Diversity and Gradient Analysis of Common Yew (*Taxus Baccata* L.) Communities in Eastern Hyrcanian Forests, Northern Iran

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Research

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Abstract

Aims: To outline syntaxonomical synthesis of yew (*Taxus baccata* L.) in the eastern of Hyrcanian forest and to identify their main environmental gradients.

Location: Jahan-Nama protected area (JNPA) as a unique yew population with heterogeneous floristically composition in the east of Hyrcanian forests, Northern Iran.

Methods: Vegetation units were classified using modified TWINSPAN and were translated into syntaxonomic system. Syntaxa were determined by re-arrangement of each relevé based on diagnostic species occurrences and expert knowledge with the aim to increase the floristic distinctiveness of vegetation units. Syntaxa were finally evaluated by diagnostic species and environmental parameters according to phi- values and ANOVA, respectively. DCA was used to visualize the dissimilarity of syntaxa and their relationships with the environmental factors. We also used species combination concept for determining diagnostic species in the second association.

Results: The classification of JNPA yew forests resulted in 6 Vegetation unites. These patterns were translated into four associations, two sub-associations and two variants. (Asso.1) *Fago orientalis-Taxetum baccatae* is found in northern aspects with lower slopes and higher soil depth; (Asso.2) *Aceri velutini-Taxetum baccatae* is occurring in the moderate but rocky slopes. Asso.1 and Asso.2 are the same in altitude and involving *Carpinus betulus* as a co-dominant. (Asso.3) *Carpino betuli-Carpino orientale-Taxetum baccatae* developed in the intermediate slopes. (Asso.4) *Carpino orientale -Taxetum baccatae* appeared in the highest slope of northeast and northwest aspects with shallow soil depth. The main factors determining the species composition of the JNPA syntaxa are slope, eastness, elevation and clay content.

Conclusions: Our study provides the first syntaxonomic of yew communities in east of Hyrcanian forests and it also used the concept of species combination for exploring diagnostic species for proposing *Carpino betuli- Carpino orientale- Taxetum baccatae* association. We also showed that yew could be associated with different plant species which are distributing in different site suitability. It caused to have various yew syntaxa in JNPA and considerably reiterate high floristically and ecologically capacity of this area.

Introduction

The Hyrcanian forests with a total area of 1.85 million ha and approximately 800 km long and 20–110 km width encompasses a variety of forest types ranging from sea level to the altitude of 2,800 m in the Northern slopes of Alborz Mountains (Marvi-Mohadjer, 2006). Hyrcanian forest is one of the relict patches of Euxino- Hyrcanian province in Euro-Siberian region from Holarctic kingdom and encompasses a variety of different temperate forest types. The high air humidity and the higher winter temperatures at lower altitudes make the greater part of this area most favorable for the mesic forest, not unlike those of western or southern Europe (Sagheb-Talebi et al., 2014). These types of forests are extraordinary rare partially represent the last relicts of the primary temperate broadleaf (Knapp, 2005). Broad-leave deciduous trees are the most outstanding feature of the Hyrcanian forests. Also, seven coniferous species including *Taxus baccata*, *Juniperus polycarpus*, *J. communis*, *J. Sabina*, *Thuja orientalis* and *Cupresus sempervirens are* presenting in limited sites of these forests.

Common yew, *Taxus baccata* L., is the only coniferous species that could distribute to the main Hyrcanian forest types. *Taxus baccata* is often individually scattered or consisting small populations in humid sites (i.e. with high air humidity, but not humid soils) of northern steep slopes as well as hillslopes of northern valleys throughout Hyrcanian mountainous forests but in much more humid sites of Hyrcanian forests it forms pure and mixed dense large populations such as: Afratakhteh (Esmailzadeh et al. 2005), Siah- rudbar (Lesani, 1999) and Jahn nama (Jafari and Akhani,2008) in Golestan province; Gazoo (Golabian et al. 2016), Vaz (Ahmadi et al. 2000), western and eastern parts of Haraz watershed (Hosseinzadeh and Esmailzadeh. 2017) in Mazandaran province; Dorfak (Rostami Shahraji et al. 2002) and Veisroud (Pourbabaei et al. 1998) in Guilan province in Iran. It also found in Arasbaran region as a western fragmented section of the main part of the Hyrcanian forests in the Azarbaijan province, Northwest of Iran (Ebady and Omidvar, 2011). The area of *Taxus baccata* pure stands in the aforesaid sites is usually exceeding 5–10 ha and even more than 20 ha in Poune-Aram as the main population in Siah- Rudbar (Lesani, 1999).

Taxus baccata distribution ability in the Hyrcanian forests similar to its global distribution is limited by low air saturation moisture at lower altitudes and by low temperatures as well as long drought on high altitudes. Highland Hyrcanian temperate forests are lacking the *T. baccata* because of establishing beyond the cloudy zone of Alborz mountain and vicinity to semi- dry climate of Irano-Turanian ecological zone. The maximum elevation range of *T. baccata* in northern Iran is limited up to 2000 m.a.s.l in Afrathakhteh protected yew area (Esmailzadeh et al. 2007). The main reasons for the yew decline in the Hyrcanian forest are human land- use, deforestation, anthropogenic firing, selective felling and browsing by herbivores. However, certain factors/parameters such as to high suitability of site conditions caused by influencing humid air masses raising from the Caspian Sea in the north and various topographical features, high fluctuation of topographical properties accompanying with high distance from rural communities which limits the accessibility of villagers and smuggler cause to some populations of this species have been preserved to date. However, most yew populations in the Europe are isolated and extremely limited area (Zitti et al. 2014; Thomas and Garcia-Martai, 2015). Phytosociological study in these intact areas gives substantial insights to the structure of yew communities and their ecological characteristics in the Hyrcanian forests.

Unfortunately, little is known about plant communities dominated by yew in the Hyrcanian forests. Sagheb-Talebi et al. (2014) demonstrated three yew associations including: *Lauroceraceto- Taxetum*; *Taxeto-Fagetum* and *Carpino-Taxetum* in the Hyrcanian forests. Phytosociological study of yew in the Afratakhteh protected area (in the eastern of the Hyrcany) revealed two association including *Capineto betuli- Taxetum baccatae* and *C. orientalis- Taxetum baccatae* with three sub-associations and two variants. It also emphasized that yew trees could be associated to various phtyo taxa such as *Danae racemosa*, *Ruscus hyrcanus* and *Ilex spicigera* in northern aspect with the higher site suitability and higher air moisture, while it is associated to *Colutea persica* and *Juniperus communis* and occasionally with *J. Sabina* as indicator of high altitude as well as high slopes with shallow soil in the Hyrcanian forests (Esmailzadeh et al. 2007). Recently, *Euonymo latifolii-Taxetum baccatae* (in the eastern part of the Hyrcanian forests) and the *Taxo baccatae-Fagetum orientalis* (in west and central parts of the Hyrcanian forests) as two associations with (co-)dominance of *Taxus baccata* were also reported (Gholizadeh et al. 2020). Spreading of yew populations along a variety of environmental gradients causes to various plant community of this species with different floristically and ecologically entities are formed in the Hyrcanian forests. Vegetation classification of yew communities in these forests with the aim to provide a reliable and more detailed understandings of yew associability as well as its ecological niches is necessitate. Jahan-nama protected area (JNPA) is one of the unique yew population with heterogeneous floristically composition in the east of Hyrcanian forests where *T. baccata* occurs in both scattered and pure types accompanying with Oriental beech (*Fagus orientalis* Lipsky), Chestnut-leaved oak (*Quercus castaneifolia* C.A.M.), Common hornbeam (*Carpinus betulus* L.), Iron wood (*Parrotia persica* L.), Persian maple (*Acer velutinum* Boiss.) and Cappadocian tree (*A. cappadocicum* Gled.). It also contributes with Oriental hornbeam (*Carpinus orientalis* L.) in steep slopes. In the present study, we are going to outline Phytosociological classification and ecology of yew populations in JNPA. We aimed to answer (1) what is syntaxonomical diversity of yew (*Taxus baccata* L.) in the eastern of Hyrcanian forest? and (2) which environmental gradients are correspond to the phytosociological syntaxa's differentiation?

