversity and composition of the shrub and herb layers are influenced by variations in canopy cover. If the canopy is relatively open, many xeric steppe species may survive under the trees (Erdős et al., 2015). Under a closed canopy, mesic conditions develop, providing suitable habitats for plants adapted to more humid conditions (Walter and Breckle, 1989).

5. Conclusion

With long dry summers and open to pastoralism, most forests of the Zagros Mountains turned into rather open wooded pasture. The biodiversity values of the study area compared to the Protected Area of Dena in Zagros (Zamani and Zolfaghari, 2013) indicates that the study region is certainly also worth being protected due to its high biological diversity. As many as 50 regional endemic species, corresponding to 34% of the endemics of the Protected Area of Dena, were observed in this area (Table 1A). In view of the particularly many endemic species in PC2, the areas of this high-elevation forest type are of considerable conservation value and can be considered “hotspots within hotspots” at the local scale (Cañadas et al., 2014; Noroozi et al., 2008; Mehrabian et al., 2020). The currently low proportion and low conservation efficiency of Protected Areas and Biosphere Reserves in the Zagros Mountains calls for enhanced efforts in national and regional nature conservation.

The high morphological and genetic variability found by Shiran et al. (2011) among populations of *Q. brantii* is likely related to local-scale ecological (climatic) variation. Forest conservation to cover tree variation and community diversity is therefore mandatory at all different topographical and edaphic sites. Higher altitude, fine soil particles but lower CEC are strongly related to OM as a key indicator of Mediterranean and Irano-Turanian soil quality (Wang et al., 2009; Schoenholtz et al., 2000).

This study also invokes that the indicators, especially woody species, can be used for habitat identification, vulnerability assessment and to alert ecosystem changes. For instance, high oak frequency in higher altitudes and a decrease in lower altitudes as observed in the study area can signal ecosystem shift, triggered by intensified land use and/or by climate change (Ruiz-Labourdette et al., 2012). The most xeric open woodlands at lower elevations in the southern Zagros are most vulnerable due to hampered natural regeneration. We demonstrated that the prevailing oak (*Q. brantii*), keystone species of the southern Zagros woodlands, can improve soil fertility and forest health by its canopy and litter effects. We recommend the restoration of the easternmost Irano-Turanian oak woodlands in the Zagros Mountains whenever possible by natural regeneration to stabilize the soil and improve forest sustainability.

Acknowledgments

Financial support was provided by Yasouj University under the project named “Vegetation study in teaching and research forests of Yasouj University”.

References

Adel MN, Pourbabaei H, Dey DC (2014). Ecological species group-environmental factors relationships in unharvested beech forests in the north of Iran. Ecological Engineering 69: 1-7. doi: 10.1007/s13595-014-0428-7

Al-Fredan MA (2011). Nitrogen fixing legumes in the plant communities. American Journal of Environmental Sciences 7 (2): 166. doi: 10.3844/ajessp.2011.166.172

Arekhi S, Heydari M, Pourbabaei H (2010). Vegetation-Environmental Relationships and Ecological Species Groups of the Ilam Oak Forest Landscape, Iran. Caspian Journal of Environmental Sciences 8 (2): 115-125.

Allison LE, Richards LA (1954). Diagnosis and improvement of saline and alkali soils, No. 60. Soil and Water Conservative Research Branch, Agricultural Research Service, USA: Department of Agriculture.

Assadi, M (1989-2002). Flora of Iran, Vols. 1-35. Tehran, Iran: Research Institute of Range and Forest Management Press (in Persian).

