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Environmental factors–ecological species group relationships in the Surash lowland-mountain forests in northern Iran

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Identification of the primary factors that influence the ecological distribution of species groups is important to managers of lowland-mountain forests in northern Iran. The aim of this study was to identify main ecological species groups, describe the site conditions associated with these species groups and the relationships between environmental factors and the distribution of ecological species groups using multi-variate analysis (Detrended correspondence analysis (DCA) and Canonical correspondence analysis (CCA)). For this purpose, 50 relevés (400 m^2 each) were sampled using the Braun-Blanquet method. Vegetation was classified into three ecological species groups using a modified two-way indicator species analysis (TWINSPAN). In each relevé, environmental factors (topographic and soil variables) were measured and analysed using one-way ANOVA and Pearson r statistics. Further, species diversity indices were determined for the identified ecological species groups. Our results show that the environmental factors, e.g. elevation, slope, slope aspect, soil texture, pH and organic matter, were the most important factors explaining the distribution of the three ecological species groups in the study area. The diversity of the ecological species groups decreased with elevation. The results provide an ecological basis for forest management and for developing strategies for forest conservation in the study area.

In ecological studies, vegetation composition data has commonly been used to detect relationships between environmental variables and plant species combinations, and to identify ecological species groups (White and Hood 2004). The use of ecological species groups, and the presence/absence or cover of their respective indicator species, facilitates developing management plans and proposing preferred practices for sustainable ecosystem management (Barnes 1982). Ecological studies evaluate consistent patterns in species-specific relationships with environmental variables, patterns that arise from species specific ecological demands. Further, data on ecological species groups can be used to infer site conditions, and for vegetation classification. Classification of species groups (plant communities) enables managers to detect the primary conditions affecting forest dynamics and identify those plant species that are best adapted to and desirable for that site (Hassanzad Navroodi et al. 2004). Once species groups have been characterized in an area, their occurrence in the field can be used for inferring soil properties and other variables that are relatively difficult to measure (Meilleur et al. 1992). One of the main attributes of forest ecosystems is the consistent assemblage of vegetation that is controlled by environmental variables such as climate, soil and topography (Stendhal et al. 2002). The effects of environmental variables such as soil on different plant communities have been the subject of many ecological studies (Pinto et al. 2006, Wang et al. 2012, Toure et al. 2015). Quantitative analyses of vegetation data, such as statistical classification and ordination, are important methods to generate and test hypotheses with respect to vegetation and its dependance on the environment (ter Braak and Šmilauer 2002, Zhang and Zhang 2007). These hypotheses have a practical value for estimating site conditions, and are tractable for refinement through experimental research with the aim of identifying the causal relationships between species and environmental conditions that determine species distributions (Pabst and Spies 1998).

The Hyrcanian forests forms a green insular belt surrounded by arid and semiarid ecosystems. It is located along the southern shores of the Caspian Sea on the northern slopes of the Alborz Mountains, northern Iran. The Hyrcanian forests provide a refuge for broad-leaved deciduous trees including Arcto–Tertiary relicts such as *Zelkova carpinifolia*, *Parrotia persica*, *Pterocarya fraxinifolia* and *Quercus castaneifolia*, and Asian subtropical trees such as *Gleditsia caspica* and *Albizia julibrissin* (Djamali et al. 2009). Recently, several studies relating vegetation and ecological species groups to environmental variables have been carried out within the Hyrcanian forests (Esmailzadeh and Hosseini 2007, Jalilvand et al. 2007, Kooch et al. 2007, Salehi et al. 2007, Naqinezhad et al. 2008, Eshaghi Rad and Banj Shafiei 2010, Kialashaki and Shabani 2010, Kooch 2011, Pourbabaei and

Haghgooy 2012, Naqinezhad et al. 2013, Pourbabaei and Abedi 2013, Adel et al. 2014, Bazdid Vahdati et al. 2014, Moradi et al. 2016). The present study aims to identify the main ecological species groups in the Surash forest as a pristine pilot study site in the western Hyrcanian area, based on TWINSPAN classification, and to evaluate the relationships between environmental factors (elevation, slope, aspect and soil variables) and ecological species groups using multivariate analyses (DCA and CCA). This study also evaluates how environmental factors affect the distribution of the ecological species groups.

Material and methods

Study area

We selected forests that were relatively pristine in nature, i.e. undisturbed by humans, within the Hyrcanian region for this study. The Surash forest is situated 25 km south of Lahijan (Gilan province), and elevation ranges between 250–1600 m a.s.l. (37°08′21.4″ – 37°08′26.1″N, 50°03′08.3″ – 50°02′06.2″E). The climate is very humid according to data from the Lahijan climatological station, the nearest to the study area, for the period 1985 to 2015. The mean total annual precipitation and mean annual temperature are 1284.5 mm and 18.6°C, respectively (Fig. 1). In a recent bioclimatic classification of Iran, the climate of the area is classified as temperate oceanic (Djamali et al. 2011).

Data collection

Vegetation analysis

The vegetation coverage was surveyed phytosociologically during 2011–2014 by the Braun-Blanquet method (Braun-Blanquet 1964, Mueller-Dombois and Ellenberg 1974), using the seven-degree scale (r, +, 1…5). A total of 50 relevés with an area of 400 m² were sampled.