Materials And Methods

Study Area

JNPA with an area of 38,340 ha. is located in the eastern parts of Alborz Mountains, between 36º 35' to 36º 42' northern latitudes and 54º 08' to 54º 36' eastern longitudes, with an altitude ranging from 800 to 3100 m.a.s.l (Jafari and Akhani, 2008). Common yew populations are extending in humid north- facing slopes in 1200 to 1700 m.a.s.l especially in Tarkat district. This area has been protected since 1973 (Kiabi and Ghaemi, 2001). Moreover, harsh topographical features that lead to difficult accessibility made JNPA yew populations relatively intact. The mean annual temperature is 17.7ºC and the mean annual precipitation is 618 mm. The soil of the area is categorized as Alfisols with sandy-loam to loamy texture and Mull humus (Jafari and Akhani, 2008).

Field surveys

The phytosociological survey was conducted by using Braun- Blanquet approach with emphasis on the representative stand concept in mid-June 2018, when it is expected that the most plant species are presented and fully developed in the study area. In total, 86 relevé with 400 m^2 area (Dengler et al. 2008) were selected in all types of yew populations. In order to include any possible change in floristically composition in JNPA yew populations, we created transects which were 400-m stretches systematically set along the altitudinal gradient and relevés were conducted whenever floristically or environmental (especially in topographical features) alteration was perceived. So we made releve´ subjectively in order to represent the maximum diversity of yew populations in the JNPA.

In each relevé, first geographical coordinates, elevation, aspect and slope inclination were recorded and then a list of all vascular plants was recorded and the canopy cover percentage of each species was visually estimated using a modification of the ordinal van der Maarel (1979) cover-abundance scale (0: absent, 1: 0-1, 2: 1-2.5, 3: 2.5-5, 4:5-12.5, 5:12.5-25, 6:25-50, 7:50-75, 8:75-100). Cover values of plant species that were estimated using different cover scales were transformed to mid- percentage values for each degree prior to analysis. Flora Iranica (Rechinger, 1963-2015) and flora of Iran (Assadi et al. 1988-2017) were used as the main source for identification and nomenclature of plants. We also provided a soil core sample from 0- 20 cm at the center of each relevé and the following soil parameters were determined. Texture of the sieved mineral soil was characterized by Bouyoucos hydrometer method (Bouyoucos, 1962); total organic carbon (OC) by Walkley and Black method (Allison 1975); total nitrogen (N) by Kjeldahl method (Bremner and Mulvaney 1982) and pH (soil:water ratio 1:2.5). Moreover, soil water content was measured by drying soil samples at 105 °C for 24 h. The aspect measured in degrees was transformed into Northness (Cos (A)+1) as a continuous north-south gradient or and Eastness (Sin (A)+1) which are continuous north-south and east-west gradients respectively. Where A is the Azimuth of the slope (Tavakoli et al. 2020).

Vegetation classification

The vegetation of the study area was classified by using a three steps approach. In the first, a modified TWINSPAN (two-way indicator species analysis; Hill 1979) algorithm (Rolecek et al. 2009) available in Juice program (Tichy, 2002) was applied. The pseudospecies cut levels were set to 0%, 1%, 2.5%, 5%, 12.5%, 25%, 50%, 75% and 100%. Species with less than five occurrences were excluded as suggested by Willner et al. (2017). The maximum number of division levels was five, and minimum group size for each division was four relevé. Total inertia was used as a measure of group heterogeneity (Rolecek et al. 2009). These resulted groups were considered as initial groups for the next step.

In the second step, indicator species of each initial groups were identified using group-equalized and presence-absence based phi coefficient of species- site group association (Tichy and Chytry, 2006). The number of relevé in the initial groups was equalized to 16.67% (1/k multiplied 100, k= 6 as the number on initial groups) of the entire data set. Only species with both a significant concentration in a target group (using Fisher exact test as a measure of significant at $p<0.05$) and a phi coefficient values≥ 0.3 were considered to be diagnostic (Chytry et al. 2002). Also constancy was calculated by dividing the number of occurrence of a species in the target site group to the number of sites that belongs to the site group.

In the final step, the diagnostic species of the initial groups were sorted in juice synoptic table and then exported to the Braun-Blanquet synoptic table. In the Braun- Blanquet hierarchical synoptic table, re-arrangement of each relevé to the final vegetation units were made based on diagnostic species occurrences and expert knowledge to achieve syntaxa that would be sufficiently homogeneous and ecologically interpretable as well as clearly floristically distinguishable, (Noorozi et al. 2014; Reczynska, 2015). Then, each final vegetation unit was considered as a target syntaxa (TSY) and subjected to diagnostic species analysis with the most closely allied syntaxa, i.e. the floristically closest syntaxa, as a reference groups (REF). This strategy is well known as context II in Decaceres et al. (2008), while initial group diagnostic species were analyzed within the context of a higher syntaxa, i.e. context I, as the most widely used strategy in the diagnostic species analysis. The difference between two mentioned contexts is that TSY was compared with the rest of the releve´s in the data set, which were taken as a single undivided group, were designated as REF in context I while in context II, comparison was made between syntaxa of the same hierarchical rank and belonging to the same syntaxa of the next hierarchical rank (Tsiripidis et al. 2009; Peinado et al. 2013). This criterion which corresponds to Dengler et al. (2005) requires that the determination of differential taxa being performed between syntaxa of the same hierarchical rank and belonging to the same syntaxa of the next hierarchical rank.

We also use species combination concept (Decaceres et al. 2012) whenever we were not normally able to determine the diagnostic species. In this case, the joint (i.e. simultaneous) occurrence of *C. betulus* and *C. orientalis* was considered as a combined (i.e. virtual) species and its fidelity to all syntaxa was assessed. To assess relative frequency of this combined species (*C. betulus* + *C. orientalis*) in a syntaxa, the number of relevé of that syntaxa where both C. *betulus* and *C. orientalis* occur is divided by the number of relevé that belong to that syntaxa. Phi fidelity of this combined species was also assessed based on its combined form frequency values in the TSY and REF syntaxa.

