



Effects of mixed beech and hornbeam stands on soil properties and plant species diversity indices in Hyrcanian forests of Iran

Efecto de rodales mixtos de haya y carpe en las propiedades del suelo y en los índices de diversidad de especies de plantas en bosques Hircanos, Irán

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ABSTRACT

Revealing the effect of mixed beech and hornbeam stands on herb layer diversity is essential for sustainable forestry and biodiversity conservation since little is known in Hyrcanian forests. So, we studied the effects of such stands on understory diversity and soil physico-chemical properties in Hyrcanian forests of Iran. Forty sampled plots were established by random systematic sampling method with a regular 100 m × 200 m grid. At each sample point we recorded species identity and percent cover of each tree layer and herb layer species within plots of size 400 m² (20 m × 20 m) and 100 m² (10 m × 10 m) respectively. Soil samples were taken from 0 cm - 10 cm and 10 cm - 30 cm soil depths. Cluster analysis was used to classify the samples based on the floristic composition data. Also detrended correspondence analysis (DCA) method was employed to assess the relationship between vegetation and environmental variables. There was no significant difference in terms of species richness, and diversity between mixed beech stands and hornbeam stands, but cluster analysis indicated that these stands were separated in two different groups based on herb layer species composition. DCA results showed that litter thickness, soil texture, total nitrogen, and organic carbon in the first layer were considered effective environmental variables in the distribution of sample plots in two stands. We observed that tree layer composition and soil characteristics were crucial contributors to variations of understory species composition which may be changed by forest management approaches over time. Tree layer composition and soil attributes can be considered effective factors for controlling and assessment of understory plant species composition. These findings could provide guidelines for conserving plant species diversity within any framework of sustainable forest management in Hyrcanian forests.

KEYWORDS: biodiversity conservation, herb layer diversity, species composition, species richness, sustainable forestry.

RESUMEN

Determinar el efecto de los rodales mixtos de haya y carpe sobre la diversidad del estrato herbáceo es esencial para la conservación de la biodiversidad y la silvicultura sostenible. De este tema se conoce poco en los bosques Hyrcanian y, por ello, en este trabajo se estudian los efectos de los rodales mixtos de hayas y carpe sobre la diversidad del sotobosque y las propiedades físicoquímicas del suelo en los bosques Hircanos, en Irán. Se establecieron 40 parcelas mediante un muestreo sistemático aleatorio con una retícula regular de 100 m × 200 m. En cada punto de muestreo, se registró la identidad de las especies y el porcentaje de cobertura de los estratos herbáceo y arbóreo, dentro de parcelas 400 m² (20 m × 20 m) y 100 m² (10 m × 10 m). Se tomaron muestras de suelo a profundidades de 0 cm - 10 cm y 10 cm - 30 cm. Se utilizó el análisis de conglomerados para clasificar las muestras con base en los datos de composición florística. También se empleó el método de análisis de correspondencia sin tendencia (DCA) para evaluar la relación entre la vegetación y las variables ambientales. No hubo diferencias significativas en términos de riqueza de especies, uniformidad y diversidad entre los rodales mixtos de hayas y de carpe, pero el análisis de conglomerados indicó que estos rodales estaban separados en dos grupos diferentes, basado en la composición de especies por estrato. Los resultados del DCA mostraron que el espesor de la hojarasca, la textura del suelo, el nitrógeno total y el carbono orgánico en la primera capa se consideraron variables ambientales efectivas en la distribución de las parcelas de muestreo en dos rodales. Se observó que la composición del estrato arbóreo y las características del suelo contribuyeron de manera crucial a las variaciones de la composición de las especies del sotobosque que pueden cambiar con los enfoques de manejo forestal con el tiempo. Por lo tanto, la composición del estrato arbóreo y los atributos del suelo pueden considerarse factores efectivos para controlar y evaluar la composición de las especies de plantas del sotobosque. Además, estos hallazgos podrían proporcionar directrices para la conservación de la diversidad de especies vegetales dentro de cualquier marco de ordenamiento forestal sostenible en los bosques Hircanos.

PALABRAS CLAVE: conservación de la biodiversidad, diversidad del estrato herbáceo, composición de especies, riqueza de especies, manejo forestal sustentable.