Environmental analysis

Topographic variables (elevation, aspect and slope) were measured using GPS (Garmin, model Geko), Suunto compass and Suunto clinometers in each relevé, respectively. The aspect measured in degrees was transformed using the equation Cos (45-Aspect) + 1 (Beers et al. 1966). At each relevé, two soil samples were taken from the 0 to 10 and 10 to 30 cm depths of the mineral soil. Soil samples were air-dried and sieved with a 2 mm mesh before analysis. Soil texture (the proportions of sand, clay and silt) was determined by the hydrometer method (Bouyoucos 1951) and soil pH was measured electrometrically (Satorius Model PB-10, Germany). Soil organic matter and the proportion of $CaCO_3$ were estimated by Walkley and Black's and the Calcimetry method, respectively (Allison and Moodie 1965, Nelson and Sommers 1996).

Data analysis

A classification was performed using the modified TWINSPAN method (Roleček et al. 2009) embedded in the JUICE 7.0 program (Tichý 2002). Pseudo-species cut levels were set to 0, 5 and 25. Two relevés were selected as a minimum sample size from which to base group divisions. The fidelity of species to clusters and diagnostic species for vegetation units were calculated using the phi-coefficient, based on presence/absence data (Chytrý et al. 2002, Tichý and Chytrý 2006). A threshold value of phi = 0.25 was used (Illyés et al. 2007). Unconstrained ordination analysis (detrended correspondence analysis, DCA) and canonical correspondence analysis (CCA) were conducted using Canoco 4.5 for Windows (ter Braak and Šmilauer 2002) to find the axes with maximum variation of floristic composition and determine correlations between the species groups and the environmental variables, respectively (Lepš and Šmilauer 2003). A Monte Carlo permutation test based on 499 permutations was conducted to test the effect of these variables on species composition in the CCA.

Two indices were selected to estimate diversity: 1) species richness (SR), i.e. the total number of plant species recorded in each relevé (Timilsina et al. 2007), and 2) the Shannon Wiener Index of diversity $\left(H' = -\sum_{i=1}^{s} P_i \ln p_i \right)$ where: p_i is the relative cover of ith species and S is the total number of species in the sampled relevés (Pielou 1975). These indices were computed after transformation of the Braun-Blanquet scale values to percentage cover: r = 0.1%; 1 = 2.5%; 2 = 15.0%; 3 = 37.5%; 4 = 62.5%; 5 = 87.5% (Pyšek et al. 2004). The significance of the difference between environmental variable means among groups identified by TWINSPAN was analyzed by an one-way ANOVA, followed by the Tukey test. The Pearson r correlation coefficient was calculated to examine relationships between ordination scores for sites and the distribution of species and environmental variables. Scatter plots were used to show significant relationships between the studied variables. All diversity indices and statistical analyses were performed using Ecological Methodology (Krebs 1999) and SPSS for Windows, respectively.

Results

Classification of vegetation using modified TWINSPAN

The results of the modified TWINSPAN analysis showed three main groups of relevés at the first level of analysis (Table 1). Ecological species group I (15 relevés) was characterized by *Fagus orientalis*, which was the diagnostic and dominant species. This ecological group was confined to the upper mountain areas, between 1250–1600 m a.s.l., and was largely restricted to the northern aspects. Other diagnostic species of group I were *Rubus hirtus* Waldst. & Kit., *Mercurialis perennis* L., and *Salvia glutinosa* L.

Ecological species group II (19 relevés) occurred at elevations of 300–1050 m a.s.l.

Carpinus betulus L. was the indicator species of group II, and diagnostic understory species were *Oplismenus undulatifolius* (Ard.) P. Beauv., *Pteris cretica* L., and *Fragaria vesca* L.

Ecological species group III consisted of 16 relevés, where *Quercus castaneifolia* C. A. Mey. and *Buxus hyrcana* Pojark.