After the determination of diagnostic species in Braun-Blanquet syntaxa and followed by characterizing the character species (species indicated as diagnostic for a single vegetation unit) from differential species (those indicated as diagnostic for more than one syntaxa), associations as principal community units in Braun-Blanquet tabular hierarchical synthesis method were identified (Chytry and Tichy, 2003). Eventually the higher and lower syntaxa of association units were determined. The nomenclature of syntaxa were done using double names based on two frequent species, with the first one normally being highly diagnostic and the second one particularly dominant (Luther-Mosbach, et al. 2012) and it was also done according to the International Code of Phytosociological Nomenclature rules (Weber et al. 2000).

Environmental gradient analysis

Detrended Correspondence Analysis (DCA) was performed to illustrate the dissimilarity of syntaxa and their relationship to main environmental factors influencing their species composition, using the *decorana* function from the R package vegan (Oksanen et al. 2019). Relationships between first fourth DCA axis and environmental factors were determined using multiple regression by '*envfit*' function in '*vegan*' package. Species cover values were logarithmically transformed without down weighting of rare taxa to compress the high values and decrease the variability of the attribute (Nowak et al. 2017). Releve scores on each ordination axis were used as predictor variables, whereas soil and topographical properties as environmental factors were considered as responses. Then the coefficient of determination (R^2) was calculated to measure the proportion of variation explained by environmental variables. Environmental variables were plotted into DCA diagram only if they showed significant ($p<0.05$) multiple linear regressions with the first two DCA ordination axes.

Environmental differences between clusters at each step of division in Braun-Blanquet hierarchical syntax dendrogram were tested by the independent samples t test. The significance of differences in variables among the syntaxa was also tested with the one-way ANOVA and tukey post-hoc multiple comparisons. Normality for environmental variables was tested with the Shapiro-Wilk test and homogeneity (equality) of variance with Levene's test. Univariate statistics were derived by Minitab software 16.0 (http://www.minitab. com/).

Results

The results of modified TWINSPAN revealed that JNPA yew forests contain two major groups of (i) *T. baccata*- *Carpinusbetulus* (1-5) and (ii) *T. baccata*- *Carpinusorientalis* (6). At the next division, the first group was split into two sub groups including: with (1-2) and without (3, 4 and 5) oriental beech (*Fagusorientalis* Lipsky) whereas the second one was not divided. In overall, six ecological units (i.e. initial groups) were divided at fifth cut level (Fig. 3). These six initial group were considered to species-group association analysis (result were not reported) for determination of diagnostic species and then releve- group association was manually modified by emphasizing diagnostic species preferences in expert- based Braun-Blanquet tabular system and consequently finally six floristically and ecologically uniform syntaxa were defined (Fig. 4).

As in Braun-Blanquet synoptic table (Table 1) as well as syntaxa dendrogram are shown, yew forms two variants, five sub-associations, two associations and an alliance in the JNPA. Association of *C. betulus*, *Galiumodorata*, *Soloanumkiezeriski*, *Rubus hyrcanus, Polystichumaculeatum,Dryopyeris caucasica* and *Asplenimscolopendrium* as a differential species with syntaxa 1-5 cause to these community types were distinctively separated as *Carpinusbetulus-Taxusbaccata* communities from the syntaxa 6 at the first cut level of Braun-Blanquet syntaxa dendrogarm. *Carpinusbetulus-Taxusbaccata* communities in the second level of JNPA Braun-Blanquet syntaxa dendrogram is divided into two associations including and thus JNPA includes four associations:

(1) *Fago orientalis-Taxetumbaccatae* Esmailzadeh and Soofi 2020 ass. nov. hoc loco

Nomenclature type: relevé no. 1 in Table 2 (holotypus hoc loco designatus)

This association, co-dominated by Taxus baccata (with mean percentage cover of 50%), *Carpinusbetulus* (50%), *Fagusorientalis* (25%), *Tiliarubra* (20%), *Acercappadocicum* (15%) and *Quercus castaneifolia* (10%) in upper story and *Ilexspinigera* (50%) as an evergreen shrub in the understory. *Fagus orientalis,* and *Quercus castaneifolia* are differential species against the following three associations (Table 1). This association occurs in mesic sites in the easternmost range of oriental beech distribution in the Hyrcanian forests between 1250 and 1650 m a.s.l., mostly on north and northeast facing low (15-40%) slopes.

(2) *Aceri velutini-Taxetum baccatae* Esmailzadeh and Karami 2020 ass. nov. hoc loco

Nomenclature type: relevé no. 2 in Table 2 (holotypus hoc loco designatus)

This association, co-dominated by Taxus baccata (with mean percentage cover of 75%), *Tiliarubra* (20%), *Carpinusbetulus* (10%), *Acercappadocicum* (10%) and *Acer velutinum* (10%) in upper story and also with *Solanumkiezeritski* (10%), *Hedera pastuchovii* (5%) and *Ilexspinigera* (5%) as the most shrub in the understory. *Acer velutinum, Carex sylvatica, Circaalutetiana* and *Lamiumalbum* are the differential species in this association (Table 1). This association occurs in moderately mesic sites and mostly on northwest facing with moderate (40-75%) slopes between 1300 and 1650 m a.s.l.

(3) *Carpino betuli-Carpino orientale -Taxetumbaccatae* Esmailzadeh and Soofi 2020 ass. nov. hoc loco

Nomenclature type: relevé no. 3 in Table 2 (holotypus hoc loco designatus)

This association is distinctively characterized with the Asso.1 because of the absence of *F. orientalis* and *Quercuscastaneifolia* but the high frequency of simultaneous occurrence of *C.orientalis* and *C. betalus*. In order to better differentiation of this syntaxa with the sub-association 5 as another yew mixed stand with oriental hornbeam, we inevitably used species combination for exploring diagnostic species and nomenclature of this syntaxa to *Carpino betuli- Carpino orientale- Taxetumbaccatae*. Species combination of *C. betulus + C. orientalis* has shown high frequency and fidelity values to this association and so it is considered as character species in this syntaxa (table 1). This association is *dominated by Taxus baccata* (with mean percentage cover of 75%) and also co-dominated by *Tiliarubra* (25%), *Carpinusorientalis* (20%) and *Carpinusbetulus* (15%) as well as *Ilexspinigera* (15%) in the understory. This association is distributed between 1200 and 1700 m a.s.l., mostly on north or northeast facing slopes

(4) *Carpino orientale -Taxetumbaccatae* Esmailzadeh and Soofi 2020 ass. nov. hoc loco

Nomenclature type: relevé no. 4 in Table 2 (holotypus hoc loco designatus)

Mixed yew with oriental hornbeam stands, which has no *C.betulus* as the most frequent species in JNPA is the most outstanding of this association. *C. orientalis* is considered as the only characteristic species in this syntaxa. This association is distributed between 1300 and 1600 m a.s.l., mostly on northeast and northwest facing steep and rocky slopes. This association, co-dominated by *Taxus baccata* (75%) and *Carpinusorientalis* (50%) and it also constitutes continuously dense patches of *Ilexspinigera* (50%) in the understory.