Benito-Garzón M, Ruiz-Benito P, Zavala MA (2013). Inter-specific differences in tree growth and mortality responses to environmental drivers determine potential species distributional limits in Iberian forests. Global Ecology and Biogeography 22 (10): 1141-1151. doi: 10.1111/geb.12075

Bergmeier E (1995). Die Höhenstufung der Vegetation in Südwest-Kreta (Griechenland) entlang eines 2450 m-Transektes. Phytocoenologia 25: 317-361. 10.1127/phyto/25/1995/317

Brooker RW (2006). Plant–plant interactions and environmental change. New Phytologist 171 (2): 271-284. doi: 10.1111/j.1469-8137.2006.01752.x

Cañadas EM, Fenu G, Peñas J, Lorite J, Mattana E et al. (2014). Hotspots within hotspots: endemic plant richness, environmental drivers, and implications for conservation. Biological Conservation 170: 282-291. doi: 10.1016/j.biocon.2013.12.007

Cianfrani C, Buri A, Vittoz P, Grand S, Zingg B et al. (2019). Spatial modelling of soil water holding capacity improves models of plant distributions in mountain landscapes. Plant and Soil 438 (1): 57-70. doi: 10.1007/s11104-019-04016-x

Day PR (1965). Particle fractionation and particle size analysis. In: Black CA (editors). Methods of Soil Analysis. USA: American Society of Agronomy, pp. 545-565.

Dehnavi S, Matinkhah SH, Nourbakhsh F (2014). The role of Hackberry "*Celtis caucasica*" as nitrogen-fixing trees on understory's soil properties in reserved area in Ardasteh-Dehaghan in Isfahan. Iranian Journal of Forest and Poplar Research 21 (4): 643-653 (in Persian with an abstract in English).

Demelash M, Stahr K (2010). Assessment of integrated soil and water conservation measures on key soil properties in South Gonder, North-Western Highlands of Ethiopia. Journal of Soil Science and Environmental Management 1 (7): 164-176.

Dewan ML, Famouri J (1964). The soils of Iran. Food and Agriculture Organization of the United Nations.

Ellenberg H, Weber HE, Düll R, Wirth V, Werner W et al. (1992). Zeigerwerte von Pflanzen in Mitteleuropa. Scripta Geobotanica 18: 3-258.

Erdős L, Tölgyesi C, Körmöczi L, Bátori Z (2015). The importance of forest patches in supporting steppe-species: a case study from the Carpathian Basin. Polish Journal of Ecology 63 (2): 213-222. doi: 10.3161/15052249PJE2015.63.2.005

Erdős L, Ambarl, D, Anenkhonov OA, Bátori Z, Cserhalmi D et al. (2018). The edge of two worlds: A new review and synthesis on Eurasian forest-steppes. Applied Vegetation Science 21 (3): 345-362. doi: 10.1111/avsc.12382

García-Valdés R, Zavala MA, Araújo MB, Purves DW (2013). Chasing a moving target: projecting climate change-induced shifts in non-equilibrial tree species distributions. Journal of Ecology 101: 441-453. doi: 10.1111/1365-2745.12049

Gregorich EG, Carter MR, Angers DA, Monreal CM, Ellert BH (1994). Toward minimum data set to assess soil organic-matter quality in agricultural soils. Canadian Journal of Soil Science 74: 885-901. doi: 10.4141/cjss94-051

Gusian A, Weiss SB, Weiss AD (1999). GLM versus CCA spatial modeling of plant species distribution. Plant Ecology 143: 107–122. doi: 10.1023/A:1009841519580

Heydari M, Pourbabaei H, Atar Roushan S (2010). Natural regeneration of Persian oak (*Quercus brantii*) between ecological species group in Kurdo-Zagros region. Iranian Journal of Biology 24 (4): 578-592 (in Persian with an abstract in English).

Hill MO, Gauch HG (1980). Detrended correspondence analysis: an improved ordination technique. Vegetatio 42: 47-58. doi: 10.1007/BF00048870

Jackson ML (1975). Soil Chemical Analysis: Advanced Course. Madison, USA: University of Wiscon, College of Agriculture, Department of Soil.

Jafari A, Aarifian A (2015). Floristic study of Saverz mountain in Kohgiloyeh and Boyerahmad province. Journal of Plant Research 28 (5): 929-951 (in Persian with an abstract in English).

