http://silvaworld.org
SilvaWorld
e-ISSN: 2822-6127
PRENSIP
https://prensip.gen.tr

RESEARCH ARTICLE

Evaluation of Plant Species Diversity and Floristic Characteristics in Plant Ecological Group in Relation to Altitudinal Gradient, Kourdkoy Forest, North of Iran

Hassan Pourbabaei • Morteza Masoudi Gazi

University of Guilan, Faculty of Natural Resources, Department of Forestry, Sowme'eh Sara/Iran

ARTICLE INFO

Article History
Received: 20.12.2025
Accepted: 09.03.2026
First Published: 27.03.2026

Keywords
Hyrcanian forests
Plant communities
Species diversity
TWINSPAN

ABSTRACT

Forest ecosystems have vegetation cover as their fundamental structural element that demonstrates how environmental parameters operate. This study investigated the effect of altitude variations on plant community and diversity patterns in the Kourdkoy Forest located in Golestan province of northern Iran. We established 48 circular plots with an area 1000 m^2 at each of the six different elevational belts from 500 to 1700 m above sea level at 200 m intervals using random-systematic sampling method. Tree species at each plot were measured, while the herbaceous species survey in 100 m² subplots. Using Two-Way Indicator Species Analysis (TWINSPAN) identified five plant communities known as Cyclameno-Fagetum community, Carexeto-Fagetum community, Athyriumeto-Fagetum community (appeared on two classes), and Galiumo-Fagetum community named according to their dominant and indicator species. among the 60 plant species belonging to 37 families and 55 genera which were found in the studied area. ANOVA test showed that altitude served as the significant variable leading to significant diversity index differences ($P \leq 0.05$) among the communities for Shannon-Wiener, Smith-Wilson, and Margalef. The Raunkiaer method indicated hemicryptophytes prevailed as life-forms over cryptophytes by 43% and 22%, respectively and Euro-Siberian chorotype earned first place position with 40%. The research demonstrated that altitude-caused ecological transformations which occur in a vital forest system enabling understanding for temperate region conservation and management activities.

Please cite this paper as follows:

Pourbabaei, H., & Gazi, M. M. (2026). Evaluation of plant species diversity and floristic characteristics in plant ecological group in relation to altitudinal gradient, Kourdkoy forest, North of Iran. *SilvaWorld*, *5*(1), 1-12. https://doi.org/10.61326/silvaworld.v5i1.446

1. Introduction

The most vital natural resources that support sustainable economic development are renewable forest resources (Kulakowski et al., 2017; Acwin Dwijendra et al., 2022). Natural resources attribute together with their changing patterns have increased human interest in understanding environmental effects on plant communities (Kulakowski et al., 2017; Acwin Dwijendra et al., 2022). Vegetation cover functions as an essential ecosystem element that both demonstrates environmental characteristics and serves as a secure information base for ecological examination (Sun et al., 2015; Mucina et al., 2016). Plant communities use species recognition and classification activities at the plant community level to derive valuable health and biodiversity information about their ecosystems (Brosofske et al., 2001). Plants do not arrange themselves at random throughout environments since their spatial patterns align closely with environmental factors (Gao et al., 2015), while multiple important elements substantially influence their organization and species structures (Kraft et al., 2015; Bjorkman et al., 2018). Plant community distribution and species frequency patterns are closely associated with

Corresponding author
E-mail address: hpourbabaei@gmail.com

CC BY

topographic and environmental factors, including altitude, slope, climate, and soil conditions (Jafarian et al., 2019). The substantial climatic effects caused by altitudinal gradients guide the formation of various vegetation classes and forest types (Krömer et al., 2013; Sinha et al., 2018).

The creation of different climatic zones across forest ecosystems at different altitudes influences plant diversity because results from Wani et al. (2023) and Rezende et al. (2015) show peak species diversity occurs in intermediate elevation areas. The importance of conducting thorough investigations about these gradients affecting biodiversity becomes clear (Zhang et al., 2021). The most vital natural economic development resource base consists of renewable timber resources along with forests (Kulakowski et al., 2017; Acwin Dwijendra et al., 2022). Researchers accelerate their research on environmental conditions and plant community responses through heightened interest in these resources (Kulakowski et al., 2017; Acwin Dwijendra et al., 2022). Environmental conditions influence vegetation covers and plant community structure, providing an important basis for ecological assessment (Gao et al., 2015; Kraft et al., 2015; Sun et al., 2015; Mucina et al., 2016; Bjorkman et al., 2018). The identification, and classification of plant communities helps scientists understand the biodiversity of ecosystems (Brosofske et al., 2001).

Altitudinal gradients are important environmental factors that create climatic variation and provide valuable opportunities to study plant community responses to environmental change that develop unique vegetation groups and forest types (Krömer et al., 2013; Sinha et al., 2018). Research conducted by Wani et al. (2023) and Rezende et al. (2015) indicated that plant species diversity reaches its maximum peak at middle altitude levels across the world. Detailed research needs to focus on the impact of these gradients since they influence biodiversity patterns (Zhang et al., 2021). The Hyrcanian forest regions extend over 1.8 million hectares of north Iranian territory that accounts for 7% of the national landscape (Kooch et al., 2023; Pourghasemi, 2016). This forest ecosystem maintains 80 tree species combined with 50 shrub species (Ali et al., 2020; Bayat et al., 2020). The broadleaved deciduous forests of the Alborz Mountains' northern slopes overlooking the Caspian Sea because they possess wide-ranging climatic elements and terrain characteristics (Pourbabaei & Haghgoy, 2013).

Biological management of variability occurs in forests alongside crucial nutrient cycling processes which support ecosystem development and maintain complete sustainability (Hosseini et al.., 2024). Prior studies have reported varying peaks of diversity at different altitudes in the region, such as tree species richness peaking at 500 m in areas like Kourdkoy Forest (Ahmadi et al., 2023), while other research indicates peaks at higher elevations, such as 2070 m in adjacent regions (Ataei et al., 2021), suggesting potential regional variation (Mouquet et al., 2015; Zhou et al., 2020; He et al., 2023; Lu et al., 2023; Rahman et al., 2022; Schroeder et al., 2024; Su et al., 2024; Zhang et al., 2024).

Despite the ecological importance of Hyrcanian forests, detailed information on plant community classification and diversity patterns along altitudinal gradients in the Kourdkoy forest remains limited. Research needs to address an essential knowledge gap because scientists have confirmed altitude's impact on worldwide plant diversity (Scherrer & Körner, 2011), Understanding how plant communities change along elevation gradients is important for improving ecological knowledge and supporting forest management and conservation (Noroozi et al., 2016). Therefore, this study aimed to classify plant communities using TWINSPAN and to evaluate plant diversity patterns along an altitudinal gradient in the Hyrcanian forest ecosystem.