Association 3 is divided into two sub-associations in the fourth level. *Carpino- Carpino- Taxetum sorbuetosum torminalis* Esmailzadeh and Soofi 2020 subass. nov. hoc loco (subass.1) and *Carpino- Carpino- Taxetum parrotietosum persicae* subass. nov. hoc loco (subass.2) are the subdivision of *Carpinobetuli- Carpinoorientale- Taxetumbaccatae* association which are characterized by higher altitude in subass.1 and instead higher slope in Subasso.2. *Sorbustorminalis* and *Polygonatumorientale* are as differential spices in subass.1 and *Parrotiapersica* is the only differential species in subass.2. Subasso.1 is extending from 1230-1660 m.a.s.l. altitudinal gradient. Higher altitude ranges with the mean elevation 1520 m.a.s.l. is characterized by *Euonymuseuropaeus* variant while *Juglansregia* is being diagnostic species at the lower altitude range (i.e. mean elevation of 1394 m.a.s.l.) of variant 2. *Juglansregia* as a multi-purposed indigenous tree species which is distributed individually in some part of the Hyrcanian forests, is occurring with high fidelity (78.9%) and more frequent (78%) with mean percentage cover of 10% (table 1) in the syntaxa 4 as variant 2. These two variants are also separated by the different preferentially of occurring *Carpinusbetulus* and *Carpinusorientalis* (table 1). Being higher altitude and higher slopes in variant 1 causes for decreasing of *Carpinusbetulus* frequency in this syntaxa compared with variant 2 but *Carpinusorientalis* as a tolerant species to the rocky slopes is more frequent in variant 1.

In order to visually compare environmental differences at each level of syntax dendrogram, significant factors responsible for particular binary cluster branching were indicated in the dendrogram (Fig. 5). Asso.4 is extending in steep slopes with a high percent of sand particles. Association 1 and 2 are occurring in lower slope but higher organic carbon in comparison Asso. 3. In this regard, Asso.1 is characterized from ass.2 by higher eastness, OC, sand and N but lower slope and silt content. Two subdivisions of asso.3 are characterized by the lower elevation and higher slope. Subasso.2 is extending in the sites with lower elevation but with the highest slopes in JNPA. On the contrary Subassoo. 1 is involving the sites with higher elevation but the lowest slopes. Two variants of asso.3 are characterized by elevation. Var.1 has higher altitude (mean 1520 m.a.s.l.) than var.2 (mean 1394 m.a.s.l.).

Multiple comparison of environmental variables revealed similar pattern (Fig. 6). Clay, pH and N were not significantly different among the JNPA Braun-Blanquet syntaxa. Multiple comparison of environmental variables revealed that JNPA syntaxa were significantly different in their relationship with soil and physiographic factors and these pattern were similar with binary cluster branching of environmental differences. Association 1 with the lowest slope but highest soil organic carbon is significantly different by the other syntaxa in JNPA. Subassoo.2 as the syntaxa 5 has the lowest elevation but syntaxa 3 as a variant 1 has the highest elevation. Association 4 with having the highest eastness but lowest northness is quietly different from other syntaxa.

Five environmental variables were significantly related to the first two DCA ordination axes (Table 3). These two axes are representing 25.3% of species composition variation in JNPA. Slope, clay (both of them negatively), northness and elevation (both of them positively) were associated to the first axis while eastness which was negatively correlated with both two first axes. The above mentioned variables were assessed as the main gradients in JNPA plant communities' differentiation (Fig. 7).

Discussion

Yew communities in JNPA benefit favorable ecological fitness and have been protected from anthropic factors as the main disappearance of many yew areas in the Hyrcanian forest similar to its European areas (Thomas and Polwart, 2003). Even though Afratakhteh and Siah-roudbar have been proposed as the most extensive old yew communities in the Hyrcanian forests, also JNPA yew stands can be introduced as the third ones. Occurring large yew populations (i.e. Afratakhteh, Siah-Roudbar and JNPA) in some area of the eastern parts of the Hyrcanian forests with the lower environmental suitability compared with the western parts of these forests (Sagheb-Talebi et al. 2014) indicate that yew forest attitude in the Hyrcanian forests have not been attributed to climate change. In this case our results are in contrast to Alavi et al. (2019). We also imply that JNPA yew communities because of long-term protection and away from rural have not been fragmented, whereas, some areas of Afratakhteh and Siah-roudbar are suffering by habitat fragmentation which is consequence of human activities (i.e. burning, logging, land use changes and grazing. Plant community classification of the yew in the JNPA is so necessary to achieve more details of yew ecological capabilities and to complete yew forest vegetation database in the Hyrcanian forests.

Our results allowed the development of 6 phyto syntaxa of yew communities in JNPA which considerably reiterate high floristically and ecologically capacity of this area and demonstrate that JNPA can be considered as unique yew forests as well as Afratakhteh yew reserved area (Esmailzadeh et al. 2007), in eastern of Hyrcanian forests. Although, Sagheb-Talebi et al. (2014) reported *Fago orientalis- Taxetum baccatae* as a high altitude yew community in the central and western part of Hyrcanian forests but for the first time, the current research indicated that associability of *Taxus baccata* and *Fagus orientalis* is also occurred in northern sites with low slope and high air humidity in JNPA as an eastern Hyrcanian forests. The *Taxo baccatae-Fagetum orientalis* belongs to the alliance *Solano kieseritzkii-Fagion orientalis*, was also accepted by Gholizadeh et al (2020). Although *Fago orientalis- Taxetum baccatae* Esmailzadeh and Soofi 2020 ass. nov. hoc loco association in JNPA is similar to the *Taxo baccatae-Fagetum orientalis* Gholizadeh, Naqinezhad et Chytrý 2020 as montane association in the western and central part of the Hyrcanian ecoregion but they are different in locality and the abundances of *Taxus baccata* as well as *Fagus orientalis* as co-dominant taxa. Since JNPA located in the eastern part of the Hyrcanian forests with lower annual precipitation comparison with the central and western parts of these forests, so the site quality for the establishment of *Fagus orientalis* is significantly decreased in the middle and highland forest belt in the Alborz mountain (northern Iran). Actually, *Fagus orientalis* is the dominant (high frequently and more abundance) taxa in the *Taxo –Fagetum* Gholizadeh, Naqinezhad et Chytrý 2020 association and *Taxus baccata* has the lower frequency as well as lower abundance. While, *Taxus baccata* is the most dominant and frequently tree species in the *Fago-Taxetum* association whereas *Fagus orientalis* occurs with the lower frequency or dominance. The lack of *Prunus laurocerasus* as the mesic indicator species which has fidelity with *Taxo –Fagetum* Gholizadeh, Naqinezhad et Chytrý 2020 association in the JNPA implies that the association of *Taxus baccata* and *Fagus orientalis* in the eastern Hyrcanian forests differs from central and western parts of these forests.

Aceri velutini-Taxetum baccatae similarly to *Fago orientalis- Taxetum baccatae* due to occurring in the moderate slope is involved *Carpinus betulus* as a co-dominant tree in the upper story and absent of *Carpinus orientalis*. Indeed, these two associations are quite different by other four syntaxa in the JNPA which are compromised by *Carpinus orientalis*. However, Asso.1 and Asso.2 are the same in altitude but having differences in slope and aspect, higher slope with northwest facing slopes in Asso.2 whereas Asso.1 occurs in lower with north or northeast facing slopes (Fig. 6), accompanying being rocky slopes in Asso.2 caused to *Fagus orientalis* and *Quercus castaneifolia*, which are mainly driven by suitable air humidity and soil layer depth respectively (Marvi-Mohadjer, 2006), are unable to developing in the Asso.2. Lack of *Fagus orientalis* and *Quercus castaneifolia* along with decreasing of *Carpinus betulus* dominance are providing the occurrence of *Acer velutinum* as a tolerant tree species to rocky slopes. *Acer velutinum* and *Alnus subcordata* are the most pioneer tree species in the Hyrcanian forests which are capable individually occurring in the climax stage (Sagheb-Talebi et al., 2014). So, the present study reiterates that *Acer velutinum* could be associated with *Taxus baccata* and constitute a unique association representing mesic yew sites but with rocky slopes and shallow soil.