INTRODUCTION

Biological conservation is considered an important issue in sustainable forest management as a reaction to biodiversity loss (Verstraeten *et al.* 2013) since forest ecosystems have an essential role in the conservation of plant diversity. Plant species diversity has been recognized as an important determinant of the abundance and species richness in forest ecosystems (Barantal *et al.* 2019). The forest biodiversity not only responds to the changes in environmental conditions but is one of the important elements of ecosystem functions (Lucakc, 2017). Many studies have suggested that the stability of the plant community can be influenced by biodiversity where plant species richness has a strong correlation with plant species diversity in forests (Zeller & Pretzsch, 2019; Versluijs, Roberge, Eggers, Boers, & Hjältén, 2019; Barantal *et al.* 2019). In forest ecosystems, many factors (such as anthropogenic disturbances, physiographic factors and resources availability, etc.) influence the plant species diversity and its interaction with environmental factors (Kooijman & Cammeraat, 2010; Jafari, Tabari, Hosseini, & Kooch, 2014; Modabberi & Minaie, 2014). Many researchers have extensively reported positive relationships between biodiversity and aboveground productivity in forest ecosystems (Ali, Yan, Chang, Cheng, & Liu 2017; Prado-Junior *et al.* 2016; Wang *et al.* 2011; Zhang *et al.* 2017). On the other hand, soil characteristics are essential factors for driving plant species diversity in forest ecosystems (Petersen & Luxton, 1982; Enright, Miller, & Akhter, 2005; Hattenschwiler, 2005; Fujii *et al.* 2018). It has been reported that plant diversity has positive effects on the nutrient pools and ecosystem productivity (Midolo *et al.* 2018). Tree species have an essential role in protecting the soil Carbon (C) storage through the inputs of organic carbon and other nutrients via leaf litter decomposition (Prescott & Vesterdal, 2013; Kerdraon, Drewer, Castro, Wallwork, & Hall 2019). This process is an important driver for soil characteristics such as soil carbon content, nitrogen content, cation exchange capacity and pH in the forest topsoil layer (Augusto *et al.* 2015; Dawud *et al.* 2016; Bohara, Yadav, Dong, Cao, & Hu,

2019). Xiao, Chen, Kumar, Chen, & Guan, (2019) stated that tree species diversity affects the microenvironment conditions and litter decomposition rate as well as the chemical composition of the litter of overstory species which are an essential factor for the soil carbon and nitrogen content (Guendehou *et al.* 2014) and influencing the soil pH and nutrients (Eshaghi Rad, 2014; Lorenz & Thiele-Bruhn, 2019). Also, Bartels and Chen (2013) concluded that total nitrogen content, exchangeable phosphorus, and cation exchange capacity had a significant positive correlation with the composition of tree species in the overstory stratum. In this context, a significant positive correlation was demonstrated between tree species diversity and soil carbon content by Gamfeldt *et al.* (2013). Furthermore, Modabberi and Minaie (2014) indicated that the correlation between herb layers as well as tree layers and the organic matter was positive. Elsewhere, Yang *et al.* (2017) reported that soil carbon and nitrogen content in the forest topsoil layer had a positive effect on the herbaceous species. Kooch, Samadzadeh, & Hosseini (2017) demonstrated that tree species have a significant effect on litter quality and other soil physicochemical characteristics in the mixed stands. Bakhshandeh Navroud, Abrari Vajari and Kooch. (2018) illustrated a positive significant correlation between carbon content tree layer diversity in mature natural stands of eastern forests, and deciduous broadleaved forests that are mainly located in the northern hemisphere (Mestre, Toro-Manríquez, Huertas-Herrera, Martínez-Pastur, & Lencinas, 2017) where understory vegetation has a significant effect in these forests (Ampoorter, Baeten, Koricheva, Vanhellemont, & Verheyen, 2014). Hyrcanian forests were one of the most important refuges for the temperate deciduous broadleaved forests during Pleistocene glaciations (Ramezani, Mohadjer, Knapp, Ahmadi, & Joosten, 2008), they extend to the southern and south-western coasts of the Caspian Sea (Habashi & Waez-Mousavi, 2017). In these forests, oriental beech (*Fagus orientalis* Lipsky.) stands and hornbeam (*Carpinus betulus* L.) stands represent the greatest volume (Adel, Pourbabaei, Omid, & Dey, 2013).



OBJECTIVES

The aim of this investigation was to assess the effect of mixed beech and hornbeam stands on soil properties and plant species diversity in Hyrcanian forests which can be essential for forest ecologists and managers. Specifically, it was hypothesized that:

- 1) There is significant difference between mixed beech and hornbeam stands in terms of herb layer diversity indices.
- 2) Tree layer composition affects herb species composition and soil physico-chemical properties.

MATERIALS AND METHODOS

Study area

This investigation was conducted in Hyrcanian forests of northern Iran encompassing Dehga (mixed hornbeam stand) and Lakooon (beech stand) districts (Fig. 1). Two compartments were selected in Dehga district located in the southern part of Tonekabon city. (Longitude: 50° 52' 34"- 50° 75' 15"; Latitude: 36° 40' 15"- 36° 44' 25"). The average annual precipitation and temperature are 1188.6 mm and 15.2 °C, respectively. The elevation ranges from 300 m to 400 m. The dominant overstory species are hornbeam (*Carpinus betulus* L.), Persian ironwood (*Parrotia persica* (DC.) C.A. Mey.) Lilac persimmon (*Diospyros lotus* L.), Caucasian alder (*Alnus subcordata* C.A.Mey) and Caucasian wingnut (*Pterocarya fraxinifolia* (Lam.) spach in mixed hornbeam stands; Oriental beech (*Fagus orientalis* L.), hornbeam (*Carpinus betulus* L.), Persian maple (*Acer velutinum* Boiss.), Cappadocian maple (*Acer cappadocicum* Gled.) and Lime tree (*Tillia begonifolia* stev.) are dominant tree species in beech stands. Also, two compartments were selected in Lakobone district located in the western part of Nowshahr city. (Longitude: 51° 16' 15"- 51° 18' 50" and Latitude: 36° 36' 50"- 36° 40'). The average annual precipitation and temperature are 1093 mm and 12.3 °C, respectively. The elevation ranges from 800 m to 900 m. In addition to Oriental beech (*Fagus orientalis* Lipsky), the dominant tree species are Persian maple (*Acer velutinum* Boiss.), Cappadocian maple (*Acer cappadocicum* Gled.), hornbeam (*Carpinus betulus* L.) and Lime tree (*Tillia begonifolia* stev.).