2. Materials and Methods

2.1. Study Area

The study was conducted in Kourdkoy Forest where is situated in Golestan Province, northern Iran. It occurs at 36° 39' 00" to 36° 41' 30" N, 54° 04' 30" to 54° 07' 38" E of Golestan Province with an altitudinal gradient of 300 to 2000 m a.s.l. According to estimated climatic data from the nearest stations, annual precipitation, and mean annual temperature were 1240 mm and 12.6°C and also a 2.5-month dry season between June and August. Its temperate climate and varied topography support diverse vegetation typical of the Hyrcanian Forests (Department of Natural Resources and Watershed Management of Golestan Province, 2013).

2.2. Data Collection

Sampling was focused on the elevation range from 500 to 1700 m a.s.l. and the effects of altitude on plant community distribution were determined. The studied area was divided into six altitudinal classes at 200 m intervals according to previous methods (Pourbabaei & Haghgoy, 2013; Kessler et al., 2014). A random-systematic design established eight circular plots with a 1000 m² area in each altitudinal class through the use of 150 m spacing between the plots (Pourbabaei et al., 2019; 2020). The slope percentage and geographic aspect were documented for each plot. The diameter at breast height (DBH≥7.5 cm) was measured for all trees (Pourbabaei et al., 2014). The Whittaker's nested plot sampling method provided a basis for choosing appropriate subplot sizes by determining the optimized subplot size to obtain representative herbaceous species data. Results from the analysis led researchers to choose 100 m² subplots as the proper size for herbaceous species estimation. We evaluated herbaceous species occurrence in every subplot using the Braun-Blanquet criterion to measure their cover percentage (Manish et al., 2017; Pourbabaei et al., 2019).

2.3. Data Analysis

Sampling was conducted in two seasons (spring and Summer), the species were dried and pressed before identifying by using Iranica Flora (Rechinger, 1963-1998), Turkey Flora (Davis, 1965-1988), Iran Flora (Assadi, 1988-2003) and the Colorful Flora of Iran (Ghahreman, 1975-2000) in the herbarium of the Faculty of Natural Resources in University of Guilan. Moreover, the chorology of species was determined according to the Zohary and Takhtajan method (Takhtajan, 1986). In order to determine the plant communities, analysis was done with Two-Way Indicator Species Analysis (TWINSPAN) using PC-ORD software for Windows, version 4.17 that the resulting groups are referred to as plant communities based on dominant and indicator species, rather than formal phytosociological associations (Hasanpori et al., 2014). In each community, Species Important Values (SIV) were computed for tree and herbaceous species using equations 1 and 2, respectively (Pourbabaei et al., 2014):

SIV = relative frequency + relative dominance + relative density (1)

SIV = relative frequency + relative dominance (2)

Finally, diversity indices including Shannon-Wiener (H´) which is sensitive for comparison among plant communities (Kent, 2011), Smith-Wilson as it is mathematically independent of species richness and therefore allows a more reliable assessment of abundance distribution patterns among plant communities (Smith & Wilson, 1996), and Margalef indices that diminish the bias associated with differences in total abundance among plant communities (Gómez et al., 2000) were calculated using Ecological Methodology software for Windows, version 6.0 (Hosseinzadeh et al., 2016). Kolmogorov-Smirnov and Levene's tests demonstrated that the data passed the requirements of normality and homogeneity of variances. The analysis consisted of One-way ANOVA at $\alpha = 0.05$ with Tukey's post-hoc tests for mean comparisons between communities and altitudinal classes in SPSS v16.0.

3. Results

3.1. Floristic Composition

It has been identified 60 species belonged to 37 families, and 55 genera (6 trees, and 54 herbaceous species). The prominent families were Rosaceae (5 species), Lamiaceae (4 species), Apiaceae, Aspleniaceae, Asteraceae, Brassicaceae, and Fabaceae (each family with three species), which had the highest frequency. The result of life form classification indicated that hemicryptophytes (26 species), cryptophytes (13 species) were dominance. Other life forms were present with lower frequency, including phanerophytes (11 species), therophytes (7 species), and chamaephytes (3 species) (Figure 1).

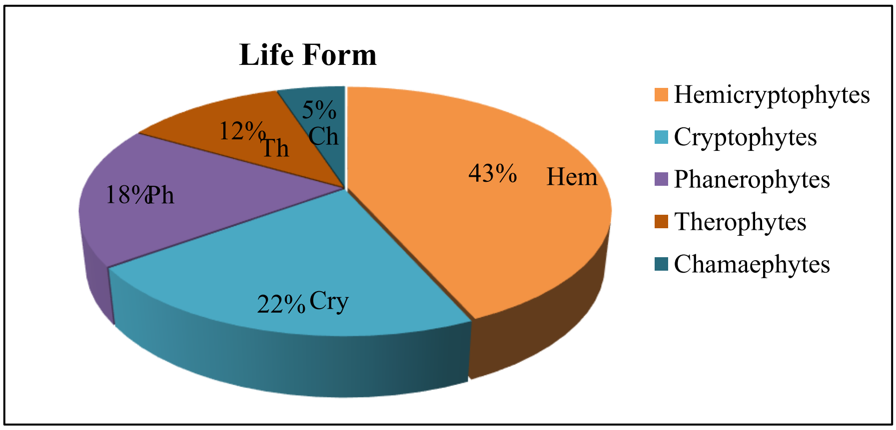

Figure 1. Life forms of trees and herbaceous species in the study area, Hem: Hemicryptophytes; Ch: Chamaephytes; Th = Therophytes; Ph = Phanerophytes; Cry: Cryptophytes.

The chorotype indicated that Euro-Sibria was dominant with 24 species (40%), Euro-Siberian-Irano-Turanian-Mediterranean with 10 species (17%), Euro-Siberian-Irano-Turanian with 7 species (11%), Euro-Siberian-Mediterranean with 6 species (10%), Polyregional with 5 species (8%), Cosmopolitan with 4 species (7%), and Irano-Turanian with 3 species (5%) (Figure 2).

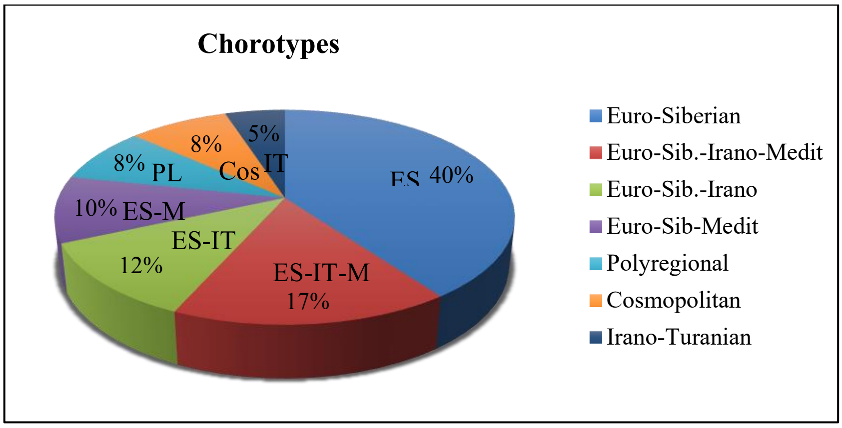

Figure 2. Chorotype of trees and herbaceous species in the study area, note: ES: Euro-Siberian; ES-M-IT: Euro-Siberian-Mediterranean-Irano-Turanian; ES-IT: Euro-Siberian-Irano-Turanian; IT: Irano-Turanian; Cos: Cosmopolitan; ES-M: Euro-Siberian-Mediterranean; Pl: Polyregional; Hyrc: Hyrcani.