Carpino orientale -Taxetum baccatae Esmailzadeh and Soofi 2020 ass. nov. hoc loco which is representative of steep slopes with shallow soil and low air humidity of northeastern as well as northwestern aspects (apart from northern slopes) in the JNPA was also reported on calcareous rocky slopes in Afratakhteh yew reserved area in Golestan province as an eastern Hyrcanian forests (Esmailzadeh et al. 2007). Although, this association is characterized by *Centaurea hyrcanica, Jniperus communis, Lathyrus cyaneus, Vicia crocea, Berbris vulgaris, Acer platanoides* and *Colutea buhesi* as differential species in Afratakhteh yew reserved area but none of them did not occur in the JNPA. Higher elevational ranges as well as occurring on the eastern longitudinal gradients, which both of them limit the availability of humidity, are the main causes for the presence of these drought tolerant and the upper mountain Hyrcanian forests diagnostic species in the *Carpino orientale -Taxetum baccatae* in Afratakhteh. Highest elevational ranges of this association in Afratakhteh is to 2100 m a.s.l. while it limited to 1600 m a.s.l. in JNPA. The less site suitability (i.e. high slopes with west aspects and low soil layer depth) in syntaxa 6 prevents the development of *Carpinus betulus* as the most frequent species in the other JNPA syntaxa and so it is replaced by *C. orientalis* as a low demanding tree species in this syntaxa. High accurrencing of *Carpinus orientalis* and also lack of *Carpinus betulus* differentiated this syntaxa from other yew syntaxa (i.e. syntaxa 1 to 5) in JNPA. *Carpinus betulus* is a tall arboreal element of temperate forest growing on relatively deep soil but *Carpinus orientalis* prefer open steep places with almost thin layer of soil.

Associability of *C. betulus, Galium odorata, Solanum kiezeritski, Rubus hyrcanus, Polystichum aculeatum, Dryopteris caucasica* and *Asplenium scolopendrium*, to the syntaxa 1–5 at the higher rank of JNPA yew syntaxa implies these units can be assigned to *Carpino betuli- Taxion baccatae* alliance. This alliance with asso.4 due to having similar constant species, i.e. *Taxus baccata*, *Salvia glutinosa*, *Euphorbia amygdaloides*, *Carex divulsa*, *Acer cappadocicum*, *Hedera pastochovii*, *Ilex spicigera*, *Viola alba*, *Sanicula europea*, *Festuca drymeja* and *Dannae racemose* (only species with frequency more than 50 is listed), could be classified in *Salvia glutinosae- Taxentalia baccatae* as a sub order syntaxa. Our field observations in yew tree stands in the Hyrcanian forests imply that S. *glutinosa* has low frequency in the western and central parts of Hyrcanian forests but this species is more frequent in eastern Hyrcanian forests, the same as all of the JNPA yew syntaxa. Therefor it is expectable to introduce *Salvia glutinosae- Taxentalia baccatae* as a new yew syntaxa in the eastern Hyrcanian forests. However, additional information and also supplementary floristically composition data of yew relevé which would be made in the western and central Hyrcanian forests is necessary to confirm this hypothesis. These two higher ranks of yew communities have not been reported from Hyrcanian forests yet.

Carpino betuli- Carpino orientale- taxetum baccatae has been recorded as a new yew syntaxa in the Hyrcanian forests. This syntaxa is easily distinguishable in the field by using species combination of *C. betulus + C. orientalis* as a compound diagnostic species. Determination algorithm of indicator species combination was developed based on the joint occurrences of several species (two species in this paper) in a site group, in order to remove the problem in the case of the list of indicator species for that site group is empty, even if this site group has a distinct community composition and it is clearly differentiated from other groups (DeCaceres et al. 2012). So in the present study, exploration of association 3 only can be performed by the concept of diagnostic species combination. Because, calculating of traditional diagnostic species analysis did not resulted in any characteristic species in this association. Defining Asso. 3 is provided by combining of *C. betulus* and *C. orientalis* as a characteristic species with high frequency and high fidelity values in this syntaxa.

Proposing *Carpino betuli-Carpino orientale-Taxetum baccatae* for nomenclature syntaxa 3 by using two species with quietly contrasting habitat ecology may be challenging. *Carpinus betulus* is the most frequently tree species with the high distribution area in the Hyrcanian forests growing on relatively deep soil from lowland with zero elevation a.s.l to the elevation of 2000–2300 m a.s.l. (Marvi Mohadjer, 2005). *Carpinus orientalis* is a co-dominated tree species in the *Carpino orientale- Quercetum macranterae* association (Sagheb-talebi et al. 2014) and in the *Centaureo hyrcanicae-Carpinetum orientalis* Gholizadeh, Naqinezhad et Chytrý 2020 association (Gholizadeh et al, 2020) at the highest elevational forest zone (2000–2300 or to 2800 m a.s.l) with steep slopes and almost thin layer of soil in the Hyrcanian region. *C. orientalis* is also occurring in the steep slopes of the lower elevational zone in the Hyrcanian forests (Gholizadeh et al, 2020). It is specially extending in the western or eastern facing hillslope of north-sought deep valleys which are being steep slopes with shallow soil and rocky outcrops. This kind of land terrain lead to forming *C. orientalis* communities which are surrounded by *C. betulus* forest types in the lower elevational zone of the Hyrcanian forests. Although, these two *Carpinus* species are involving different ecological niches but fluctuating of hillslopes azimuth in these valleys from east to northeast as well as from west to northwest improve the air humidity of sites and the favor condition for occurring of *C. betulus* is available. So, *C. betulus* and *C. orientalis* co-occur in the northwest and northeast facing steep hillslopes and consequently a specific pattern of forest community type between *C. betulus* and *C. orientalis* is formed. Increasing slope limit the abundance of *C. betulus* but the higher northness is providing the more desirability of *C. betulus* and also limiting the *C. orientalis* because of being the lower competition power caused by being lower tree height. This property capable *C. betulus* and *C. orientalis* to co-occur in northwest and northeast facing steep slopes by sharing the available resources, however, their ecological niche is quietly different. Associability of *Taxus baccata* with this communalized forest type in the syntaxa 3 as well as the lack of diagnostic species in this syntaxa caused to use species combination concept to nomenclature of this association. Nomenclature of a syntax with 3 taxa was also used by Walter (1985) for separation of *Carpino- Querceto- Pinnatum* association from *Querceto- Pinnatum* and *Querceto- Carpinetum* as the two typical oak communities in Eastern Europe.