Sampling strategy

For this study, sampled plots were established by a regular 100 m × 200 m grid (ten plots in each compartment). Percent cover of tree species was estimated by Braun-Blanquet scale in 400 m² plots. Also, in the centre of each main plot, a 100 m² (10 m × 10 m) subplot was set up to record herb species. Soil samples were taken from 0 cm – 10 cm and 10 cm -30 cm soil depth. For laboratory analysis, the soil samples were air-dried and passed through a 2 mm sieve. Some phisico-chemical soil properties were measured for both depths, including: soil texture (sand, silt, and clay) by the Bouyoucos hydrometer method, soil pH by pH meter, total nitrogen (N) using the Kjeldahl method and available phosphorus (mg/kg) by Olsen method. Further, exchangeable potassium (mg/kg) extracted by ammonium acetate 1 N was estimated using flame photometric method; organic carbon content (C) was measured using Walkley and Black method.



FIGURE 1. Location of studied area in Mazandaran Province, Northern Iran

Data analysis

The Kolmogorov- Smirnov test was applied to check the data normality, and Levene's test was applied to test the homogeneity of the data variance. T-test (normally distributed data) and Mann-Whitney U-test (not normally distributed data) were utilized to test the significant differences in the species richness, diversity, and evenness indices as well as soil properties between the mixed beech and mixed hornbeam stands. This analysis was conducted using SPSS 18. We employed cluster analysis to classify of samples based on the floristic composition data using a Sørensen distance measurement and flexible beta linkage method (Eshaghi Rad, 2014). Also, the detrended correspondence analysis (DCA) method was applied to assess the relationship between vegetation and environmental variables. Pearson correlation analysis was employed to evaluate the correlation between sample plot scores of DCA axes and environmental variables as well as species diversity indices.

The plant species diversity was estimated using species richness as number of species, Shannon-Wiener evenness, Shannon-Wiener diversity (H') and Simpson diversity. PC-ORD software was used for calculating diversity indices and multivariate analysis.

RESULTS

Some of the frequent species were *Acer velutinum*, *Carpinus betulus*, *Fagus orientalis*, *Hypericum androsaemum*, *Athyrium filix-femina*, *Asperula odorata* and *Solanum kieseritzkii* in the mixed beech stands and *Ilex aquifolium*, *Carpinus betulus*, *Parrotia persica*, *Asplenium adiantum-nigrum*, *Pteris cretica* and *Rubus hyrcanus* in the mixed hornbeam stands (Tables 1 and 2). The mean numbers of trees, basal areas, volume per hectare and DBH are provided in table 3 and 4. *Fagus orientalis* had the maximum number of trees (176.25 ha^{-1}), DBH (44.30 cm), basal area ($33.68 \text{ m}^2 \text{ ha}^{-1}$), and volume ($\text{m}^3 \text{ ha}^{-1}$) in the mixed beech stand. Also, the highest number of trees, basal area and volume per hectare belonged to *Carpinus betulus* trees in the mixed hornbeam stand.

TABLE 1. Relative frequency (%) of woody species in two stands (number of plots in which every species was recorded in relation to total number of plots* 100).

Species scientific name	Beech stand	Hornbeam stand
<i>Acer cappadocicum</i> Gled.	20	5
<i>Acer velutinum</i> Boiss.	70	0
<i>Ilex aquifolium</i> L.	0	100
<i>Alnus subcordata</i> C. A. Mey.	0	50
<i>Carpinus betulus</i> L.	65	75
<i>Diospyrus lotus</i> L.	0	45
<i>Fagus orientalis</i> Lipsky.	100	0
<i>Fagus orientalis</i> Lipsky	0	35
<i>Parrotia persica</i> (DC.) C.A. Mey.	0	95
<i>Hypericum androsaemum</i> L.	70	35
<i>Laurocerasus officinalis</i> Roemer	25	0
<i>Danae racemosa</i> (L.) Moench.	10	0
<i>Ruscus hyrcanus</i> Woron.	15	60
<i>Rhumnus frangula</i> L.	10	0
<i>Tillia begoniifolia</i> stev.	10	0



TABLE 2. Relative frequency (%) of herbaceous species in two mixed stands (number of plots in which every species was recorded in relation to total number of plots* 100).