Jazirehi MH, Ebrahimi Rostaghi M (2003). Silviculture in Zagros. Tehran, Iran: University of Tehran Press (in Persian).

Jobbagy EG, Jackson RB (2000). The vertical distribution of soil organic carbon and its relation to climate and vegetation. Ecological Applications 10 (2): 423-436. doi: 10.1890/1051-0761

Khalyani AH, Mayer AL, Falkowski MJ, Muralidharan D (2012). Deforestation and landscape structure changes related to socioeconomic dynamics and climate change in Zagros. Journal of Land Use Science 8 (3): 321-340. doi: 10.1080/1747423X.2012.667451

Khanhasani M, Talebi KS, Khodakarami Y, Safari H (2016). The role of soil and physiographic factors on morphologic parameters of *Cerasus microcarpa* CA Mey. in Kermanshah forests. Iranian Journal of Forest and Poplar Research 24 (2): 227-235 (in Persian with an abstract in English).

Klimek S, Marini L, Hofmann M, Isselstein J (2008). Additive partitioning of plant diversity with respect to grassland management regime, fertilisation and abiotic factors. Basic and Applied Ecology 9 (6): 626-634. doi: 10.1016/j.baae.2007.11.005

Lachenbruch PA, Mickey MR (1968). Estimation of error rates in discriminant analysis. Technometrics 10 (1):1-11. doi: 10.1080/00401706.1968.10490530

Leskiw LA (1998) Land capability classification system for forest ecosystems in the oil sands region. Edmonton, Alberta, Canada: Alberta Environmental Protection. Environmental Sciences Division, Report ESD/LM/98-1.

Maestre FT, Cortina J, Bautista S, Bellot J, Vallejo R (2003). Small-scale environmental heterogeneity and spatiotemporal dynamics of seedling establishment in a semiarid degraded ecosystem. Ecosystems 6: 630-643. doi: 10.1007/s10021-002-0222-5

Mahdavi A, Hydari M, Eshaghirad J (2010). Investigation on biodiversity and richness of plant species in relation to physiography and physicochemical properties of soil in Kabirkoh protected area. Iranian Journal of Forest and Poplar Research 3: 426-436 (in Persian with an abstract in English).

Manrique LA, Jones CA, Dyke PT (1991). Predicting cation- exchange capacity from soil physical and chemical properties. Soil Science Society of America Journal 55: 787–794. doi: 10.2136/sssaj1991.03615995005500030026x

Mc Cune B, Mefford MJ (2006) PC-ORD Multivariate Analysis of Ecological Data Version 5.10. Oregon, USA: Gleneden Beach: MjM Software.

Mehrabian AR, Sayadi S, Kuhbenani MM, Yeganeh VH, Abdoljabari M (2020). Priorities for conservation of endemic trees and shrubs of Iran: Important Plant Areas (IPAs) and Alliance for Zero Extinction (AZE) in SW Asia. Journal of Asia-Pacific Biodiversity 13 (2): 295-305. doi: 10.1016/j.japb.2019.09.010

Mi XC, Zhang JT, Zhang F, Shangguan TL (1996). Analysis of relationships between vegetation and climate in Shanxi Plateau. Acta Phytoecological Sinica 20: 549-560 (in Chinese with an abstract in English)

Mills LS, Soulé ME, Doak DF (1993). The keystone-species concept in ecology and conservation. BioScience, 43 (4): 219-224. doi: 10.2307/1312122

Mirdavoodi HR, Marvi Mohadjer MR, Zahedi Amiri GH, Etemad V (2013). Disturbance effects on plant diversity and invasive species in western oak communities of Iran (case study: Dalab forest, Ilam). Iranian Journal of Forest and Poplar Research 21 (1): 1-16 (in Persian with an abstract in English).