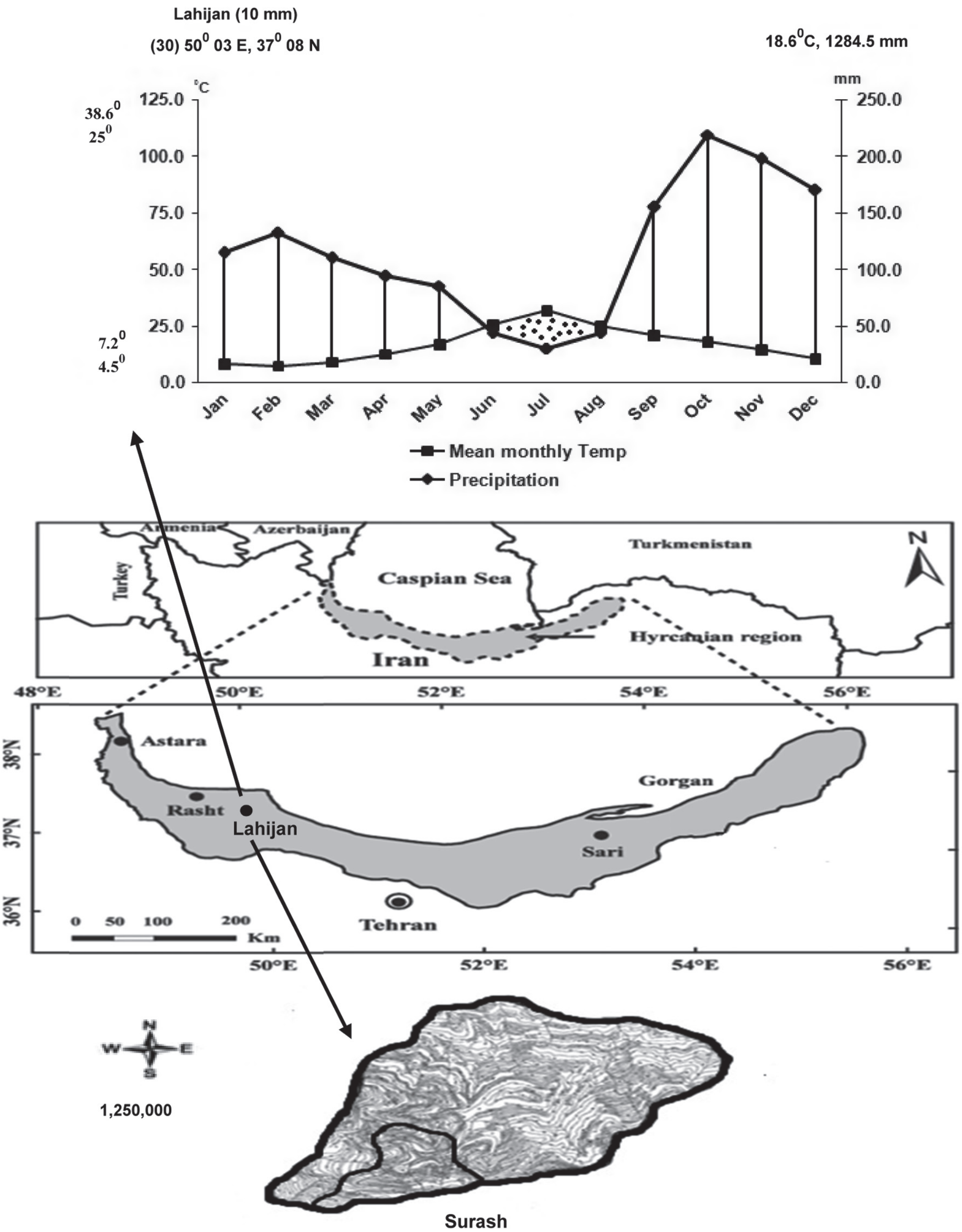

Figure 1. The location of the study site (Surash forest) in the Hyrcanian region and climatological diagram.

were identified as diagnostic and dominant species. This group had a distinctive floristic composition and occurred between elevations of 250–910 m a.s.l. The most important diagnostic woody and liana species of this group were *Parrotia persica* C. A. Mey., *Pterocarya fraxinifolia* (Poir.) Spach., *Hedera pastuchovii* Woronow and *Smilax excelsa* L.

Ecological species groups in relation to environmental parameters (DCA and CCA analysis)

A separation between the ecological species groups could be observed in the DCA analysis. The DCA analysis produced eigenvalues of 0.38 and 0.32 for the first two axes, respectively, explaining 14.9% of total species inertia. The longest gradient length was 3.8 SD. The first and second axes were highly correlated with the studied environmental variables ($r = 0.96$ for the first and $r = 0.94$ for the second axes). The first axis of the DCA ordination was strongly correlated ($p < 0.01$) with elevation, slope, proportions of sand, silt and clay, pH and species richness. The second axis was correlated ($p < 0.01$) with elevation, slope, aspect, proprtions of sand and clay, organic matter content, $CaCO_3$ content, Shannon-Wiener diversity and species richness (Table 3, Fig. 2). Many of the variables that were correlated with these

Table 1. Combined synoptic table of percentage frequency (constancy) and fidelity (phi coefficient × 100, upper indices). Only species with phi coefficient ≥ 0.25 (frequency and fidelity in bold) were considered as diagnostic species for specific vegetation groups, and species with frequency > 7 showed in the table.