Species scientific name	Beech stand	Hornbeam stand	Species scientific name	Beech stand	Hornbeam stand
<i>Acer cappadocicum</i> Gled.	15	5	<i>Lamium album</i> L.	5	5
<i>Acer velutinum</i> Boiss.	70	20	<i>Mespilus germanica</i> L.	0	20
<i>Asplenium adiantum-nigrum</i> L.	5	10	<i>Oplismenus hirtellus</i> (L.) P. Beauv	40	70
<i>Athyrium filix-femina</i> (L.) Roth	85	50	<i>Polystichum aculeatum</i> (L.) Roth	55	5
<i>Alnus subcordata</i> C.A. Mey	20	5	<i>Petasites hybridus</i> (L.) P. Gaertn	10	0
<i>Asperula odorata</i> L.	95	0	<i>Parrotia persica</i> C.A. Mey	0	65
<i>Carpinus betulus</i> L.	0	65	<i>Prunella vulgaris</i> L.	0	10
<i>Carex divulsa</i> Stokes.	55	70	<i>Pteris cretica</i> L.	20	75
<i>Carex remota</i> L.	0	25	<i>Primula heterochroma</i> Stapf.	25	50
<i>Clinopodium umbrosum</i> (M.B.) C. Koch	10	35	<i>Phyllitis scolopendrium</i> (L.) Newman	30	20
<i>Circaea lutetiana</i> L.	25	55	<i>Rubus hyrcanus</i> L.	15	60
<i>Cephalanthera caucasica</i> Kranz.	0	20	<i>Symphyandra odontosepala</i> (Bioss.) Esfandiari	10	0
<i>Cratagegus monogyna</i> Jacq.	5	65	<i>Stachys sylvatica</i> L.	50	0
<i>Dryopteris filix-mass</i> (L.) Schott	80	30	<i>Solanum kieseritzkii</i> C.A. Mey	100	45
<i>Diospyrus lotus</i> L.	5	10	<i>Sanicula europaea</i> L.	20	10
<i>Euphorbia amygdaloides</i> L.	85	70	<i>Tamus communis</i> L.	30	0
<i>Epimedium pinnatum</i> Fisch.	40	5	<i>Tillia begoniifolia</i> Stev.	25	0
<i>Fagus orientalis</i> Lipsky.	95	0	<i>Ulmus glabra</i> Hudson.	15	0
<i>Festuca drymeia</i> Mert. & Koch	25	0	<i>Vincetoxicum scandens</i> Sommier & Levier	20	0
<i>Fragaria vesca</i> L.	15	75	<i>Viola odorata</i> L.	75	90
<i>Gleditsia caspica</i> Desf.	0	20			
<i>Geranium robertianum</i> L.	70	0			
<i>Hedera helix</i> L.	30	60			

TABLE 3. Statistical parameters for dominant species in the mixed beech stand (Mean \pm standard deviation).

	Total stem number/ha	DBH (cm)	Basal area (m ² /ha)	Volume (m ³ /ha)
<i>Fagus orientalis</i>	176.25 (\pm 16.67)	44.30 (\pm 3.67)	33.68 (\pm 4.28)	464.69 (\pm 75.02)
<i>Carpinus betulus</i>	40.00 (\pm 10.48)	31.85 (\pm 4.04)	2.92 (\pm 0.69)	29.63 (\pm 7.58)
<i>Acer velutinum</i>	37.50 (\pm 8.79)	38.57 (\pm 5.82)	4.21 (\pm 1.10)	40.85 (\pm 9.45)
<i>Acer cappadocicum</i>	6.25 (\pm 4.00)	31.00 (\pm 7.55)	0.48 (\pm 0.30)	5.76 (\pm 3.79)
<i>Tilia begoniifolia</i>	3.75 (\pm 2.74)	17.50 (\pm 3.50)	0.11 (\pm 0.9)	1.19 (\pm 1.11)

TABLE 4. Statistical parameters for dominant species in mixed hornbeam stand (Mean \pm standard deviation).

	Total stem number (ha ⁻¹)	DBH (cm)	Basal area (m ² /ha)	Volume (m ³ /ha)
<i>Carpinus betulus</i>	136.25 (\pm 33.95)	40.66 (\pm 3.75)	14.59 (\pm 2.74)	161.80 (\pm 31.28)
<i>Qercus castanifolia</i>	13.75 (\pm 6.14)	70.50 (\pm 12.62)	4.78 (\pm 1.73)	57.64 (\pm 22.91)
<i>Alnus subcordata</i>	32.5 (\pm 11.49)	59.44 (\pm 3.67)	8.77 (\pm 3.47)	102.96 (\pm 40.36)
<i>Parrotia persica</i>	195.25 (\pm 30.60)	16.42 (\pm 0.83)	4.98 (\pm 0.92)	39.75 (\pm 7.10)
<i>Diospyrus lotus</i>	60.00 (\pm 22.83)	17.22 (\pm 0.82)	1.55 (\pm 0.59)	12.58 (\pm 4.84)
<i>Pterocaria fraxinifolia</i>	1.25 (\pm 1.25)	20.00 (\pm 0.00)	0.54 (\pm 0.04)	0.18 (\pm 0.18)

TABLE 5. Species diversity indices in the studied stands (Mean \pm standard deviation).