Mirzaei J, Akbarinia M, Hosseini SM, Sohrabi H, Hosseinzadeh J (2007). Biodiversity of herbaceous species in related to physiographic factor in forest ecosystems in central Zagros. Iranian Journal of Biology 20(4): 375-382 (in Persian with an abstract in English).

Moore ID, Gessler PE, Nielsen GAE, Peterson GA (1993). Soil attribute prediction using terrain analysis. Soil Science Society of America Journal 57: 443–452. doi: 10.2136/sssaj1993.03615995005700020026x

Nabiollahi K, Golmohamadi F, Taghizadeh-Mehrjardi R, Kerry R, Davari M (2018) Assessing the effects of slope gradient and land use change on soil quality degradation through digital mapping of soil quality indices and soil loss rate. Geoderma 318: 16-28. doi: 10.1016/j.geoderma.2017.12.024

Nabiollahy K, Khormali F, Bazargan K, Ayoubi SH (2006). Forms of K as a function of clay mineralogy and soil development. Clay Minerals 41: 739-749. doi: 10.1180/0009855064130216

Noroozi J, Akhani H, Breckle SW (2008). Biodiversity and phytogeography of the alpine flora of Iran. Biodiversity and Conservation 17 (3): 493-521. doi: 10.1007/s10531-007-9246-7

Olsen SR, Cole CV, Watanabe FS, Dean LA (1954). Estimation of available Phosphorus in soil by extraction with Sodium Bicarbonate. No. 939. Washington, USA: Department of Agriculture.

Penna D, Borga M, Norbiato D, Dalla Fontana G (2009). Hillslope scale soil moisture variability in a steep alpine terrain. Journal of Hydrology 364 (3-4): 311-327. doi: 10.1016/j.jhydrol.2008.11.009

Rechinger KH (1963). Flora Iranica. *Flora des iranischen Hochlandes und der umrahmenden Gebirge*, Vols. 1–174. Graz, Austria: Akademische Druck- und Verlagsanstalt Graz (in Germany).

Reichstein M, Bahn M, Ciais P, Frank D, Mahecha MD et al. (2013). Climate extremes and the carbon cycle. Nature 500 (7462): 287-295. doi: 10.1038/nature12350

Rubiales JM, Morales-Molino C, Alvarez SG, García-Antón M (2012). Negative responses of highland pines to anthropogenic activities in inland Spain: a palaeoecological perspective. Vegetation History and Archaeobotany 21 (4): 397-412. doi: 10.1007/s00334-011-0330-2

Rubioa A, Escuderob A (2005). Effect of climate and physiography on occurrence and intensity of decarbonation in Mediterranean forest soils of Spain. Geoderma 125: 309-319. doi: 10.1016/j.geoderma.2004.09.005

Ruiz-Labourdette D, Nogues DB, Ollero HS, Schmitz MF, Pineda FD (2012). Forest composition in Mediterranean mountains is projected to shift along the entire elevational gradient under climate change. Journal of Biogeography, 39 (1): 162-176. doi: 10.1111/j.1365-2699.2011.02592.x

Sagheb-Talebi K, Pourhashemi M, Sajedi T (2014). Forests of Iran: A Treasure from the Past, a Hope for the Future. Springer.

Sawchik J, Dufrêne M, Lebrun P (2003). Estimation of habitat quality based on plant community, and effects of isolation in a network of butterfly habitat patches. Acta Oecologica 24 (1): 25-33. doi: 10.1016/S1146-609X(02)00005-X

Schoenholtz SH, Van Miegroet H, Burger JA (2000). A review of chemical and physical properties as indicators of forest soil quality: challenges and opportunities. Forest Ecology and Management 138 (1-3): 335-356. doi: 10.1016/S0378-1127(00)00423-0

Sebastiá MT (2004). Role of topography and soils in grassland structuring at the landscape and community scales. Basic and Applied Ecology 5 (4): 331-346. doi: 10.1016/j.baae.2003.10.001