We differentiate *Parrotio persicae- Taxetosum baccatae* and *Sorbo torminalis- Taxetosum baccatae* as two sub-associations of *Carpino- Carpino- Taxetum* association which have significant difference in elevation and slope variables. *Parrotietosum persicae* occurs in the sites with the lowest elevation but the steepest slopes in JNPA and it can be distinguished with the other yew communities by high frequency and abundant of *Parrotia persica* as a differential species. In contrast, *Sorboetosum torminalis* sub-association due to occurring in the higher elevation and lower slopes can be differentiated with *Parrotietosum persicae* sub-association, as the most floristically closest syntaxon in JNPA. *Sorbus torminalis* and *Polygonatum orientale* as an indicator of northern slopes with high air humidity in Hyrcanian mountainous forests (Esmailzadeh et al. 2011) are presented in this syntax. This implies that subasso.1 has the highest air humidity, which provides suitable sites for development of yew trees. Field observations indicated that yew trees in this syntax form the denser stand with more height and more diameter sizes rather than other JNPA syntax.

Suitable site conditions of *Sorbo torminalis- Taxetosum baccatae* sub-association and its proximity to the Tarkat as a summer grazing zone in JNPA in the late of 19th century might lead to spreading *Juglans regia* to some part of this syntaxa. Developing of *J. regia* especially in the lower part of this syntaxa is so conspicuous that we can differentiate the variant of *J. regia* as a distinct yew community in JNPA. V*ariant 2 is unique because of spreading Juglans regia and its associability by Taxus baccata.* Our field observations surprisingly showed that most yew regeneration is happening in this syntax. It might be due to high air humidity of this syntax as well as light crown of *J. regia* which permits supplying light for seed germination and seedlings rehabilitation of yew trees.

The next variant of *Sorbo torminalis- Taxetosum baccatae* sub-association, *Euonymus europaeus*, is distributing in the higher elevation as well as higher slopes of this syntax. *Northern faced rocky slopes in syntaxa 3 as variant 1 is suppling favorite site desirability for occurring Euonymus europaeus as a high demanding of sunlight as well as air humidity diagnostic species. Availability of sufficient light caused by decreasing the abundances of dominance tree layer in rocky slopes with shallow soil and being mesic site could be due to exposure the northern faced slopes of this variant to the raised moist air from Caspian Sea.* In this variant, rocky outcrops are relatively prevalent however high air humidity because of facing of this syntax to northern foggy air and desirable seed releasing of yew tree by birds which nestle in the rocks is caused to yew trees could be established in the rock- ribbed lands. Supporting of yew seedlings establishment in a humid rocky terrain due to possible attraction of more seed dispersers, higher light availability and protection from damage by herbivores was also reported by (Vencurik et al. 2019). The ability of yew distribution in steep slopes and rocky terrin was also reported by Piovesan et al (2009). Frequently occurring of *Asplenium scolopendrium* in this syntax is also reiterating high air moisture. *These two variants not only constitute two distinctively sub-divisions of sub-asso3, they also are unique due to higher regeneration of the yew trees compared with the other syntaxa. This property could be important for conservation planning in the JNPA.*

Conclusions

Our results showed that yew could be associated with various plant species which occur in the sites with different suitability and ecological attitudes. This adeptness of yew causes to have various yew syntaxa in JNPA and considerably infers high floristically and ecologically capacity of this area. It forms *Fago- Taxetum* in northern aspect with lower slopes and higher soil depth while *C. orientalis* and forms *C. orientale- Taxetosum* syntaxa is associated with appearing in the high slope of northeast and northwest hill slopes with lower soil depth. Moreover, it forms *Carpino betuli- Carpino orientale- Taxetum baccatae* in the intermediate slopes. Eventually, it can be concluded that yew has high adaptability with broad ecological amplitude.

Abbreviations

JNPA = Jahan-Nama Protected Area; TWINSPAN= Two Way Indicator Species Analysis; DCA= Detrended Correspondence Analysis; Asso.= Association; Subasso.= Sub-association; Var.= Variant; ANOVA= Analysis of Variance.

Declarations

Ethics approval and consent to participate

The authors declared that the present research has been done following all local, national or international guidelines and legislations.

Consent for publication

Not applicable.

Availability of data and materials

The data will be presented in Hyrcanian forest vegetation database.

Competing of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author contributions

Omid Esmailzadeh as project administrator and supervisor of the research and manuscript editing had designed the early framework of the research. Meysam Soofi and Pari Karami conducted the field sampling and also analyzed the data and wrote the first draft. The final manuscript is revised and approved by all of the authors.

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Tables

Table 1

Braun-Blanquet synoptic table of JNPA yew communities including alliance (All.), association (Asso.), sub-association (Subasso.) and variant (Var.) with percentage values of species frequencies and fidelities. Fidelity was computed using the phi coefficient and context II (phi coefficient × 100 and only shown when positive). Phi fidelity measures of all species along with their relative frequency or constancy were shown in power format (constancy is in the base and fidelity is in the power) in the synoptic table. Dots in the table indicate species absence and grey shade values indicates significant fidelity at $p < 0.05$ (light gray); $p < 0.01$ (medium gray) and $p < 0.001$ (dark gray). Diagnostic species are those with phi > 0.3 and significant at least at $p < 0.05$ is underlined in the table.

	Higher rank of *C. betulus- T. baccata* communities	**Asso.1**	**Asso.2**	**Asso.3**	**Asso.4**	**Subasso.1**	**Subasso.2**	**Var.1**	**Var.2**
		Association				**Sub-association**		**Variant**	
Initial groups	1,2,3,4,5	1	2	3,4,5	6	3,4	5	3	4
No. of relevé	70	17	22	31	17	21	10	12	9
Initial groups	1,2,3,4,5	1	2	3,4,5	6	3,4	5	3	4
No. of relevé	70	17	22	31	17	21	10	12	9
Diagnostic species at the higher rank of classification									
Carpinus betulus	$79^{73.6}$	$95^{40.2}$	$72^{13.3}$	$71^{11.8}$	6^{---}	$76^{17.4}$	60^{---}	58^{---}	$100^{51.3}$
Galium odorata	$57^{55.2}$	$65^{21.7}$	$72^{30.1}$	42^{---}	6^{---}	33^{---}	$60^{26.7}$	33^{---}	33^{---}
Solanum kiezeritski	$83^{65.2}$	65^{---}	$89^{27.6}$	$94^{26.1}$	18^{---}	$90^{\cdots}$	$100^{22.4}$	$100^{35.4}$	78^{---}
Rubus hyrcanus	$64^{54.1}$	$55^{4.5}$	67^{18}	$71^{22.9}$	12^{---}	62^{---}	$90^{32.9}$	50^{---}	$78^{28.9}$
Polystichum aculatum	63^{60}	25^{---}	$94^{52.4}$	$71^{25.3}$	6^{---}	$71^{1.6}$	70^{---}	83^{---}	$56^{28.9}$
Dryopteris caucasica	$27^{39.6}$	$30^{14.9}$	17^{---}	$32^{18.2}$	.	$33^{3.6}$	30^{---}	$50^{30.2}$	11^{---}
Asplenium scolopendrium	30^{42}	20^{---}	$61^{47.9}$	19^{---}	.	$24^{18.4}$	10^{---}	$42^{51.3}$	.
Salvia glutinosa	$76^{36.6}$	$90^{4.7}$	$94^{12.4}$	$100^{20.3}$	100^{---}	100^{---}	100^{---}	100^{---}	100^{---}
Brachypodium pinnatum	$31^{43.2}$	$45^{23.4}$	50^{30}	13^{---}	.	$14^{6.6}$	10^{---}	.	$33^{44.7}$
Fago orientalis-Taxetum baccatae **Esmailzadeh and Soofi 2020 ass. nov. hoc loco**									
Fagus orientalis	$24^{37.2}$	85^{90}	.	.	.	.	.	.	.
Quercus castaneifolia	$20^{33.3}$	$65^{76.3}$	.	.	.	.	.	.	.
Aceri velutini-Taxetum baccatae **Esmailzadeh and Karami 2020 ass. nov. hoc loco**									
Acer velutinum	$39^{48.9}$	$45^{14.6}$	$78^{54.8}$	10^{---}	.	5^{---}	$20^{23.1}$	$8^{20.9}$	.
Carex sylvatica	$17^{30.6}$	5^{---}	$56^{62.5}$	3^{---}	.	$5^{15.6}$	.	$8^{2.9}$	.
Circea lutetiana	$11^{24.6}$	.	$33^{45.1}$	6^{---}	.	$10^{22.4}$	.	8^{---}	$11^{4.7}$