3.2. The Classification of Plant Communities

The results of TWINSPAN analyses were shown in Figure 3. that five distinct plant communities were identified along the altitudinal gradient, and also their accessory species in each elevation class were listed (Supplementary Table 1). At first level, 48 plots with eigenvalue 0.6059 were divided to two groups. Sixteen plots were located on left group (negative group). *Epipactis* sp. was an indicator herbaceous species in this group. In the right and positive group, there were 32 plots with *Geranium columbinum* as the indicator species. These groups did not have any indicator tree species. In the second level of classification, a group with 16 species, and eigenvalue 0.1826 was divided in 2 groups. In negative group, 8 plots were identified with *Alnus glutinosa* as indicator species without any herbaceous species. The positive group also involved 8 plots with *Euphorbia amygdaloides*. In the next step, two groups were obtained of a group with 32 plots (eigenvalue; 0.5092), 15 plots with *Dryopteris pallida* and 17 plots with *Phedimus stoloniferus* as indicator species were presented in negative and positive group, respectively. In the third level of classification a group including 15 species and eigenvalue 0.2778 was divided to two groups. 8 plots with *Clinopodium umbrosum* were belonged to negative group and 7 plots with *Geranium* sp. were belonged to positive group. Indicator species for first level of groups has been achieved of plots that the presence of indicator species in those plots was a factor to separation. Classification process was stopped with five communities in third level. Overall, sampling plots were divided into five groups using TWINSPAN. First group was belonged to first class of altitude (i.e., from 500 to 700 m a.s.l.) and included plots 1 to 8 (A). The second group had plots from 9 to 16 and was located in altitude from 700 to 900 m a.s.l. (B). The plots 17 to 24 were presented in third group that were located in altitude from 900 to 1100 m a.s.l. (C). The fourth group was belonged to 1100 to 1300 m a.s.l. (D) with 7 plots (from 25 to 31). Finally, the fifth group which was located in altitude range from 1300 to 1700 m a.s.l. (1300-1500= E_1, 1500-1700= E_2), with 17 plots. According to identification of plant ecological group using TWINSPAN, each group was considered as a plant community (Abla et al., 2024) and was named by Species Important Value

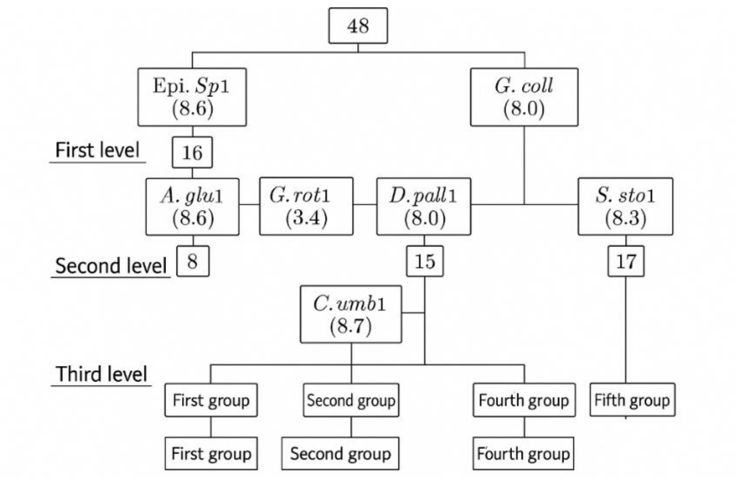

Figure 3. Classification of sampling plots using TWINSPAN.

3.3. Diversity, Evenness and Richness Values among Plant Communities

The results of ANOVA test indicated that there was a significant difference among plant communities in terms of Shannon-Wiener, Smith-Wilson and Margalef indices ($P \leq 0.05$) (Table 1). The highest value of Shannon-Wiener was belonged to second community (4.20). While, the fourth community had the lowest value (2.8) (Figure 4). The highest and lowest value of evenness was obtained for the first and third communities, respectively (Figure 5). Finally, the first community had the highest value of Margalef richness index (5.13) and the lowest was belonged to fifth community (2.39). There was a significant difference between the third community with others (Figure 6).

Table 1. Results of ANOVA test of diversity indices among plant communities.

Variables	DF	MS	Mean± SE	*P*	F
Shannon-Wiener	4	3.825	3.44±0.11	0.000^{*}	15.54
Smith-Wilson	4	0.133	0.42± 0.02	0.000^{*}	6.46
Margalef	4	14.824	3.46± 0.18	0.000^{*}	52.30

MS: mean square, SE: standard error.

3.4. Diversity, Evenness and Richness Values in Altitude, Slope and Aspect Classes

ANOVA test showed that altitude influenced all indices including Shannon-Wiener, Smith-Wilson and Margalef richness, and returned statistical significance (P-value ≤ 0.05) as indicated in Table 2. The data of this research demonstrated that altitude influenced diversity ($F = 13.47$, $P = 0.000$) as well as evenness ($F=4.23$, $P=0.003$) and richness ($F=44.4$, $P=0.000$). The values obtained for these indices showed no significant correlation to slope measurements since their corresponding *P*-values were 0.252 for diversity, 0.327 for evenness, and 0.121 for richness.

Table 2. Results of ANOVA test of diversity values in altitude, slope and aspect classes.

Variations source	Indices	DF	MS	*P*	F
Altitude	diversity	5	3.188	0.000^{*}	13.47
	evenness	5	0.095	0.003^{*}	4.23
	richness	5	12.28	0.000^{*}	44.4
Slope	diversity	2	0.76	0.252^{ns}	1.42
	evenness	2	0.034	0.327^{ns}	1.14
	richness	2	3.20	0.121^{ns}	2.21
Aspect	diversity	46	0.036	0.682^{ns}	0.17
	evenness	46	0.042	0.221^{ns}	0.074
	richness	46	0.309	0.787^{ns}	4.54

The results of means comparison revealed that the highest value of Shannon-Wiener was belonged to altitudinal class B (2.4), however, the altitudinal range of E_1 had the lowest value (0.55) (Figure 7). In relation to evenness, the highest and lowest value was gained in altitudinal classes including A and C, respectively (Figure 8). Eventually, the altitudinal range of A had the highest value of Margalef richness index and the lowest was belonged to E_2 class (Figure 9).

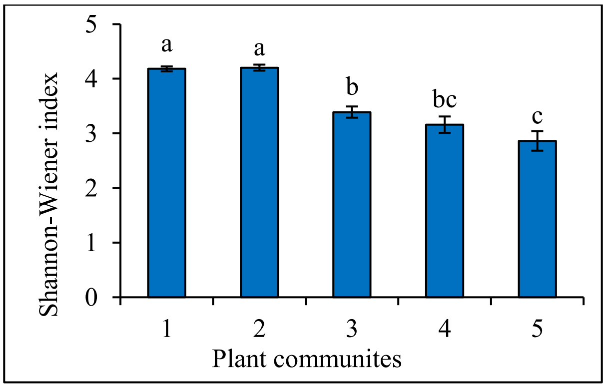

Figure 4. Diversity indices among plant communities.