Shakeri Z, Mohammadi-Samani K, Bergmeier E, Plieninger T (2021). Spiritual values shape taxonomic diversity, vegetation composition, and conservation status in woodlands of the Northern Zagros, Iran. Ecology and Society 26 (1): 30. [online] URL: https://www.ecologyandsociety.org/vol26/iss1/art30/

Shearman DJ, Walker GPL, Booth B, Falcon NL (1976). The geological evolution of southern Iran: the report of the Iranian Makran expedition. Geographical Journal 1: 393-410. doi: 10.2307/1795293

Shen Z, Fei S, Feng J, Liu Y, Liu Z et al. (2012). Geographical patterns of community-based tree species richness in Chinese mountain forests: the effects of contemporary climate and regional history. Ecography 35 (12): 1134-1146.

Shiran B, Mashayekhi S, Jahanbazi H, Soltani A, Bruschi P (2011). Morphological and molecular diversity among populations of *Quercus brantii* Lindl. in western forest of Iran. Plant Biosystems 145: 452-460. doi: 10.1080/11263504.2011.558718

Stevenson FJ (1994). Humus chemistry: genesis, composition, reactions. John Wiley & Sons.

Tárrega R, Calvo L, Marcos E, Taboada A (2006). Forest structure and understory diversity in *Quercus pyrenaica* communities with different human uses and disturbances. Forest Ecology and Management 227: 50–58. doi: 10.1016/j.foreco.2006.02.008

Tieszen LL, Tappan GG, Touré A (2004). Sequestration of carbon in soil organic matter in Senegal: an overview. Journal of Arid Environments 59 (3): 409-425. doi: 10.1016/j.jaridenv.2004.04.002

Valipour A, Plieninger T, Shakeri Z, Ghazanfari H, Namiranian M et al. (2014). Traditional silvopastoral management and its effects on forest stand structure in northern Zagros. Forest Ecology and Management 327: 221-230. doi: 10.1016/j.foreco.2014.05.004

Vesterdal L, Schmidt IK, Callesen I, Nilsson LO, Gundersen P (2008). Carbon and nitrogen in forest floor and mineral soil under six common European tree species. Forest Ecology and Management 255: 35-48. doi: 10.1016/j.foreco.2007.08.015

Vitek E, Noroozi J (2017). *Gundelia tehranica* (Compositae), a new species from Iran. Annalen des Naturhistorischen Museums in Wien, Serie B 119: 243–248

Vogiatzakis IN, Griffiths GH, Mannion AM (2003). Environmental factors and vegetation composition. Global Ecology Biogeography 12: 131-146. doi: 10.1046/j.1466-822X.2003.00021.x

Walter H, Breckle SW (1989). Ecological systems of the geobiosphere 3 temperate and polar zonobiomes of northern Eurasia. Berlin, Germany: Springer Science & Business Media.

Wang Y, Zhang XC, Zhang JL, Li SJ (2009). Spatial variability of soil organic carbon in a watershed on the loess plateau. Pedosphere 19: 486–495. doi: 10.1016/S1002-0160(09)60141-7

Zamani SM, Zolfaghari R (2013). Investigation of tree and grass biodiversity in the protected area of Western Dena and its relationship with environmental factors. Environmental Sciences 11 (1): 131-140 (in Persian with an abstract in English).

Zohary M, Heyn CC, Heller D (1980-1993). Conspectus Flora Orientalis, an annotated catalogue of the flora of the Middle East, Vols. 1-8. Jerusalem: The Israel Academy of Sciences and Humanities.