Diversity indices	Beech stand	Hornbeam stand	P- value
Species richness	19.15 \pm 3.51	17.05 \pm 4.23	0.096
Shannon winner Evenness	0.42 \pm 0.13	0.46 \pm 0.09	0.318
Shannon- Winner (H')	1.24 \pm 0.4	1.28 \pm 0.26	0.738
Simpson index	0.54 \pm 0.18	0.60 \pm 0.12	0.142

There were no significant differences in plant species diversity indices between beech and hornbeam stands (p -value < 0.05 based on Mann-Whitney test), (Table 5). Litter thicknesses and humus layers depth as well as the percentage of clay (in 0 cm - 10 cm depth) were significantly higher in the beech stand compared to hornbeam stand (Table 6). Further, hornbeam stands had higher means in organic carbon and total nitrogen (in 0 cm - 10 cm depth) along with percentage of sand in two depths compared to beech stands.

According to the diagram of cluster analysis, there are two distinct groups (Fig. 2). A total of 20 sampled plots of the mixed beech stand were considered as the first group and 20 sampled plots of the mixed hornbeam stand were regarded as the second group.

The result of DCA analysis clearly indicated that the thickness of the litter layers and humus, sand percent, total nitrogen, and organic carbon in the first layer could be

considered as effective and powerful environmental variables in the distribution of sample plots in the mixed beech stand and the mixed hornbeam stand (Fig. 3). There was no significant correlation between soil organic carbon content, total nitrogen, carbon to nitrogen ratio, exchangeable potassium, exchangeable phosphorus, or pH of second layer and DCA axis (Table 7).

Pearson correlation analysis revealed that the species richness index was significantly negatively correlated with the percentage of silt ($R = -0.346$, $P < 0.05$) and positively correlated with percentage of clay ($R = 0.331$) in first depth of soil (0 cm - 10 cm). There were no significant correlations between soil thickness of the litter layer, thickness of the humus of layer, organic carbon content, total nitrogen, carbon to nitrogen ratio, exchangeable potassium, exchangeable phosphorus, sand percentage, pH of both layers and silt, clay or percentage in the second layer on all diversity indices (Table 8).

Table 6. Soil variables in the studied stands (Mean \pm standard deviation).

Soil variables	Beech stands	Hornbeam stand	P- value
Litter (cm)	3.16 \pm 0.59	1.74 \pm 0.51	0.00*
Humus (cm)	4.08 \pm 1.77	0.55 \pm 1.78	0.00*
pH1	5.43 \pm 0.29	5.44 \pm 0.36	0.96
pH2	5.64 \pm 0.44	5.65 \pm 0.27	0.93
OC1 (%)	2.69 \pm 0.92	4.63 \pm 1.38	0.00*
OC2%	1.11 \pm 0.57	1.30 \pm 1.12	0.429
N1 (%)	0.27 \pm 0.094	0.46 \pm 0.13	0.00*
N2 (%)	0.12 \pm 0.05	0.13 \pm 0.11	0.383
C/N1	9.77 \pm 0.22	9.88 \pm 0.12	0.06
C/N2	9.23 \pm 0.52	9.26 \pm 0.45	0.87
K1 (Mg/kg)	179.1 \pm 62.48	215 \pm 50.28	0.05
K2 (Mg/kg)	174.30 \pm 90.19	152.95 \pm 61.2	0.698
PI (Mg/kg)	3.09 \pm 1.73	5.18 \pm 2.60	0.05
P2 (Mg/kg)	2.27 \pm 2.88	2.64 \pm 2.091	0.91
Clay1 (%)	30.75 \pm 7.84	20.85 \pm 3.34	0.00*
Clay2 (%)	40.80 \pm 8.53	38.85 \pm 9.26	0.49
Silt1 (%)	53.50 \pm 7.11	55.65 \pm 6.40	0.32
Silt2 (%)	46.15 \pm 7.13	42.70 \pm 9.54	0.231
Sand1 (%)	15.75 \pm 3.02	22.50 \pm 6.49	0.00*
Sand2 (%)	13.05 \pm 3.08	18.45 \pm 7.97	0.04*

OC: organic carbon content, N: total nitrogen, K: potassium, P: phosphorus, 1: soil depth at 0 cm - 10 cm (first layer), 2: soil depth at 10 cm - 30 cm (second layer). * p - value < 0.05

TABLE 7. Pearson correlation between DCA Axes and soil properties.