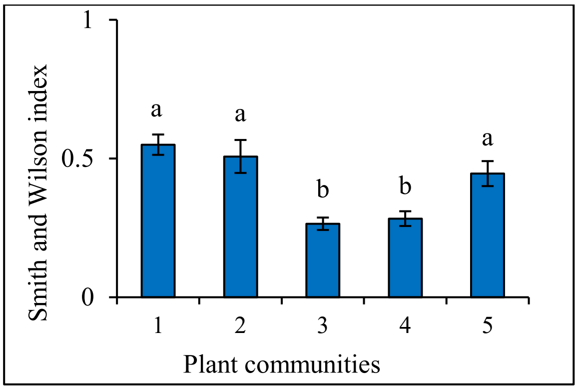

Figure 5. Evenness indices among plant communities.

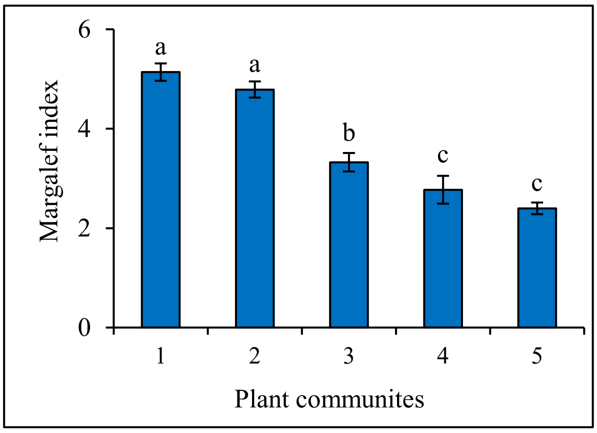

Figure 6. Richness indices among plant communities.

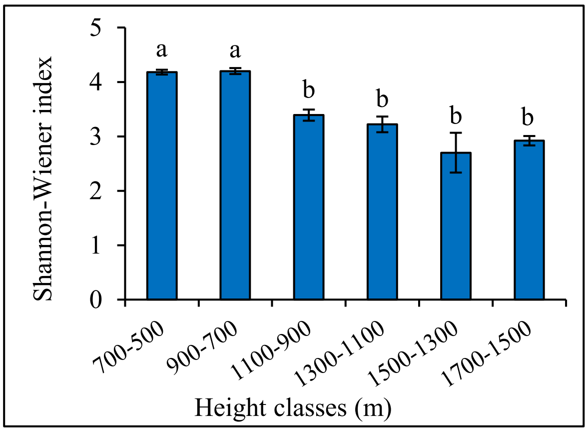

Figure 7. Diversity indices among altitudinal classes.

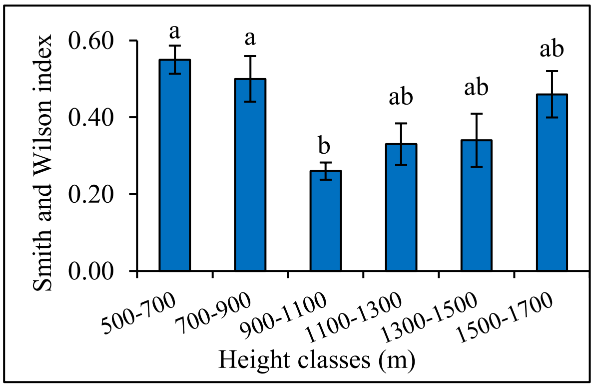

Figure 8. Evenness indices of altitudinal classes.

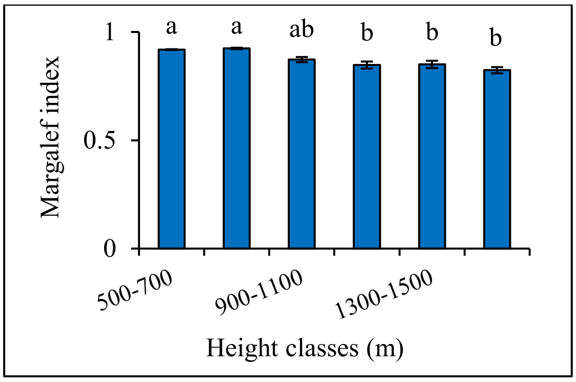

Figure 9. Richness indices of altitudinal classes.

4. Discussion

In an ecosystem, the study of floristic characteristics, and chorotype form of plant species are effective method for understanding the capacities, management, and conservation of genetic resources which can determine ecosystems position in the natural conservation global network (Haq & Badshah, 2021). According to the results, 60 species were identified in the studied area. The highest number of species was belonged to Rosaceae and Lamiaceae families. It may be related to geographical position as well as topographical heterogeneity in the studied area that possibly provided suitable edaphic conditions for species of these families (Naqinezhad et al., 2010). The results of life form classification showed that Hemicryptophytes and Cryptophytes were dominant. The highest frequency of Hemicryptophytes in an ecosystem can be a result of mountainous, and cold climates (Das et al., 2020; Ghafari et al., 2020; Wagner et al., 2021). Species belonged to this life form are tolerant to these kind of climate by keeping reviver buds in the soil (Naqinezhad et al., 2010).

Kourdkoy region is a temperate area with mountainous and cold climate, and dominance of Hemicryptopehytes confirm the adaptation of these life form to climatic condition (Midolo et al., 2024). Hemicryptophytes were associated with humid, and cold climate in higher geographical latitude. While, Therophytes and Chamaephytes were tolerant in dry, and unfavorable conditions (Alzamel, 2024; Di Biase et al., 2021). The geographical distribution of plant species in an area is affected by the surrounding vegetation regions (Liu et al., 2016). The temperate forests of Northern Iran belong to the Euxino-Hyrcanian province of the Pontic subregion within the Europe-Siberian region. Therefore, the presence of species belonging to these geographical ranges in the flora is reasonable (Ghorbanalizadeh et al., 2022).

The classification of plant communities indicated that there was a significant difference among diversity values. In addition, altitudinal ranges were significant among topographic factors. Therefore, it can be concluded that TWINSPAN has more reasonable in the vegetation unites differentiation by various ecological characteristics than topographic classification.

Moreover, it indicates a favorable description of vegetation in compared to floristic methods (Witte, 2002).