Table 1A. List of all plant species recorded in study area

Genera	Family	Life form	Phyto-region	IUCN list	Endemic	Life cycle
Aegopordon berardioides Boiss.	Asteraceae	He	IT			P
Aethionema carneum (Banks & Soland.) B.Fedtsch.	Brassicaceae	Th	IT			A
Alcea hohenakeri (Boiss. & Huet)Boiss.	Malvacae	He	IT			P
Alium sp.	Alliaceae	Ge	IT			P
Allium ampeloparsum L.	Alliaceae	Ge	IT	EN		P
Allium jesdianum	Alliaceae	Ge	IT	EN		P
Allium scabriscapum	Alliaceae	Ge	IT			P
Alyssum linifolium Steph.	Brassicaceae	Th	IT-M			A
Alyssum meniocoides Boiss.	Brassicaceae	Th	IT			A
Anchusa italica	Boraginaceae	He	IT			P
Anemone biflora DC.	Ranunculaceae	He	IT			P
Anthemis odontostephana Boiss.	Asteraceae	Th	IT			A
Arabis caucasica Willd. ssp. caucasica	Brassicaceae	Th	IT-M-ES			A
Aristolochia olivieri	Aristolochiaceae	He	IT	LR	Endemic	P
Arrhenatherum kotschyi Boiss.	Poaceae	Th	IT			A
Arum giganteum A. Ghahreman.	Araceae	Ge	IT	VU	Endemic	P
Astragalus murinus Boiss.	Papilionaceae	Ch	IT	LR	Endemic	P
Astragalus ovinus Boiss.	Papilionaceae	He	IT			P
Astragalus pseudovinus Maassoumi & Podl	Papilionaceae	He	IT	LR	Endemic	P
Astragalus rhodosemius	Papilionaceae	Ch	IT			P
Astragalus sp	Papilionaceae	He	IT			P
Astrodaucus orientalis (L.)	Apiaceae	He	IT			P
Avena sativa L.	Poaceae	Th	IT- M-SS			A
Ballota aucheri Boiss.	Lamiaceae	He	IT-Nb.s			P
Bellevalia pycnantha (C.Koch) A. Los.	Liliaceae	Ge	IT			P
Biebersteinia multifida DC.	Geraniaceae	Ge	IT			P
Boissiera squarrosa (Banks & Soland.) Nevski	Asteraceae	Th	IT			A
Bongardia chrysogonum (L.) Spach	Podophyllaceae	Ge	IT-ES-Nb			P
Bromus danthoniae	Poaceae	Th	IT			A
Bromus tectorum L.	Poaceae	Th	Cosm			A
Caccinia macranthera	Boraginaceae	He	IT			P
Callipeltis microstegia Boiss.	Rubiaceae	Th	IT			A
campanula cicila	Campanulaceae	Th	IT			A
Campanula sp	Campanulaceae					A
Cardaria draba (L.) Desv.	Brassicaseae	Th	Cosm			A
Carthamus oxyacantha M. B.	Asteraceae	He	IT- SS			P
Centaurea iberica	Asteraceae	He	IT			P