	Higher rank of *C. betulus- T. baccata* communities	**Asso.1**	**Asso.2**	**Asso.3**	**Asso.4**	**Subasso.1**	**Subasso.2**	**Var.1**	**Var.2**
		Association				**Sub-association**		**Variant**	
Lamium album	$11^{24.6}$	10^{---}	$33^{41.8}$	.	.	.	.	.	.
Carpino betuli-Carpino orientale -Taxetum baccatae **Esmailzadeh and Soofi 2020 ass. nov. hoc loco**									
C. betulus + *C. orientalis*	$27^{28.6}$	5^{---}	·	$58^{62.4}$	6^{---}	57 —	$60^{2.9}$	42 —	$78^{36.8}$
Carpino orientale -Taxetum baccatae **Esmailzadeh and Soofi 2020 ass. nov. hoc loco**									
Carpinus orientalis	37^{---}	5^{---}	·	$81^{39.6}$	100^{62}	71^{---}	$100^{40.8}$	$78^{12.4}$	33^{---}
Carpino -Carpino -Taxetum sorbuetosum torminalis **Esmailzadeh and Soofi 2020 subass. nov. hoc loco**									
Sorbus torminalis	29^{13}	$50^{33.8}$	6^{---}	$26^{1.4}$	18^{---}	$38^{51.5}$	·	33^{---}	$44^{11.4}$
Polygonatum orientale Desf	21^{---}	15^{---}	11^{---}	$32^{23.3}$	$24^{2.5}$	$43^{37.3}$	10^{---}	25^{---}	$67^{41.8}$
Carpino -Carpino -Taxetum parrotietosum persicae **Esmailzadeh and Soofi 2020 subass. nov. hoc loco**									
Parrrotia persica	$10^{22.9}$	·	·	$23^{42.4}$	·	·	$70^{73.4}$	·	·
Var. 1: Euonymus europaeus									
Euonymus europaeys	$14^{3.7}$	$25^{20.6}$	6^{---}	10^{---}	12^{---}	$14^{27.7}$	·	$25^{37.8}$	25^{---}
Table 2. (Continued)									
	Higher rank of *C. betulus- T. baccata* communities	Asso.1	Asso.2	Asso.3	Asso.4	Subasso.1	Subasso.2	Var.1	Var.2
		Association				Sub-association		Variant	
Initial groups	1,2,3,4,5	1	2	3,4,5	6	3,4	5	3	4
No. of relevé	70	17	22	31	17	21	10	12	9
Initial groups	1,2,3,4,5	1	2	3,4,5	6	3,4	5	3	4
No. of relevé	70	17	22	31	17	21	10	12	9
Var. 2: Juglans regia									
Brachypodium sylvaticum	$17^{30.6}$	$25^{20.5}$	11^{---}	16^{---}	·	$19^{12.8}$	10^{---}	·	$44^{53.8}$
Juglans regia	$11^{24.6}$	5^{---}	·	$23^{35.7}$	·	$33^{44.7}$	·	·	$78^{79.8}$
Diagnostic species at the higher rank of classification									
Taxus baccata	100^{---}	100^{---}	100^{---}	100^{---}	100^{---}	100^{---}	100^{---}	100^{---}	100^{---}
Ulmus glabra	$24^{16.3}$	30^{9}	$39^{21.1}$	13^{---}	17^{8}	$14^{6.6}$	10^{---}	17^{8}	11^{---}
Athyrium filix-femina	$17^{30.6}$	$25^{15.4}$	$33^{28.7}$	3^{---}	$8^{20.9}$	$5^{15.6}$	·	$8^{20.9}$	·

	Higher rank of *C. betulus- T. baccata* communities	Asso.1	Asso.2	Asso.3	Asso.4	Subasso.1	Subasso.2	Var.1	Var.2
		Association				Sub-association		Variant	
Euphorbia amygdaloides	59^{---}	$80^{15.4}$	44^{---}	52^{---}	$94^{32.8}$	$52^{2.4}$	50^{---}	42^{---}	67^{---}
Carex divulsa	66^{---}	65^{---}	61^{---}	71^{10}	100^{34}	67^{---}	$80^{15.1}$	50^{---}	$89^{42.2}$
Tilia rubra	$87^{53.2}$	$75^{2.4}$	$89^{20.5}$	$94^{26.5}$	35^{---}	$100^{33.3}$	80^{---}	100^{---}	100^{---}
Acer cappadocicum	$84^{16.4}$	$85^{5.5}$	$89^{11.3}$	81^{---}	71^{---}	$86^{18.9}$	70^{---}	75^{---}	$100^{37.8}$
Prunus avium	$74^{50.8}$	$70^{12.2}$	$61^{1.7}$	$84^{28.5}$	24^{---}	$90^{25.7}$	70^{---}	$92^{4.7}$	89^{---}
Hedera pastuchovii	$77^{0.8}$	70^{---}	$83^{7.9}$	$81^{4.9}$	76^{---}	$81^{1.2}$	80^{---}	75^{---}	$89^{18.1}$
Ilex spinigera	90^{---}	$10^{17.7}$	72^{---}	$94^{4.3}$	$100^{17.7}$	$95^{1.2}$	90^{---}	92^{---}	$100^{20.9}$
Viol alba	53^{---}	30^{---}	44^{18}	$71^{24.4}$	$76^{24.7}$	67^{---}	$80^{15.1}$	50^{---}	$89^{42.2}$
Sanicula europea	64^{---}	60^{---}	28^{---}	$87^{27.5}$	$82^{21.7}$	$90^{14.8}$	80^{---}	$92^{4.7}$	89^{---}
Festuca drymeja	66^{---}	50^{---}	$67^{14.6}$	$74^{3.8}$	$94^{29.2}$	71^{---}	80^{10}	$92^{50.6}$	44^{---}
Frangula alnus	$56^{26.6}$	$65^{20.3}$	28^{---}	$68^{23.4}$	29^{---}	62^{---}	$80^{19.9}$	33^{---}	$100^{70.7}$
Dannae racemosa	56^{---}	65^{10}	22^{---}	$68^{13.2}$	$71^{16.5}$	71^{12}	60^{---}	67^{---}	$78^{12.4}$
Companion species species									
Acer campestre	$4^{14.8}$	15^{---}	.	.	.	.	.	.	.
Acer mazandericum	$1^{8.5}$	$5^{19.5}$	.	.	.	.	.	.	.
Alnus subcordata	$1^{8.5}$	.	.	$3^{12.8}$	.	$5^{15.6}$	.	.	$11^{24.3}$
Tamus communis	21^{13}	5^{---}	28^{14}	$29^{15.9}$	12^{---}	$33^{15.1}$	20^{---}	17^{---}	$56^{40.5}$
Andrachne colchica	$1^{8.5}$	.	.	$3^{12.8}$	.	$5^{15.6}$	.	.	$11^{24.3}$
Anthriscus sylvestris	$1^{8.5}$	.	.	$3^{12.8}$	.	$5^{15.6}$	.	.	$11^{24.3}$
Asplenium trichomanes	$1^{8.5}$	.	.	$3^{12.8}$	.	$5^{15.6}$	.	.	$11^{24.3}$