Soil variables	DCA1	DCA2
Litter (cm)	-0.826**	0.266
Humus (cm)	-0.659**	0.221
pH1	0.037	-0.113
pH2	0.013	0.133
OC1 (%)	0.650**	0.027
OC2%	0.137	0.149
N1 (%)	0.644**	0.038
N2 (%)	0.134	0.153
C/N1	0.335*	-0.186
C/N2	0.091	0.046
K1 (Mg/kg)	0.356*	0.014
K2 (Mg/kg)	-0.094	-0.037
PI (Mg/kg)	0.489**	-0.184
P2 (Mg/kg)	0.180	-0.111
Clay1 (%)	-0.615**	0.020
Clay2 (%)	-0.150	-0.370*
Silt1 (%)	0.096	0.079
Silt2 (%)	-0.195	0.491**
Sand1 (%)	0.652**	-0.109

OC: organic carbon content, N: total nitrogen, K: potassium, P: phosphorus, 1: soil depth at 0 cm - 10 cm (first layer), 2: soil depth at 10 cm - 30 cm (second layer). * p - value < 0.05, ** p - value < 0.01

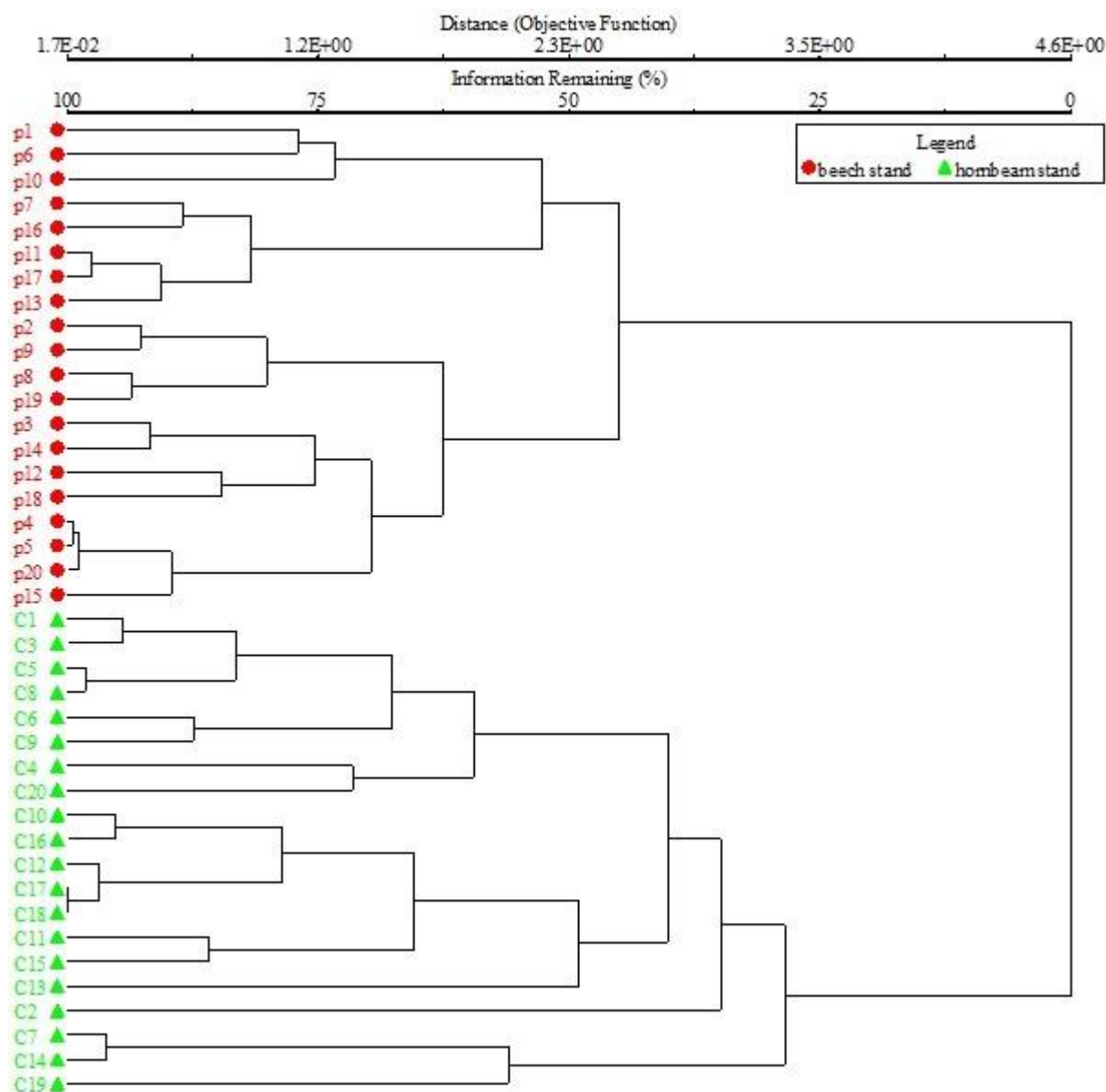


FIGURE 2. Diagram of cluster analysis on 40 sampled plots in the study area.