Centaurea sp	Asteraceae	He	IT			P
Cephalorrhynchus microcephalus (DC.) Schchian	Asteraceae	He	IT		Endemic	P
Cerastium dichotomum L.	Caryophyllaceae	Th	Plur			A
Cerasus microcarpa	Rosaceae	Ch	IT			P
Cerasus pseudoprostrata	Rosaceae	Ch	IT			P
Ceratocephalus falcata (L.) Pers.	Asteraceae	Th	IT-ES			A
Chardinia orientalis (L.) O. Kuntze	Asteraceae	Th	IT			A
Cichorium intybus L.	Asteraceae	He	IT			P
Cirsium bracteosum DC. var. brevicuspis Boiss.	Asteraceae	He	IT	LR	Endemic	P
Cirsium sp	Asteraceae					P
Colchicum persicum Baker.	Liliaceae	Ge	IT-M			P
Convolvulus leiocalycinus Boiss.	Convolvulaceae	Ch	IT			P
Crepis sancta (L.) Babcock ssp.	Asteraceae	Th	IT-M			A
Crupina crupinastrum (Moris) Vis.	Asteraceae	Th	IT-M			A
Dactylorhiza umbrosa (Kar. & Kir.) Nevski	Orchidaceae	Ge	IT			P
Daphne mucronata Royle	Thymelaeaceae	Ph	IT-ES			P
Echinophora cinerea (Boiss.) Hedge & Lamond	Apiaceae	He	IT	LR	Endemic	P
Echinops cyanocephalus Boiss. & Hausskn.	Compositae	He	IT	DD	Endemic	P
Eremostachys laevigata Bunge.	Lamiaceae	He	IT-M			P
Eremostachys macrophylla	Lamiaceae	He	IT			P
Eremurus spectabilis M. B.	Liliaceae	Ge	IT	LR		P
Erodium cicutarium	Geraniaceae	Th	IT-M-ES			A
Eryngium billardieri	Apiaceae	He	IT			P
Euphorbia helioscopia L.	Euphorbiaceae	He	IT			P
Euphorbia macrostegia Boiss.	Euphorbiaceae	He	IT	LR	Endemic	P
Euphorbia sp	Euphorbiaceae					P
Fibigia macrocarpa Boiss.	Brassicaceae	He	IT			P
Ficaria kochii (Ledeb.)	Ranunculaceae	He	IT			P
Fraxinus rotundifolia	Oleaceae	Ph	IT	LR		P
Fritillaria imperialis	Liliaceae	Ch	IT		Endemic	P
Fumaria asepala Boiss.	Fumariaceae	Th	IT			A
Gagea gageoides (Zucc.) Vved	Liliaceae	Ge	IT			P
Galium aparine L.	Rubiaceae	Th	IT			A
Geranium tuberosum L.	Geraniaceae	Ge	IT		Endemic	P
Grammosciadium sp	Apiaceae					P
Gundelia tehranica	Asteraceae	He	IT-M			P
Gypsophila elegans M.B. var. elegans	Caryophyllaceae	Th	IT-ES			A
Gypsophila polyclada Fenzl ex Boiss.	Caryophyllaceae	He	IT			P

Heteranthelium piliferum (Banks & Soland.) Hochst.	Poaceae	Th	IT-M-ES-SS			A
Hordeum bulbosum L.	Poaceae	He	IT-ES-M			P
Hyoscyamus reticulatus L.	Solanaceae	He	IT-ES			P
Hypecoum pendulum L.	Papaveraceae	Th	IT			A
Ixiolirion tataricum (Pall.)Herb.	Amaryllidaceae	Ge	IT			P
Lactuca orientalis	Asteraceae	He	IT			P
Lamium amplexicaule L.	Lamiaceae	Th	IT			A
Lasiopogon muscoides (Desf.) DC.	Asteraceae	Th	SS			A
Lathyrus aphaca L.	Popilionaceae	He	IT-ES			P
Lens culinaris Medicus	Papilionaceae	Th	IT			A
Linaria sp	Scrophulariaceae					A
Linum album Boiss.	Linaceae	He	IT	LR	Endemic	P
Linum strictum L.	Linaceae	He	IT			P
Lonicera nummulariifolia Jaub. & Spach	Caprifoliaceae	Ph	IT			P
Malva neglecta Wallr.	Malvaceae	He	IT-M-ES			P
Matthiola longipetala (Vent.)DC.	Brassicaceae	Th	IT- M- SS			A
Medicago radiata L.	Papilionaceae	Th				A
Medicago sativa L.	Papilionaceae	He	Cosm			P
Mesostemma kotschyanum	Caryophyllaceae	He	IT			P
Minuartia meyeri (Boiss.) Bornm.	Caryophyllaceae	Th	IT, M			A
Morina persica L.	Morinaceae	He	IT-ES			P
Muscari neglectum Guss.	Hyacinthaceae	Ge	Plur			P
Nonea persica Boiss.	Boraginaceae	He	IT			P
Onobrychis sp	Papilionaceae					P
Onosma sericeum Willd.	Boraginaceae	He	IT			P
Ornithogalum persicum Haussk.	Hyacinthaceae	Ge	IT			P
Orobanche sp	Orobanchaceae					P
Papaver cylindricum Cullen	Papaveraceae	Th	IT-M-ES			A
Papaver dubium L.	Papaveraceae	He	IT			P
Phlomis olivieri Benth.	Lamiaceae	He	IT-ES			P
Phlomis persica Boiss.	Lamiaceae	He	IT	LR	Endemic	P
Picnomon acarna (L.) Cass.	Asteraceae	Th	IT- M			A
Poa bulbosa L.	Poaceae	Ge	IT			P
Polygonum sp	Polygonaceae					P
Pterocephalus canus Coult. ex DC.	Dipsaceae	He	IT			P
Pyrus glabra Boiss.	Rosaceae	Ph	IT-ES			P
Quercus brantii	Fagaceae	Ph	IT			P
Ranunculus arvensis L.	Ranunculaceae	Th	IT			A
Rhamnus pallasii	Rhamnaceae	Ch	IT			P