According to TWINSPAN, five plant communities were identified. The study of diversity indices among plant communities revealed that the first community had the highest richness, and evenness among groups that can be a result of higher temperature, lower percentage cover of tree species, and also increasing the entrance light in these slopes (Tuomisto et al., 2014). The second community with *Euphorbia amygdaloides* and without an indicator tree species had the highest species diversity. Excessive utilization of tree species and diminishing tree and canopy density are reasons to increase plant species diversity in forests floor (Kashian et al., 2003). On the other hand, the greater density of tree species in higher altitude is an effective factor to limited distribution of different plant species which lead to reduce species diversity (Karami et al., 2008). The third community with *Dryopteris pallida* had the lowest evenness. This species was mainly present in gaps resulting from human activities. In addition, the larger size of these species likely increased competition for light, which may have contributed to reduced richness and percent cover of many understory plants (Ebrahimi et al., 2014). Moreover, this species can diminish growth of other species by allelopathy, and chemical release (Pourbabaei & Ahani, 2004). On the other hand, the high frequency of this species in third group can be an indicative of high humidity in the environment (Chia & Lim, 2022). The presence of this group was demonstrated in the wettest slopes of the study area. The fourth and fifth groups had the lowest value of diversity indices. It may be associated with their establishment at a higher altitude (Rathore et al., 2018; Siles & Margesin, 2016). The highest value of species richness and diversity was found at intermediate altitude. Conversely It was decreased by increasing altitude, and decreasing temperature.

Results of ANOVA test for diversity indices among altitudinal classes indicated that the first, and, second classes had the highest value, and there were significant differences among classes. By increasing altitude, plant growing season will be decreased in climate condition including extreme cold, snow, hail and strong winds which can lead to diminish plant species diversity with absence sensitive species (Zhang et al., 2022; Zhu et al., 2019). Species composition is another factor which can be effective on plant diversity reduction. At lower altitudinal gradient, *Fagus orientalis* was mixed with other tree species. Whereas, the pure communities of *Fagus orientalis* were presented at altitudinal gradient from 1400 to 1700 m a.s.l. Overall, plant species diversity in pure beech communities is lower than mixed communities (Hrivnák et al., 2014; Williams et al., 2017; Benavides et al., 2019). Variation in tree species composition may be associated with differences in light availability in the studied area, possibly reflecting the shade-tolerant characteristics of beech (Chamagne et al., 2016; Zellweger et al., 2016; Driesen et al., 2020). The minimum value of species richness was belonged to higher altitudinal gradient, which can be attributed to decrease temperature and liquid water availability in this altitude (Sharma et al., 2019). However, environmental variables such as soil properties, and microclimatic conditions were not directly measured in this study, and further research would be useful to better understand the underlying ecological factors.

5. Conclusion

This study identified five plant communities along the altitudinal gradient in the Hyrcanian forest using TWINSPAN classification. The results indicated that altitudinal gradient had a significant effect on diversity, richness, and evenness values. Plant community distributions were affected by altitudinal factor which was the most important variability factor among the groups. An altitudinal class can be effective on plant species distribution by temperature, and humidity factors. As the result showed the higher elevation had lower species diversity. Selecting tree species that match the habitat is crucial for forest reconstruction with low diversity at high altitudes. Therefore, it is essential to adjust management strategies for effective care of forest ecosystems.

Conflict of Interest

The authors declare that they have no competing interests.

References

Abla, S., Djebbouri, M., & Kefil, S. (2024). Diagnosis of the plant biodiversity of an anthropogenic zone in Algiers: Case of the Bouzaréah Forest Massif. *CRF*, *19*(01), 520-536.

Acwin Dwijendra, N. K., Sivaraman, R., Kaliyaperumal, K., & Romero-Parra, R. M. (2022). [Retracted] Balance harvest from the forest as a renewable resource using game theory. *Discrete Dynamics in Nature and Society*, *2022*(1), 1377775. https://doi.org/10.1155/2022/1377775

Ahmadi, K., Mahmoodi, S., Pal, S. C., Saha, A., Chowdhuri, I., Kolyaie, S., Linh, N. T. T., Thai, V. N., & Kumar, L. (2023). Modeling tree species richness patterns and their environmental drivers across Hyrcanian mountain forests. *Ecological Informatics*, *77*, 102226. https://doi.org/10.1016/j.ecoinf.2023.102226

Ali, A., Sanaei, A., Li, M., Nalivan, O. A., Ahmadaali, K., Pour, M. J., Valipour, A., Karami, J., Aminpour, M., Kaboli, H., & Askari, Y. (2020). Impacts of climatic and edaphic factors on the diversity, structure and biomass of species-poor and structurally-complex forests. *Science of the Total Environment*, *706*, 135719. https://doi.org/10.1016/j.scitotenv.2019.135719

Alzamel, N. (2024). Floristic composition, diversity, and vegetation structure in Wadi Al-Quwayiyah, Riyadh Region, Saudi Arabia. *Journal of Environmental*

Studies, *34*(1), 1-9. https://doi.org/10.21608/jesj.2024.289071.1075

Assadi, M. (1988-2003). Flora of Iran. Research Institute of Forests and Rangelands. Tehran, Iran.

Ataei, A., Kazemnezhad, F., Nimvari, M. E., & Sheykholeslami, A. (2021). Ecotones and forest communities along an elevation gradient in Hyrcanian forests, north of Iran. *Caspian Journal of Environmental Sciences*, *19*(2), 317-323. https://doi.org/10.22124/CJES.2021.4605

Bayat, M., Bettinger, P., Heidari, S., Henareh Khalyani, A., Jourgholami, M., & Hamidi, S. K. (2020). Estimation of tree heights in an uneven-aged, mixed forest in northern Iran using artificial intelligence and empirical models. *Forests*, *11*(3), 324. https://doi.org/10.3390/f11030324

Benavides, R., Scherer-Lorenzen, M., & Valladares, F. (2019). The functional trait space of tree species is influenced by the species richness of the canopy and the type of forest. *Oikos*, *128*(10), 1435-1445. https://doi.org/10.1111/oik.06348

Bjorkman, A. D., Myers-Smith, I. H., Elmendorf, S. C., Normand, S., Rüger, N., Beck, P. S., ... & Weiher, E. (2018). Plant functional trait change across a warming tundra biome. *Nature*, *562*, 57-62. https://doi.org/10.1038/s41586-018-0563-7

Brosofske, K. D., Chen, J., & Crow, T. R. (2001). Understory vegetation and site factors: Implications for a managed Wisconsin landscape. *Forest Ecology and Management*, *146*(1-3), 75-87. https://doi.org/10.1016/S0378-1127(00)00447-3

Chamagne, J., Paine, C. T., Schoolmaster Jr, D. R., Stejskal, R., Volařík, D., Šebesta, J., Trnka, F., Koutecký, T., Švarc, P., Svátek, M., Hector, A., & Matula, R. (2016). Do the rich get richer? Varying effects of tree species identity and diversity on the richness of understory taxa. *Ecology*, *97*(9), 2364-2373. https://doi.org/10.1002/ecy.1479

Chia, S. Y., & Lim, M. W. (2022). A critical review on the influence of humidity for plant growth forecasting. *IOP Conference Series: Materials Science and Engineering*, *1257*, 012001. https://doi.org/10.1088/1757-899X/1257/1/012001

Das, D. S., Rawat, D. S., Maity, D., Dash, S. S., & Sinha, B. K. (2020). Species richness patterns of different life-forms along altitudinal gradients in the Great Himalayan National Park, Western Himalaya, India. *Taiwania*, *65*(2), 154-162. https://doi.org/10.6165/tai.2020.65.154

Davis, P. H., (1965-1985). *Flora of Turkey and the East Aegean islands*. Edinburgh University Press.