Group number	I	II	III
No. of relevés	15	19	16
Fagus orientalis Lipsky.	**94**$^{72.7}$	35	.
Rubus hirtus Waldst. & Kit.	**81**$^{64.1}$	13	33$^{1.8}$
Mercurialis perennis L.	**68**$^{58.6}$	.	8
Salvia glutinosa L.	**62**^{525}	.	25
Sedum spurium M.Bieb.	**48**$^{44.5}$	.	8
Evonymus latifolia (L.) Mill.	**38**$^{31.5}$	.	.
Potentilla adscharica Sommier & Levier ex R. Keller.	**31**$^{29.3}$	8	.
Carpinus betulus L.	**56**$^{18.6}$	**65**$^{77.2}$	12
Oplismenus undulatifolius (Ard.) Roemer.	25	**74**$^{64.6}$	29
Pteris cretica L.	.	**61**$^{58.2}$	25
Fragaria vesca L.	12	**58**$^{56.3}$	8
Diospyrus lotus L.	.	**57**$^{48.8}$	8
Bromus japonicus Thunb.	12	**52**$^{42.4}$	.
Geum urbanum L.	.	**48**$^{41.8}$	8
Cystopteris fragilis var. *fragilis* Bernh.	19	**48**$^{38.4}$	8
Centaurea hyrcanica Bornm.	12	**43**$^{37.6}$	.
Viola caspia (Rupr.) Freyn subsp. *caspia*	.	**33**$^{37.4}$	8
Quercus castaneifolia C.A.Mey.	.	9	**79**$^{77.5}$
Buxus hyrcana Pojark.	.	.	**62**$^{72.5}$
Hedera pastuchovii Woronow.	.	**.**	**46**$^{60.1}$
Smilax excelsa L.	.	30$^{1.3}$	**58**$^{54.5}$
Parrotia persica (DC.) C.A.Mey.	12	.	**52**$^{48.4}$
Oxalis corniculata L.	19	22	**62**$^{42.0}$
Pterocarya fraxinifolia (Poir.) Spach.	.	9	**49**$^{35.2}$
Galanthus nivalis L.	.	.	**42**$^{38.6}$
Asplenium trichomanes L.	10	13	**42**$^{37.5}$
Fraxinus excelsior L.	10	.	**33**$^{35.0}$
Cardamine impetiense L. var *pectinata* (Pall) Trautv.	62$^{51.5}$	9$^{12.1}$	.
Veronica crista-galli Steven.	.	17$^{35.1}$	.
Polystichum lonchitis (L.) Roth.	.	17$^{35.1}$	.
Euphorbia stricta L.	.	22$^{33.0}$	8
Carex divulsa Stokes.	.	13$^{30.2}$	.
Thelypteris limbosperma (All) H. P. Fuchs.	.	13$^{30.2}$	.
Poa annua L.	.	26$^{28.6}$	.
Rumex pulcher subsp. *pulcher* L.	.	13$^{29.5}$	.
Rhynchocorys maxima Richter.	12	30$^{28.6}$	8
Parietaria officinalis L.	.	17$^{27.9}$	8
Fragaria viridis Duchesne.	.	26$^{27.9}$	12
Mespilus germanica L.	.	39$^{27.6}$	29$^{10.8}$
Athyrium filix - femina (L.) Roth.	12	35$^{26.3}$	12
Thelypteris palustris Schott.	.	35$^{51.2}$	.
Rubus caesius L.	10	22$^{25.2}$	8
Geranium robertianum L.	.	.	17$^{34.3}$
Polypodium vulgare L.	.	8	21$^{31.7}$
Ficus carica L.	.	8	21$^{31.7}$
Gleditsia caspica Desf.	.	13	29$^{30.7}$
Hypericum androsaemum L.	.	35$^{12.6}$	46$^{30.2}$
Pteridium aquilinum (L.) Kuhn.	12	23	.
Celtis australis L.	.	.	12$^{29.5}$
Galium odoratum Scop.	.	.	12$^{29.5}$
Mentha aquatica L.	.	.	12$^{29.5}$
Anagallis arvensis L.	10	.	21$^{29.1}$
Crocus caspius Fisch. & C.A.Mey.	10	.	21$^{29.1}$
Crataegus pseudomelanocarpa Popov ex Lincz.	10	22	38$^{26.8}$
Cyclamen coum Mill. var. *Caucasicum* (K.Koch) Meikle.	.	8	17$^{26.8}$
Albizia julibrissin Durazz.	.	8	17$^{26.8}$
Danae racemosa Moench.	10	.	17$^{24.0}$
Origanum vulgare L.	10	.	17$^{24.0}$
Centaurium pulchellum (Sw.) Druce.	12$^{21.5}$	.	.
Scabiosa sp.	12$^{19.5}$	.	.
Andrachne colchica Fisch. & C.A.Mey. ex Boiss.	.	.	8$^{23.9}$
Zelkova carpinifolia Dippel.	.	.	8$^{23.9}$

(Continued)

Table 1. (Continued)

Group number	I	II	III
Ulmus minor Mill.	$19^{36.5}$	.	.
Ajuga reptans L.	.	.	$8^{23.9}$
Vulpia myuros (L.) C.C.Gmel.	.	.	$8^{23.9}$
Alnus glutinosa (L.) Gaertn.	.	.	$8^{23.9}$
Crataegus microphylla K.Koch var. *dolichocarpa* K.Koch.	10	$39^{13.4}$	$46^{23.7}$
Phytolacca americana L.	$19^{6.5}$	8	$29^{21.9}$
Lindelofia kandavanensis Bornm. & Gauba.	$19^{2.5}$	.	.
Carex strigosa Huds.	$19^{21.5}$	.	.
Carex digitata L.	.	8	$12^{21.1}$
Clinopodium cf.*vulgare* L.	.	8	$12^{21.1}$
Thlaspi umbellatum Steven ex DC.	.	8	$12^{21.1}$
Chelidonium majus L.	.	8	$12^{21.1}$
Carex grioletii Roem.	.	9	$17^{20.9}$
Viola caspia subsp *sylvestroides* Marcussen.	.	9	$17^{20.9}$
Veronica persica Poir.	10	13	$25^{20.4}$
Geranium molle L.	$12^{6.6}$	.	$17^{16.6}$
Viola alba Besser.	$31^{19.6}$	.	$29^{15.9}$
Nasturtium officinale R.Br.	$31^{18.2}$	.	.
Plantago major L.	$19^{19.6}$	.	8
Primula heterochroma Stapf.	.	$39^{24.7}$	$33^{15.2}$
Solanum nigrum L.	10	8	$12^{12.7}$
Dryopteris affinis (Lowe) Fraser-Jenk.	$19^{8.2}$	8	$21^{12.4}$
Prunella vulgaris L.	$12^{3.0}$	8	$17^{12.3}$
Ornithogalum sintenisii Freyn.	$10^{4.6}$	.	$8^{11.4}$
Campanula latifolia L.	10	$13^{2.3}$	$17^{10.2}$
Hypericum perforatum L.	10	$13^{2.3}$	$17^{10.2}$
Dryopteris pallida Fomin.	.	$9^{9.2}$	$8^{8.1}$
Lamium album L.	.	$9^{9.2}$	$8^{8.1}$
Viola sintenisii W.Becker.	10	$35^{21.8}$	$25^{5.1}$
Rubus saxatilis L.	10	$13^{5.6}$	$12^{4.4}$
Polystichum woronowii Fomin.	.	$13^{16.3}$	$8^{3.3}$
Viola odorata L.	10	$30^{20.2}$	$21^{3.0}$
Ophioglossum vulgatum L.	10	$9^{2.5}$	$8^{1.5}$
Urtica dioica L. subsp *dioica*	10	$9^{2.5}$	$8^{1.5}$
Sambucus ebulus L.	10	$17^{11.6}$	$12^{1.0}$
Geum iranicum Khat.	10	$26^{18.7}$	17
Rubus persicus Boiss.	$12^{10.5}$	8	12
Potentilla reptans L.	12	13	12
Dryopteris filix - mas (L.) Schott.	12	13	12
Ranunculus arvensis L.	.	$9^{15.4}$	8
Pimpinella affinis Ledeb.	.	$9^{15.4}$	8
Rumex sanguineus L.	.	$17^{22.3}$	8
Poa nemoralis L.	.	$17^{22.3}$	8
Cornus australis C.A.Mey.	$19^{24.0}$	.	8
Scilla hohenackeri Fisch. & C.A.Mey.	10	$22^{17.1}$	12
Ruscus hyrcanus Woronow.	31	$57^{19.1}$	42
Circaea lutetiana L.	10	$13^{9.4}$	8
Carex remota L. subsp. *remota*	$10^{4.3}$	8	8
Thlaspi hastulatum Steven ex DC.	$10^{4.3}$	8	8
Dioscorea communis (L.) Caddick & Wilkin	$12^{6.3}$	9	8
Asperula taurina L.	$12^{21.4}$	.	8
Sanicula europaea L.	$12^{21.4}$	.	8
Amaranthus chlorostachys Willd.	.	$13^{22.2}$	8
Arum maculatum L.	$13^{19.6}$	.	8
Milium pedicellare (Bornm.) Roshev. ex Melderis.	10	$9^{6.7}$	8
Silene apetala Willd.	$12^{15.2}$	8	8
Asplenium scolopendrium L.	12	$26^{17.0}$	12
Stellaria media Cirillo.	19	$26^{12.5}$	12
Scutellaria tournefortii Benth.	.	$9^{24.4}$	.
Taraxacum sp.	.	$9^{24.4}$	.
Cerastium glomeratum Thuill.	.	$9^{24.4}$	.
Juncus acutus L.	.	$9^{24.4}$	.
Calystegia sylvestris Roem. & Schult.	19	$30^{17.3}$	12
Polystichum braunii (Spenner) Fee.	$10^{4.1}$	$9^{12.1}$	.
Solanum kiseritzckii C.A.Mey.	6	$17^{25.0}$	.
Willemetia tuberosa Fisch. & C.A.Mey ex DC.	$12^{10.1}$	$13^{11.5}$	.
Epimedium pinnatum Fisch.	$25^{3.9}$	$35^{20.4}$	8