DISCUSSION

Our finding demonstrated that the overstory compositional dissimilarities in the mixed beech stand and mixed hornbeam stand had led to differences in the herb-layer vegetation, which is in line with the findings of Koojiman and Cammeraat (2010) in the Netherlands' forests. The composition of understory vegetation is influenced by tree species in the overstory stratum (Rawlik, Kasproicz, &

Jagodzinski, 2018; Dölle, Petritan, Biris, & Petritan, 2017). Gilliam *et al.* (2007) stated that the composition of the overstory layer directly or indirectly affects the understory species by changing light availability, moisture and soil fertility. Generally, the shade of trees is an impressive feature in reducing the understory light-demanding species (Marcos, Marcos, Taboada, & Tarrega, 2007; Marozas, Augustaitis, Armolaitis, Kliucius, & Pilkauskas, 2013). It



was proved that transmission of photosynthetically active rays (PAR) in the beech canopies was significantly lower than in canopies of other deciduous tree species. (Schmidt, 2005; Scolastri, Bricca, Cancellieri, & Cutini, 2017). We confirmed that this barrier had caused the establishment and development of shade-tolerant species in the understory vegetation in the mixed beech stands. Some shade-tolerant species which are adapted to low light condition such as *Mercurialis perennis* L., *Geranium robertianum* L., *Asperula odorata* L. were mainly observed with a high

frequency in the mixed beech stand. Indeed, the canopy cover of the beech species leads to low light infiltration into the forest floor, where the relative frequency of species such as *Carex remota* and *Clinnopus umbrosus* has decreased with increase in the ratio of the beech species in overstory layer. On the other hand, *Euphorbia amygdaloides* and *Festuca drymeia* which were light demanding species mainly occurred with a high frequency in the mixed hornbeam stands.

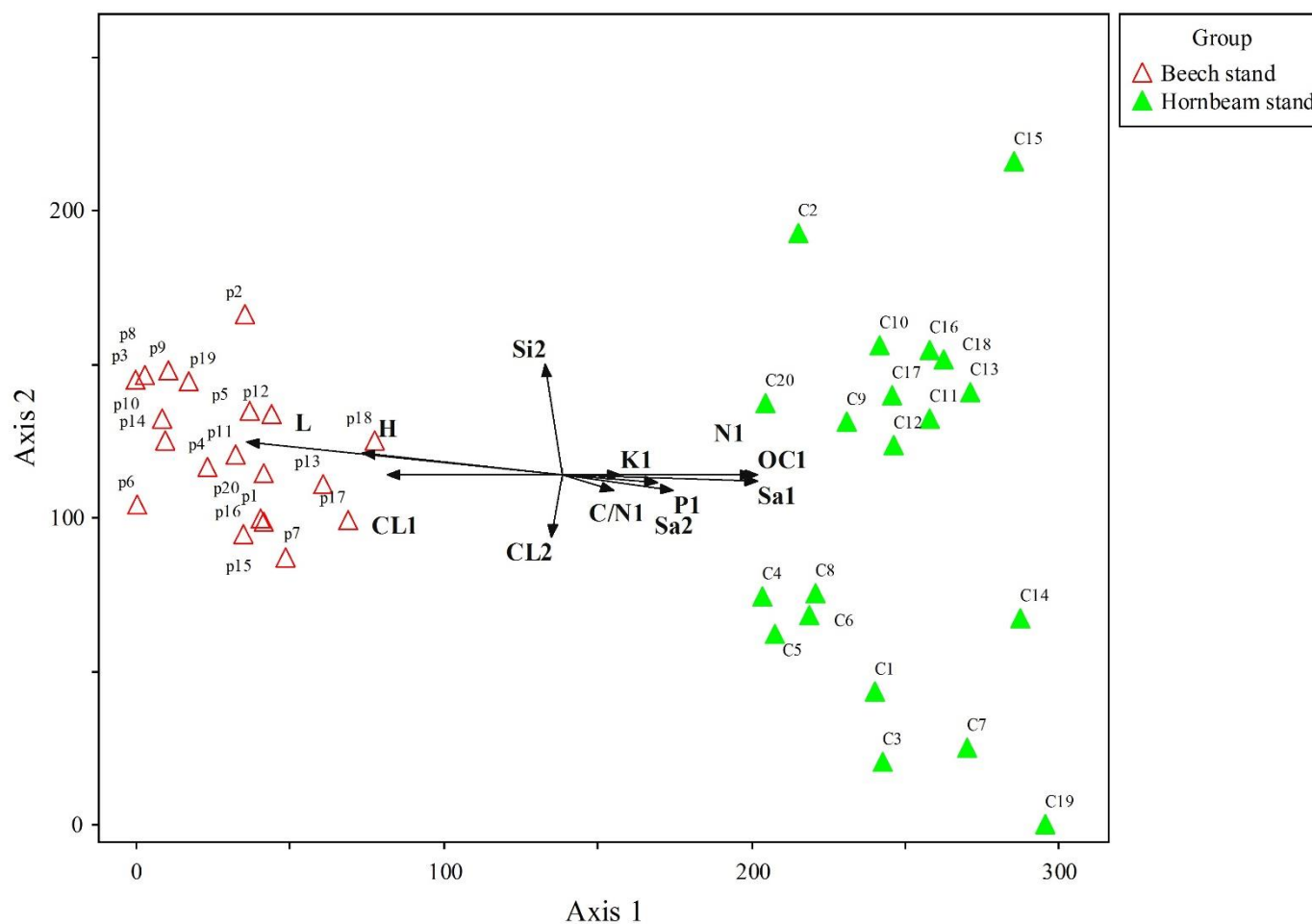


FIGURE 3. DCA ordination of herb layer species composition

TABLE 8. The Pearson correlation between soil variables, and the species diversity indices in the studied stand.