Department of Natural Resources and Watershed Management of Golestan Province. (2013). *Kourdkoy forestry plan*. Department of Natural Resources and Watershed Management of Golestan Province.

Di Biase, L., Pace, L., Mantoni, C., & Fattorini, S. (2021). Variations in plant richness, biogeographical composition, and life forms along an elevational gradient in a Mediterranean mountain. *Plants*, *10*(10), 2090. https://doi.org/10.3390/plants10102090

Driesen, E., Van den Ende, W., De Proft, M., & Saeys, W. (2020). Influence of environmental factors light, CO2, temperature, and relative humidity on stomatal opening and development: A review. *Agronomy*, *10*(12), 1975. https://doi.org/10.3390/agronomy10121975

Ebrahimi, S. S., Pourbabaei, H., Potheir, D., Omidi, A., & Torkaman, J. (2014). Effect of livestock grazing and human uses on herbaceous species diversity in oriental beech (*Fagus orientalis* Lipsky) forests, Guilan, Masal, northern Iran. *Journal of Forestry Research*, *25*(2), 455-462. https://doi.org/10.1007/s11676-014-0476-8

Gao, M., Wang, X., Hui, C., Yi, H., Zhang, C., Wu, X., Bi, X., Wang, Y., Xiao, L., & Wang, D. (2015). Assembly of plant communities in coastal wetlands—the role of saltcedar *Tamarix chinensis* during early succession. *Journal of Plant Ecology*, *8*(5), 539-548. https://doi.org/10.1093/jpe/rtu037

Ghafari, S., Ghorbani, A., Moameri, M., Mostafazadeh, R., Bidarlord, M., & Kakehmami, A. (2020). Floristic diversity and distribution patterns along an elevational gradient in the northern part of the Ardabil province rangelands, Iran. *Mountain Research and Development*, *40*(1), R37. https://doi.org/10.1659/MRD-JOURNAL-D-18-00089.1

Ghahreman, A. (1975-2000). Colored Flora of Iran. Vol. 1-20. Research Institute of forests and Rangelands, Tehran. (In Persian).

Ghorbanalizadeh, A., & Akhani, H. (2022). Plant diversity of Hyrcanian relict forests: An annotated checklist, chorology and threat categories of endemic and near endemic vascular plant species. *Plant Diversity*, *44*(1), 39-69. https://doi.org/10.1016/j.pld.2021.07.005

Gómez, J. A. A., Bellon, M. R., & Smale, M. (2000). A regional analysis of maize biological diversity in Southeastern Guanajuato, Mexico. *Economic Botany*, *54*(1), 60-72. https://doi.org/10.1007/BF02866600

Haq, A., & Badshah, L. (2021). Floristic description and ecological characteristics of the plants of Pashat Valley, Pak-Afghan border, district Bajaur, Pakistan. *Acta Ecologica Sinica*, *41*(6), 524-536. https://doi.org/10.1016/j.chnaes.2021.03.010

Hasanpori, R., Tavili, A., & Javadi, S. A. (2014). Classification and determination of indicator environmental properties in western Iran rangelands. *Asia Pacific Journal of Energy and Environment*, *1*(1), 39-44. https://doi.org/10.18034/apjee.v1i1.208

He, X., Arif, M., Zheng, J., Ni, X., Yuan, Z., Zhu, Q., Wang, J., Ding, D., & Li, C. (2023). Plant diversity patterns along an elevation gradient: The relative impact of environmental and spatial variation on plant diversity and assembly in arid and semi-arid regions. *Frontiers in Environmental Science*, *11*, 1021157. https://doi.org/10.3389/fenvs.2023.1021157

Hosseini, N., Ghorbanpour, M., & Mostafavi, H. (2024). The influence of climate change on the future distribution of two *Thymus* species in Iran: MaxEnt model-based prediction. *BMC Plant Biology*, *24*(1), 269. https://doi.org/10.1186/s12870-024-04965-1

Hosseinzadeh, R., Soosani, J., Alijani, V., Khosravi, S., & Karimikia, H. (2016). Diversity of woody plant species and their relationship to physiographic factors in central Zagros forests (Case study: Perc forest, Khorramabad, Iran). *Journal of Forestry Research*, *27*(5), 1137-1141. https://doi.org/10.1007/s11676-016-0243-0

Hrivnák, R., Gömöry, D., Slezák, M., Ujházy, K., Hédl, R., Jarčuška, B., & Ujházyová, M. (2014). Species richness pattern along altitudinal gradient in central European beech forests. *Folia Geobotanica*, *49*(3), 425-441. https://doi.org/10.1007/s12224-013-9174-0

Jafarian, Z., Kargar, M., Tamartash, R., & Alavi, S. J. (2019). Spatial distribution modelling of plant functional diversity in the mountain rangeland, north of Iran. *Ecological Indicators*, *97*, 231-238. https://doi.org/10.1016/j.ecolind.2018.10.019

Karami, P., Gorgin, K. M., Basiri, R., & Kargari, E. (2008). Analyzes of species diversity in ecological species group case study: The Kurdista's Kouhsalan habitat. *Journal of Environmental Studies*, *34*(46), 47-56.

Kashian, D. M., Barnes, B. V., & Walker, W. S. (2003). Ecological species groups of landform-level ecosystems dominated by jack pine in northern Lower Michigan, USA. *Plant Ecology*, *166*(1), 75-91. https://doi.org/10.1023/A:1023265012964

Kent, M. (2011). Vegetation description and data analysis: A practical approach. *Oikos*, *76*(1), 70-82. https://doi.org/10.2307/3545749

Kessler, M., Toivonen, J. M., Sylvester, S. P., Kluge, J., & Hertel, D. (2014). Elevational patterns of *Polylepis* tree height (Rosaceae) in the high Andes of Peru: Role of human impact and climatic conditions. *Frontiers in Plant Science*, *5*, 194. https://doi.org/10.3389/fpls.2014.00194

Kooch, Y., Parsapour, M. K., & Wirth, S. (2023). Soil functional indicators in different development stages of an oak (*Quercus castaneifolia* CA Mey.) stand. *Applied Soil Ecology*, *189*, 104922. https://doi.org/10.1016/j.apsoil.2023.104922

Kraft, N. J., Adler, P. B., Godoy, O., James, E. C., Fuller, S., & Levine, J. M. (2015). Community assembly, coexistence and the environmental filtering metaphor. *Functional Ecology*, *29*(5), 592-599. https://doi.org/10.1111/1365-2435.12345

Krömer, T., Acebey, A., Kluge, J., & Kessler, M. (2013). Effects of altitude and climate in determining elevational plant species richness patterns: A case study from Los Tuxtlas, Mexico. *Flora-Morphology, Distribution, Functional Ecology of Plants*, *208*(3), 197-210. https://doi.org/10.1016/j.flora.2013.03.003