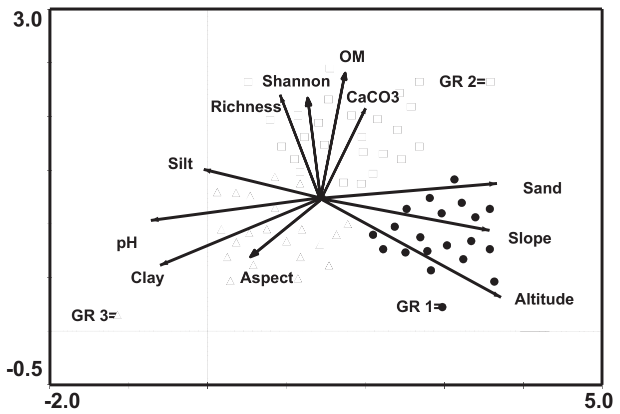

Figure 2. Ordination diagram showing the result of DCA analysis of ecological species group and environment variables in the study area. OM = organic matter.

two DCA axes were further strongly and significantly mutually correlated (Table 2, Fig. 3).

Forward selection with the Monte-Carlo permutation test ($p < 0.05$) indicated that elevation, slope, proportions of sand, clay and silt, organic matter content and pH were the significant variables, while $CaCO_3$ ($r > 0.95$, $p < 0.05$) was removed from the CCA analysis (Table 3, Fig. 3). Monte-Carlo tests on both the first canonical axis and all canonical axes were highly significant for all 499 permutations ($p = 0.002$) with 11.8% of the variation in species composition explained by the first two axes of the CCA ordination (eigenvalues 0.37 and 0.30 for first two axes, respectively). Moreover, 93% of total species–environment relationships were explained by the first two axes. The results of the CCA indicated that elevation, slope and sand content were the most important factors in the first group. Organic mater content was the most important factor in the second group, whereas clay, pH, silt and aspect were separation factors for the third group (Fig. 4). Three groups were evaluated in relation to the environmental factors, in which each environmental factor was an indicator of a specific site. We also examined by one-way ANOVA whether each of the three ecological species groups had a distinct set of characteristics. We found that all variables were significant according to the ANOVA used to compare values from each of the three ecological species groups (Table 4). The three ecological species groups were significantly different in their associations with soil and topographic factors. Elevation, slope and sand content were maximal in the first group. The highest level of organic matter, species richness and Shannon-Wiener diversity occurred in the second group, while the maximum content of silt and clay, and highest pH were associated with the third group.

Discussion

The TWINSPAN classification clearly described the distribution pattern of forest vegetation types in the study area and referred the vegetation into three distinctive ecological species groups. The distribution of these forest ecological species groups shows the comprehensive and consistent influence of environmental factors across the study region. The CCA ordination is a useful method for demonstrating the relationships between plant species and environmental gradients (ter Braak 1987). Using the environmental variables in the direct method (CCA analysis), the percentage variance explained by the first two axes (11.8%) was close to that explained by the first and second axes in the indirect method, DCA (14.9%). As a consequence, both ordinations displayed practically the same range vegetation variability.