Soil variables	Species richness index	Evenness index	Shannon- Winner (H') index	Simpson index
Litter (cm)	0.150	0.109	0.172	0.009
Humus (cm)	0.068	-0.064	-0.014	-0.162
pH1	0.103	0.155	0.170	0.135
pH2	0.103	0.038	0.068	0.08
OC1 (%)	-0.203	0.152	0.044	0.158
OC2%	-0.284	0.032	0.036	0.039
N1 (%)	-0.200	0.155	0.047	0.159
N2 (%)	0.016	-0.029	0.037	0.038
C/N1	0.086	-0.106	-0.110	-0.053
C/N2	0.045	-0.025	0.011	0.001
K1 (Mg/kg)	0.027	0.260	0.252	0.292
K2 (Mg/kg)	0.027	0.171	0.174	0.091
P1 (Mg/kg)	-0.120	0.137	0.064	0.173
P2 (Mg/kg)	-0.190	0.165	0.218	0.202
Clay1 (%)	0.331*	-0.102	0.006	-0.103
Clay2 (%)	-0.042	-0.092	-0.101	-0.072
Silt1 (%)	-0.346*	0.016	-0.079	-0.039
Silt2 (%)	-0.005	0.152	0.155	0.100
Sand1 (%)	0.051	-0.073	-0.064	-0.032
Sand2 (%)	-0.037	0.108	0.077	0.167

OC: organic carbon content, N: total nitrogen, K: potassium, P: phosphorus, 1: soil depth at 0 cm - 10 cm (first layer), 2: soil depth at 10 cm - 30 cm (second layer). * p - value < 0.05, ** p - value < 0.01

In our study the thickness of the litter layer and humus, total soil nitrogen and organic carbon were the most important soil variables that caused the variations of the understory vegetation (Fig. 3). Kooch, Samadzadeh and Hosseini (2017) mentioned that structural differences in the tree canopy resulted in a difference in the quality of litter layer. The higher mean of the thickness of the litter layer in the beech stands is caused by of the slow process of chemical decomposition of the leaves of the beech (Jacob, Viedenz, Polle, & Thomas, 2010; Mölder, Bernhardt-Römerman, & Schmidt 2008) which has been addressed in some studies. Kooijman and Cammeraan (2010) recorded the highest thickness of litter layer in beech stands. Amini, Rahmani, and Habashi (2011) reported that one of the main

reasons for the slow decomposition litters of some species is the lack of leaves' nitrogen and phosphorus content for initiation of the activity of decomposition by microorganisms. Therefore, our findings suggested that in the mixed beech stand due to the low ratio of litter decomposition, release of nitrogen (Kooch, Sanji & Tabari, 2019) was lower than in the mixed hornbeam stand. Dölle *et al.* (2017) confirmed that there was a positive significant correlation between the thickness of litter layer and beech dominance in the overstory stratum in the European beech stand. Bakhshandeh Navroud *et al.* (2018) found that an increase in the beech frequency resulted in diminished soil carbon and nitrogen content. The correlation results showed that there was no significant correlation between



soil characteristics and diversity indices. Nevertheless, other researchers found that the biodiversity loss had a negative correlation with the amount of nitrogen, where higher nitrogen levels in the soil had a negative impact on local plant diversity (Midolo *et al.* 2018). The highest pH was recorded in the hornbeam stands in the research by Kooijman and Cammeraan (2010). A positive correlation between vegetation coverage and total soil phosphorus content was verified in Zhang *et al.* (2016) research. Vahder and Irmeler (2012) indicated that the positive effect of beech dominance for mitigating the pH in the upper layer (0-5 cm) is greater than that of underlying layers in the beech dominated stands. Generally, the mixed beech stands in Hyrcanian temperate forests have a greater ratio of carbon content than pure oriental beech. Differences in soil fertility can explain the differences of variation in species composition of beech and mixed hornbeam stands. In other words, changes in soil variables can be correlated to different tree compositions in the site (Bakhshandeh Navroud *et al.* 2018). Therefore, each of these stands supports their indicator species.

CONCLUSIONS

We found that tree layer composition and soil attributes were crucial drivers in variations of understory species composition which may be altered by forest management approaches or natural disturbances over time. So, tree layer composition and soil attributes can be considered effective factors for controlling and assessment of understory plant species composition. The mixed beech and hornbeam stands differed in soil physico-chemical properties and herbaceous composition in Hyrcanian forests. These findings could enhance our knowledge about tree layer-herb layer relationship (interaction) and provide guidelines to conserve plant species composition within any framework of sustainable forest management in Hyrcanian forests. For a complete analysis of the value for nature conservation we recommend (1) to include other taxa of plants and animals into the analysis, e.g. mammals, birds, fungi, and lichens (2) to include other criteria additionally to species richness and diversity into the evaluation for

nature conservation, e.g. naturalness, rarity and endangerment, and restorability.

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