Kulakowski, D., Seidl, R., Holeksa, J., Kuuluvainen, T., Nagel, T. A., Panayotov, M., Svoboda, M., Thorn, S., Vacchiano, G., Whitlock, C., Wohlgemuth, T., & Bebi, P. (2017). A walk on the wild side: Disturbance dynamics and the conservation and management of European mountain forest ecosystems. *Forest Ecology and Management*, *388*, 120-131. https://doi.org/10.1016/j.foreco.2016.07.037

Liu, X., Zhou, W., & Bai, Z. (2016). Vegetation coverage change and stability in large open-pit coal mine dumps in China during 1990–2015. *Ecological Engineering*, *95*, 447-451. https://doi.org/10.1016/j.ecoleng.2016.06.051

Lu, S., Zhang, D., Wang, L., Dong, L., Liu, C., Hou, D., Chen, G., Qiao, X., Wang, Y., & Guo, K. (2023). Comparison of plant diversity-carbon storage relationships along altitudinal gradients in temperate forests and shrublands. *Frontiers in Plant Science*, *14*, 1120050. https://doi.org/10.3389/fpls.2023.1120050

Manish, K., Pandit, M. K., Telwala, Y., Nautiyal, D. C., Koh, L. P., & Tiwari, S. (2017). Elevational plant species richness patterns and their drivers across non-endemics, endemics and growth forms in the Eastern Himalaya. *Journal of Plant Research*, *130*(5), 829-844. https://doi.org/10.1007/s10265-017-0946-0

Midolo, G., Axmanová, I., Divíšek, J., Dřevojan, P., Lososová, Z., Večeřa, M., ... & Chytrý, M. (2024). Diversity and distribution of Raunkiær's life forms in European vegetation. *Journal of Vegetation Science*, *35*(1), e13229. https://doi.org/10.1111/jvs.13229

Mouquet, N., Lagadeuc, Y., Devictor, V., Doyen, L., Duputié, A., Eveillard, D., ... & Loreau, M. (2015). Predictive ecology in a changing world. *Journal of Applied Ecology*, *52*(5), 1293-1310. https://doi.org/10.1111/1365-2664.12482

Mucina, L., Bültmann, H., Dierßen, K., Theurillat, J. P., Raus, T., Čarni, A., ... & Tichý, L. (2016). Vegetation of Europe: Hierarchical floristic classification system of vascular plant, bryophyte, lichen, and algal communities. *Applied Vegetation Science*, *19*(S1), 3-264. https://doi.org/10.1111/avsc.12257

Naqinezhad, A., Hosseini, S., Rajamand, M. A., & Saeidi Mehrvarz, S. (2010). A floristic study on Mazibon and Sibon protected forests, Ramsar, across the altitudinal gradient (300-2300 m). *Taxonomy and Biosystematics*, *2*(5), 93-114.

Noroozi, J., Moser, D., & Essl, F. (2016). Diversity, distribution, ecology and description rates of alpine endemic plant species from Iranian mountains. *Alpine Botany*, *126*(1), 1-9. https://doi.org/10.1007/s00035-015-0160-4

Pourbabaei, H., & Ahani, H. (2004). Biodiversity of woody species in Acer platanoides sites in the Shafaroud Forests, Gilan (Iran). *Rostaniha*, *5*(2), 147-158.

Pourbabaei, H., Ebrahimi, S. S., Torkaman, J., & Pothier, D. (2014). Comparison in woody species composition, diversity and community structure as affected by livestock grazing and human uses in beech forests of northern Iran. *Forestry*, *20*(1), 1-11.

Pourbabaei, H., & Haghgooy, T. (2013). Effect of physiographical factors on tree species diversity (case study: Kandelat Forest Park). *Iranian Journal of Forest and Poplar Research*, *21*(2), 243-255.

Pourbabaei, H., Salehi, A., & Ebrahimi, S. S. (2019). Modelling of plant species richness along altitudinal gradient: Asalem Watershed basin, temperate deciduous forests in northern Iran. *Acta Ecologica Sinica*, *39*(5), 335-347. https://doi.org/10.1016/j.chnaes.2018.09.013

Pourbabaei, H., Salehi, A., Ebrahimi, S. S., & Khodaparasrt, F. (2020). Variations of soil physicochemical properties and vegetation cover under different altitudinal gradient, western Hyrcanean forest, north of Iran. *Journal of Forest Science*, *66*(4), 159-169. https://doi.org/10.17221/136/2019-JFS

Pourghasemi, H. R. (2016). GIS-based forest fire susceptibility mapping in Iran: A comparison between evidential belief function and binary logistic regression models. *Scandinavian Journal of Forest Research*, *31*(1), 80-98. https://doi.org/10.1080/02827581.2015.1052750

Rahman, I. U., Hart, R. E., Ijaz, F., Afzal, A., Iqbal, Z., Calixto, E. S., Abd_Allah, E. F., Alqarawi, A. A., Hashem, A., Al-Arjani, A.-B., F., Kausar, R., & Haq, S. M. (2022). Environmental variables drive plant species composition and distribution in the moist temperate forests of Northwestern Himalaya, Pakistan. *PloS One*, *17*(2), e0260687. https://doi.org/10.1371/journal.pone.0260687

Rathore, N., Thakur, D., & Chawla, A. (2018). Seasonal variations coupled with elevation gradient drives significant changes in eco-physiological and biogeochemical traits of a high altitude evergreen broadleaf shrub, *Rhododendron anthopogon*. *Plant Physiology and Biochemistry*, *132*, 708-719. https://doi.org/10.1016/j.plaphy.2018.08.009

Rechinger, K. (1963-1998). *Flora Iranica*. Akademishe Druck University, Graz.

Rezende, V. L., de Miranda, P. L., Meyer, L., Moreira, C. V., Linhares, M. F., de Oliveira-Filho, A. T., & Eisenlohr, P. V. (2015). Tree species composition and richness along altitudinal gradients as a tool for conservation decisions: The case of Atlantic semideciduous forest. *Biodiversity and Conservation*, *24*(9), 2149-2163. https://doi.org/10.1007/s10531-015-0939-z

Scherrer, D., & Körner, C. (2011). Topographically controlled thermal-habitat differentiation buffers alpine plant diversity against climate warming. *Journal of Biogeography*, *38*(2), 406-416. https://doi.org/10.1111/j.1365-2699.2010.02407.x

Schroeder, L., Robles, V., Jara-Arancio, P., Lapadat, C., Hobbie, S. E., Arroyo, M. T., & Cavender-Bares, J. (2024). Drivers of plant diversity, community composition, functional traits, and soil processes along an alpine gradient in the central Chilean Andes. *Ecology and Evolution*, *14*(2), e10888. https://doi.org/10.1002/ece3.10888

Sharma, N., Behera, M. D., Das, A. P., & Panda, R. M. (2019). Plant richness pattern in an elevation gradient in the Eastern Himalaya. *Biodiversity and Conservation*, *28*(8), 2085-2104. https://doi.org/10.1007/s10531-019-01699-7