The first ecological species group occurred at high elevations on steeper slopes with sandy soils. In the high forests of northern Iran, soil variables and topographic factors such as elevation and slope have been identified as being significantly related to the presence of plant species (Zarin Kafsh and Rezaee Kalantari 2006). Elevation is an important factor for vegetation distribution in mountains (Zhang and Dong 2010). Changes in elevation is associated with changes in humidity, temperature, soil type, and other factors that influence plant communities (Vittoz et al. 2010). Results of studies performed by Boll et al. (2005) demonstrated the role that slope has in determining the distribution of plant species. Ecological species group I occurred on the lightest soil texture, due to the a proportion of sand, and this affected vegetation distribution. Similarly, Ismaelzade et al. (2011) reported that the amount of sand was important for the development of different types of beech forests. Adel et al. (2014) identified elevation, slope and soil texture (clay, sand, silt) as the main factors affecting the distribution of beech communities in northern Iran. Ecological species group I,

Table 2. Pearson correlation matrix for variables measured in Surash forest.

Altitude	Altitude										
Slope	0.89**	Slope									
Aspect	0.50	0.10	Aspect								
Sand	0.92**	0.86**	0.05	Sand							
Silt	–0.82**	–0.85**	0.12	–0.80**	Silt						
Clay	–0.53**	–0.59**	0.28	–0.58**	0.67**	Clay					
OM	–0.10	0.09	–0.33**	–0.07	–0.09	–0.37**	OM				
$CaCO_3$	–0.06	–0.04*	–0.23	–0.05	0.04	–0.39**	0.30*	$CaCO_3$			
pH	–0.65**	–0.57**	0.24	–0.64**	0.69**	0.73**	–0.15	–0.35**	pH		
S	–0.34**	–0.28*	–0.01	–0.30*	0.25**	–0.05	0.50**	0.33*	0.09	S	
H′	–0.45**	–0.46**	–0.19	–0.39**	0.33**	0.14	0.33**	0.09	0.14	0.33**	H′

OM = organic matter; S = species richness; H′ = Shannon-Wiener diversity index. * $p < 0.05$, ** $p < 0.01$.