Rheum ribes L.	Polygonaceae	He	IT			P
Rubia albicaulis Boiss. var. stenophylla Boiss.	Rubiaceae	He	IT			P
Rumex crispus L.	Polygonaceae	He	Cosm			P
Salix sp	Salicaceae					P
Salvia nemorosa L.	Lamiaceae	He	IT-ES	LR		P
Sameraria stylophora (Jaub. & Spach) Boiss.	Brassicaceae	Th	IT- M- SS	LR	Endemic	A
Sanguisorba minor Scop	Rosaceae	He	IT-M-ES			P
Scandix aucheri Boiss.	Apiaceae	Th	IT-M			A
Scandix iberica M.B.	Apiaceae	He	IT-SS			P
Scorzonera calyculata Boiss.	Asteraceae	He	IT			P
Scrophularia striata Boiss.	Scrophulariaceae	He	IT			P
Serratula bachtiarica Boiss. & Hausskn.	Asteraceae	He	IT	DD		P
Silene conoidea L.	Asteraceae	Th	IT-M			A
Silene sp	Caryophyllaceae					P
Silene spergulifolia (Willd.) M. B.	Caryophyllaceae	Gr	IT			P
Smyrniopsis aucheri Boiss.	Apiaceae	He	IT			P
Smyrnium cordifolium Boiss.	Apiaceae	He	IT			P
Stachys inflata	Lamiaceae	He	IT			P
Stachys lavandulifolia Vahl	Lamiaceae	He	IT			P
Stachys pilifera Benth.	Lamiaceae	He	IT	LR	Endemic	P
Steptorrhamphus tuberosus JACQ.	Asteraceae	Th	IT			A
Taeniatherum crinitum (Schreb.) Nevski	Poaceae	Th	IT-M-SS			A
Tamarix kotschyi Bge.	Tamaricaceae	Ph	IT			P
Tanacetum polycephalum	Asteraceae	He	IT-ES			P
Taraxacum kotschyi V.Soest	Asteraceae	He	IT			P
Teucrium polium L.	Lamiaceae	He	IT-ES-Nb			P
Thalictrum isopyroides C.A.Mey.	Ranunculaceae	He	IT-M-ES			P
Torilis leptophylla (L.) Reichenb	Apiaceae	Th	IT			A
Tragopogon longirostris Bisch.	Asteraceae	He	IT- ES			P
Trigonella monantha	Papilionaceae	Th	IT			A
Tulipa montana Lindl.	Liliaceae	Ge	IT		Endemic	P
Tulipa sp	Liliaceae					P
Turgenia latifolia (L.)Hoffm	Apiaceae	Th	IT-ES			A
Veronica sp	Scrophulariaceae					P
Vicia villosa Roth.	Papilionaceae	He	IT-ES			P
Viola odorata L.	Violaceae	Th	IT-ES	LR	Endemic	A
Ziziphora tenuior L.	Lamiaceae	Th	IT			A