Siles, J. A., & Margesin, R. (2016). Abundance and diversity of bacterial, archaeal, and fungal communities along an altitudinal gradient in alpine forest soils: What are the driving factors? *Microbial Ecology*, *72*(1), 207-220. https://doi.org/10.1007/s00248-016-0748-2

Sinha, S., Badola, H. K., Chhetri, B., Gaira, K. S., Lepcha, J., & Dhyani, P. P. (2018). Effect of altitude and climate in shaping the forest compositions of Singalila National Park in Khangchendzonga Landscape, Eastern Himalaya, India. *Journal of Asia-Pacific Biodiversity*, *11*(2), 267-275. https://doi.org/10.1016/j.japb.2018.01.012

Smith, B., & Wilson, J. B. (1996). A consumer's guide to evenness indices. *Oikos*, *78*(1), 70-82. https://doi.org/10.2307/3545749

Su, Y., Gan, X., Zhang, W., Wu, G., & Huang, F. (2024). Woody plant structural diversity changes across an inverse elevation-dependent warming gradient in a subtropical mountain forest. *Forests*, *15*(6), 1051. https://doi.org/10.3390/f15061051

Sun, W., Song, X., Mu, X., Gao, P., Wang, F., & Zhao, G. (2015). Spatiotemporal vegetation cover variations associated with climate change and ecological restoration in the Loess Plateau. *Agricultural and Forest Meteorology*, *209*, 87-99. https://doi.org/10.1016/j.agrformet.2015.05.002

Takhtajan, A. (1986). *Floristic region of the world*. University of California Press.

Tuomisto, H., Zuquim, G., & Cárdenas, G. (2014). Species richness and diversity along edaphic and climatic gradients in Amazonia. *Ecography*, *37*(11), 1034-1046. https://doi.org/10.1111/ecog.00770

Wagner, J., Gruber, K., Ladinig, U., Buchner, O., & Neuner, G. (2021). Winter frosts reduce flower bud survival in high-mountain plants. *Plants*, *10*(8), 1507. https://doi.org/10.3390/plants10081507

Wani, Z. A., Negi, V. S., Bhat, J. A., Satish, K. V., Kumar, A., Khan, S., Dhyani, R., Siddiqui, S., Al-Qthanin, R. N., & Pant, S. (2023). Elevation, aspect, and habitat heterogeneity determine plant diversity and compositional patterns in the Kashmir Himalaya. *Frontiers in Forests and Global Change*, *6*, 1019277. https://doi.org/10.3389/ffgc.2023.1019277

Williams, L. J., Paquette, A., Cavender-Bares, J., Messier, C., & Reich, P. B. (2017). Spatial complementarity in tree crowns explains overyielding in species mixtures. *Nature Ecology & Evolution*, *1*(4), 0063. https://doi.org/10.1038/s41559-016-0063

Witte, J. -P. M. (2002). The descriptive capacity of ecological plant species groups. *Plant Ecology*, *162*(2), 199-213. https://doi.org/10.1023/A:1020370629402

Zellweger, F., Baltensweiler, A., Ginzler, C., Roth, T., Braunisch, V., Bugmann, H., & Bollmann, K. (2016). Environmental predictors of species richness in forest landscapes: Abiotic factors versus vegetation structure. *Journal of Biogeography*, *43*(6), 1080-1090. https://doi.org/10.1111/jbi.12696

Zhang, Q. -P., Wang, J., & Wang, Q. (2021). Effects of abiotic factors on plant diversity and species distribution of alpine meadow plants. *Ecological Informatics*, *61*, 101210. https://doi.org/10.1016/j.ecoinf.2021.101210

Zhang, W., Shi, H., Zhang, K., Shu, X., & Dang, H. (2024). Effects of abiotic and biotic factors on woody plant diversity across vertical strata in a temperate forest. *Plant Ecology*, *225*(1), 1-11. https://doi.org/10.1007/s11258-023-01370-w

Zhang, Z., Hautier, Y., Bao, T., Yang, J., Qing, H., Liu, Z., Wang, M., Li, T., Yan, M., & Zhang, G. (2022). Species richness and asynchrony maintain the stability of primary productivity against seasonal climatic variability. *Frontiers in Plant Science*, *13*, 1014049. https://doi.org/10.3389/fpls.2022.1014049

Zhou, Z., Ding, Y., Shi, H., Cai, H., Fu, Q., Liu, S., & Li, T. (2020). Analysis and prediction of vegetation dynamic changes in China: Past, present and future. *Ecological Indicators*, *117*, 106642. https://doi.org/10.1016/j.ecolind.2020.106642

Zhu, Z. -X., Nizamani, M. M., Sahu, S. K., Kunasingam, A., & Wang, H. -F. (2019). Tree abundance, richness, and phylogenetic diversity along an elevation gradient in the tropical forest of Diaoluo Mountain in Hainan, China. *Acta Oecologica*, *101*, 103481. https://doi.org/10.1016/j.actao.2019.103481

Supplementary Information

Supplementary Table 1. Characteristics of identified plant communities according to plant ecological group.

Plant communities	Height class (m.a.s.l.)	SIV of dominant species		Indicator species
		tree	herb	
Cyclameno-Fagetum community	500-700	*Fagus orientalis*	*Cyclamen coum*	*Carpinus betulus* L. *Ilex spinigera* Loes. *Myosotis anomala* Riedl, *Carex sylvatica* Huds, *Chelidonium majus* L. *Allium paradoxum* G.Don, *Hesperis hyrcana* Bornm.& *Gauba, Polystichum* sp. *Prunella vulgaris* L.
		148.85	109.52	
Carexeto-Fagetum community	700-900	*Fagus orientalis*	*Carex sylvatica*	*Carpinus betulus* L. *Pteris cretica* L. *Primula heterochroma* Stapf. *Chelidonium majus* L. *Epipactis* sp. *Geum urbanum* L. *Danae racemosa* Moench, *Allium paradoxum* G.Don, *Mentha aquatica* L.
		204.13	104.66	
Athyriumeto-Fagetum community	900-1100	*Fagus orientalis*	*Athyrium filix-femina*	*Carpinus betulus* L. *Trifolium* sp. *Prenanthes cacalifolia* Beauverd, *Sanicula europaea* L. *Geranium columbinum* L. *Geranium* sp. *Galium odoratum* (L.)Scop
		229.96	108.09	
Athyriumeto-Fagetum community	1100-1300	*Fagus orientalis*	*Athyrium filix-femina*	*Clinopodium umbrosum* (M.Bieb.) Kuntze, *Geranium columbinum* L. *Geranium* sp. *Dryopteris pallida* (Bory) Fomin, *Hedera pastuchovii* Woronow, *Galium odoratum* (L.)Scop.
		236.89	112.05	
Galiumo-Fagetum community	1300-1500 1500-1700	*Fagus orientalis*	*Galium odoratum*	*Athyrium filix-femina* (L.) Roth. *Acer cappadocicum* Gled. *Galium rotundifolium* L. *Solanum kiesseritzkii* C.A.Mey. *Lapsana communis* L.
		241.65	123.50	