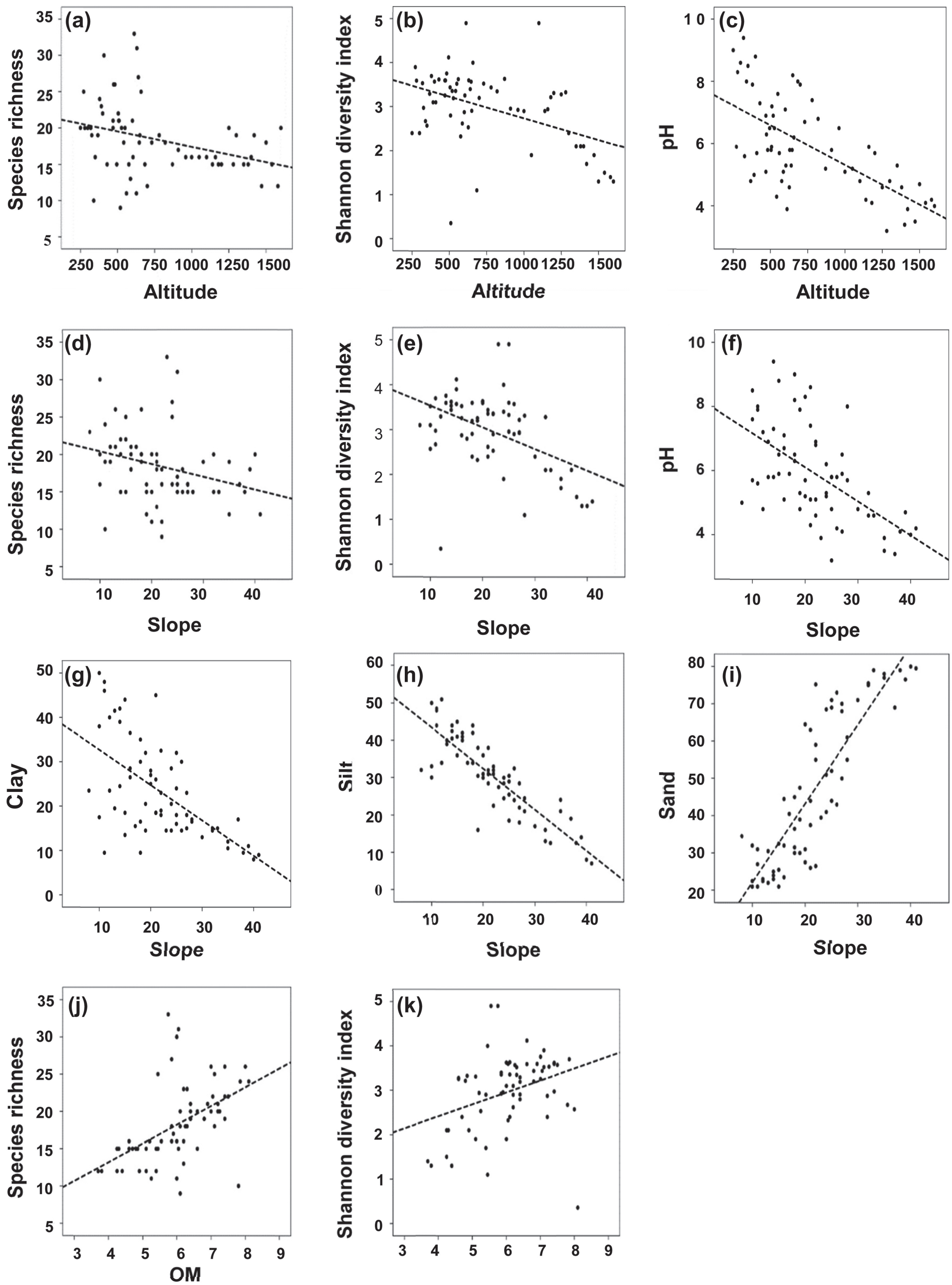

Figure 3. The relationship between altitude with (a) species richness (b) Shannon diversity index (c) pH; between slope with (d) species richness (e) Shannon diversity index (f) pH (g) clay (h) silt (i) sand and between OM with (j) species richness (k) Shannon diversity index. Values for R^2: (a) 0.11, $p < 0.01$, (b) 0.20, $p < 0.01$, (c) 0.43, $p < 0.01$, (d) 0.08, $p < 0.05$, (e) 0.21, $p < 0.01$, (f) 0.32, $p < 0.01$, (g) 0.35, $p < 0.01$, (h) 0.72, $p < 0.01$, (i) 0.74, $p < 0.01$, (j) 0.25, $p < 0.01$, (k) 0.11, $p < 0.01$.

with its indicator woody species *Fagus orientalis*, showed the lowest diversity indices, which is consistent with the results of Eshaghi Rad et al. (2009), Kialashaki and Shabani (2010) and Bazdid Vahdati et al. (2014). In this study, the relationships between elevation, slope and diversity indices were negative. Elevation is a key variable affecting species diver-

Table 3. Pearson correlation coefficients between each variable and the first two DCA and CCA axes. OM = organic matter, **p < 0.01.

Variables	DCA (axis1)	DCA (axis2)	CCA (axis1)	CCA (axis2)
Altitude (m)	0.79**	–0.53**	0.78**	–0.56**
Slope (°)	0.70**	–0.35**	0.75**	–0.37**
Aspect	–0.23	–0.22**	–0.24	–0.23**
Sand (%)	0.71**	–0.45**	0.70**	–0.47**
Silt (%)	–0.81**	0.20	–0.81**	0.23
Clay (%)	–0.79**	–0.26**	–0.80**	–0.25**
OM (%)	0.11	0.57**	0.12	0.59**
$CaCO_3$ (%)	0.22	0.54**		
pH	–0.82**	–0.01	–0.79**	–0.04
Species richness (R = S)	–0.34**	0.34**		
Shannon index (H′)	–0.18	0.32**		

sity in mountains, as has been established in numerous studies (Fetene et al. 2006, Muhumuza and Byarugaba 2009). Likewise, Fallahchai (2011) and Moradi et al. (2016) found a negative correlation between elevation above sea level and species richness in the Hyrcanian forests. The negative effects of slope on species diversity in the current investigation were obvious, which could be related to soil erosion, water drainage and unfavorable conditions for plant growth (Hall 1983). This is further confirmed by results obtained in other parts of the Hyrcanian forest (Hashemi 2010, Esmailzadeh et al. 2012). In addition, a positive correlation was observed between sand content and slope, which is consistent with the results of Weill and Sparovek (2008).

The second ecological species group, with its indicator woody species *Carpinus betulus*, had the highest species diversity and was characteristically found on soils with high amounts of organic matter. Likewise, Kavgaci et al. (2011) reported that species richness was high in *Carpinus betulus* dominated forests. Organic matter content is among the most important factors determining the distribution of the plant species. Eshaghi Rad et al. (2009) and Naqinezhad et al. (2013) found that organic matter content, in addition to P and K, are important factors delimiting ecological species groups in the Hyrcanian area. The relationship between soil organic matter and diversity indices was positive. The positive effects of organic matter in the soil include improving soil structure, increasing water holding capacity, and generally improving soil physical conditions (Hajizadeh 1990). Therefore, soils with sufficient amounts of organic matter are more fertile and provide more favorable conditions for plant growth, and support high plant diversity where ecological species group II occurs.

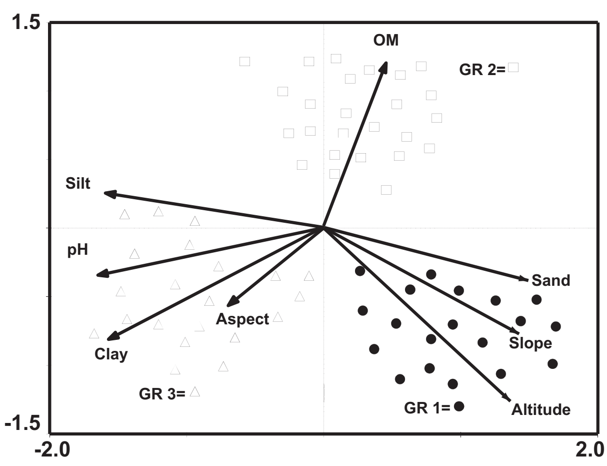

Figure 4. Ordination diagram showing the result of CCA analysis of ecological species group and environment variables in the study area.

Clay was one of the most important soil factors determining the occurrence of the third ecological species group. Other soil–site factors characteristic of this ecological species group were pH, silt content and aspect. The role of clay, as a key factor in the distribution of plant species, was described by Badano et al. (2005). Other researchers such as Zarei et al. (2010) and Naseri et al. (2009) proved that soil texture (proportions of clay, silt and sand) are one of the most important factors in determining plant distribution. Soil pH is also one of important variables in classification of ecological species groups (Taleshi 2004). Likewise, aspect has been shown to be an important factor for the distribution of ground vegetation (Olivero and Hix 1998). Aspect can affect the distribution of ecological groups through its influence on available water, light, soil temperature and moisture (Eshaghi Rad and Banj Shafiei 2010). Ecological species group III, with its indicator woody species *Quercus castaneifolia* and *Buxus hyrcanus*, tended to occur on more gentle slopes, at low elevation, and on north aspects that are moister. Likewise, this ecological species group had the highest clay and silt content, and pH. The negative correlations between clay and silt with slope in the current investigation were obvious. A mechanism for this relationship might be given by Beyrami et al. (2012) who reported that low slope areas were enriched in clay and silt as a result of rain-splash erosion. In the study area, the relationship between soil pH with slope and elevation was negative. A similar significant negative correlation between soil pH and elevation has been documented elsewhere (Naqinezhad et al. 2009). This negative correlation between pH and slope may be attributed to the accumulation of soluble cations. Also, Tsui et al. (2004) reported that foot slopes reduced the movement of soil water causing the accumulation of soluble cations, resulting in soils with higher pH. These results are consistent with the findings of Huggett (1975). Moreover, we found that in the study area, *Quercus–Buxus* forests (ecological species group III) had a relatively similar structure to lowland forests as shown by the occurrence of some common species e.g. *Albizia julibrissin*, *Gleditsia caspica*, *Pterocarya fraxinifolia*, *Hedera pastuchovii* and *Smilax excelsa*. *Buxus hyrcana*, is an endemic Hyrcanian shrub that grows on the coastal plain below 200 m a.s.l. (Zohary 1973). Mobayen and Tregubov (1970) reported that the *Querco–Buxetum* association occur in large communities in lowland areas. In contrast, *Carpinus–Fagus* forests (ecological species group I and II) are somewhat similar to submontane and montane deciduous forests because *Fagus orientalis* and *Carpinus betulus* are dominant in the montane and submontane zones of the Hyrcanian forests (Mobayen and Tregubov 1970, Asli and Nedialkov 1973).

The studied forest is habitat for some of the most endangered endemic plants, such as *Buxus hyrcana* and *Gleditsia*

Table 4. Summary statistics and p-values from ANOVAs of studied variables in different ecological species groups in the study area. OM = organic matter, Significant differences showed by different letters and the same letters are not statistically significantly different from each other at (**p < 0.01).

Variables	Group I Means (± SE)	Group II Means (± SE)	Group III Means (± SE)	p-value
Altitude (m)	$1344^{a} \pm 38.71$	$541^{b} \pm 30.86$	$574^{b} \pm 47.37$	0.001**
Slope (°)	$32.3^{a} \pm 0.23$	$18.4^{b} \pm 1.04$	$17.4^{b} \pm 1.06$	0.001**
Aspect	$1.26^{b} \pm 0.14$	$1.05^{b} \pm 0.12$	$1.06^{a} \pm 0.07$	0.002**
Sand (%)	$73.6^{a} \pm 1.26$	$37.8^{b} \pm 2.37$	$36.8^{b} \pm 3.30$	0.001**
Silt (%)	$27.2^{c} \pm 1.32$	$42.3^{b} \pm 1.37$	$48.2^{a} \pm 1.49$	0.001**
Clay (%)	$14.9^{b} \pm 1.33$	$19.0^{b} \pm 1.16$	$33.7^{a} \pm 2.00$	0.001**
OM (%)	$5.9^{b} \pm 0.26$	$7.1^{a} \pm 0.12$	$5.9^{b} \pm 0.22$	0.001**
$CaCO_3$ (%)	$2.8^{b} \pm 0.17$	$3.4^{a} \pm 0.20$	$2.3^{b} \pm 0.12$	0.001**
pH	$4.4^{c} \pm 0.18$	$5.4^{b} \pm 0.14$	$7.4^{a} \pm 0.23$	0.001*
Species richness (R = S)	$16.0^{b} \pm 0.58$	$20.5^{a} \pm 1.32$	$17.9^{ab} \pm 0.60$	0.009**
Shannon index (H′)	$2.4^{b} \pm 0.23$	$3.2^{a} \pm 0.12$	$3.0^{ab} \pm 0.17$	0.007**

caspica. In the study area, a major threat to *Buxus hyrcana* is cutting shrubs for economic purposes. Also, Schnabel and Krutovskii (2004) stated that habitat loss, fragmentation and hybridization with introduced species (*G. triacanthos*) have become major threats to *G. caspica*. We hope that understanding where the main plant species in this study occur in the landscape will be used as an ecological basis for the conservation of these distinctive communities. These endangered communities provide important ecological goods and services when they are of high ecological quality and properly functioning. In the study area, other threats to these habitats are damage and destruction resulting from of timber harvesting, livestock grazing, road building and forest land clearing for agriculture. Therefore, conservation strategies are seriously needed.

Conclusion

The ability to identify ecological species groups and understand the environmental relationships that underlie their occurrence in the landscape can be used to evaluate site conditions, assess the quality of current vegetation, identify priority sites for restoration and determine appropriate species for specific sites. Arekhi et al. (2010) reported that site conditions can be recognized across the landscape by observing plant species distributions. We believe that studies of ecological species groups provide a better understanding of vegetation–environment relationships. The results of this study showed that topographic and soil variables are useful in separating three ecological species groups, and revealed how these factors affect plant diversity. Ecological classification and grouping of forest habitats is important to forest management (Barnes 1982). Also, information about the distribution of plant species and communities can help forest managers to conserve forests in the Surash Forest Region.

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