	Higher rank of *C. betulus- T. baccata* communities	Asso.1	Asso.2	Asso.3	Asso.4	Subasso.1	Subasso.2	Var.1	Var.2
		Association				Sub-association		Variant	
Asplenium adiantum-nigrum	$7^{2.6}$	5^{---}	.	$13^{19.4}$	6^{---}	5^{---}	$30^{33.3}$	.	$11^{24.3}$
Berberis vulgaris	$1^{8.5}$	.	.	$3^{12.8}$	.	$5^{15.6}$	.	.	$11^{24.3}$
Bunium persicum	$1^{8.5}$	$5^{19.5}$	.	.	.	.	.	.	.
Cardamin tenera	3^{---}	5^{12}	.	$3^{2.0}$	.	$5^{15.6}$	.	.	$11^{24.3}$
Carex pendula	3^{12}	$10^{27.7}$	.	.	.	.	.	.	.
Cephalanthera caucasica	$10^{22.9}$	$10^{8.1}$	5^{---}	$16^{17.8}$	.	$24^{36.8}$	.	$25^{3.3}$	22^{---}
Clinopodium vulgare L.	$1^{8.5}$	.	.	$3^{12.8}$	.	$5^{15.6}$	.	.	$11^{24.3}$
Cornus australis	$6^{17.1}$	$5^{0.4}$	$11^{16.9}$	3^{---}	.	$5^{15.6}$	.	.	$11^{24.3}$
Crataegus monogyna	$1^{8.5}$	.	.	$3^{12.8}$	.	.	$10^{22.9}$	.	.
Cyclamen coum	3^{12}	$10^{27.7}$	.	.	.	.	.	.	.
Epipactis helleborin	$1^{8.5}$	$5^{19.5}$	.	.	.	.	.	.	.
Epipactis veratrifolia	$1^{8.5}$	$5^{1.5}$	.	.	.	.	.	.	.
Frangula alnus	$1^{8.5}$	$65^{20.3}$	28^{---}	.	.	.	.	.	.
Fraxinus excelsior L.	$11^{24.6}$	20^{21}	$11^{3.4}$	6^{---}	.	$10^{22.4}$	.	.	$22^{35.4}$
Hypericum androsaemum	$7^{2.6}$	5^{---}	.	$13^{19.4}$	6^{---}	$14^{6.6}$	10^{---}	.	$33^{44.7}$
Mespilus germanica	$1^{8.5}$	$5^{19.5}$	.	.	.	.	.	.	.
Parietaria variegata.	3^{12}	$5^{2.5}$	$9^{24.3}$	.	.	.	.	.	.
Perribloca gracea	$14^{3.7}$	15^{---}	11^{---}	$16^{4.7}$	12^{---}	$19^{12.8}$	10^{---}	8^{---}	$33^{30.8}$
Primula heterochroma	6^{---}	.	$6^{16.9}$	$10^{14.8}$	$18^{18.6}$	10^{---}	$10^{0.8}$	.	$22^{35.4}$
Scutelaria tourneforttii	3^{12}	.	$11^{29.3}$	.	.	.	.	.	.
Vicia crocea	$1^{8.5}$	5^{---}	.	.	.	.	.	.	.

Table 2

Nomenclature type relevés for the new associations defined in this study; author abbreviations: OE- Omid Esmailzadeh, MS-Meysam Soofi and Pk-Pari Karami. Cover percentage of each species are shown by ordinal van der Maarel (1979) cover-abundance scale (0: absent, 1: 0–1%, 2: 1-2.5%, 3: 2.5-5%, 4:5-12.5%, 5:12.5–25%, 6:25–50%, 7:50–75%, 8:75–100%).

Releve number	1	2	3	4
Altitude (m a.s.l)	1368	1575	1499	1333
Year	2018	2018	2018	2018
Author	OE and MS	OE and PK	OE and MS	OE and MS
Longitude (decimal degrees)	54°20'13"E	54°20'51"E	54°22'6"E	54°21'0"E
Latitude (decimal degrees)	36°40'53"N	36°40'37"N	36°41'15"N	36°41'2"N
Acer cappadocicum	5	4	4	4
Acer velutinum	3	4	1	0
Asplenium scolopendrium	1	1	0	0
Athyrium filix-femina	1	1	0	0
Brachypodium pinnatum	1	2	0	0
Carex divulsa	1	1	4	5
Carex sylvatica	0	1	0	0
Carpinus betulus	6	4	5	1
Carpinus orientalis	0	0	5	7
C. betulus + C. orientalis	0	0	5	1
Circea lutetiana	0	1	0	0
Dannae racemosa	1	0	1	1
Dryopteris caucasica	1	1	1	0
Euonymus europaeys	1	0	1	0
Euphorbia amygdaloides	1	1	1	2
Fagus orientalis	5	0	0	0
Festuca drymeja	3	2	4	5
Frangula alnus	2	1	3	1
Galium odorata	1	1	1	0
Hedera pastuchovii	3	4	2	1
Ilex spinigera	6	3	4	6
Juglans regia	1	0	2	0
Lamium album	0	1	0	0
Parrrotia persica	0	0	3	0
Polygonatum orientale	0	0	0	0
Polystichum aculatum	1	1	1	0
Prunus avium	4	3	4	3

Releve number	1	2	3	4
Quercus castaneifolia	4	0	0	0
Rubus hyrcanus	1	2	2	1
Salvia glutinosa	1	2	3	1
Sanicula europea	1	0	1	1
Solanum kiezeritski	2	4	2	1
Sorbus torminalis	3	1	2	1
Tamus communis	1	0	0	0
Taxus baccata	6	8	7	7
Tilia rubra	5	5	5	3
Ulmus glabra	1	2	1	1
Viol alba	1	1	1	1

Table 3
Eigen values and multiple regression of two first DCA axes with environmental variables in JNPA yew communities

	Axis 1	Axis 2	R^2	p-value
Elevation	0.400	0.317	0.21	0.05
Total Nitrogen (N)	-0.362	0.288	.0.17	0.18
Organic Carbon (OC)	-0.178	0.141	0.04	0.36
pH	-0.155	0.123	0.03	0.41
Clay	-0.473	-0.376	0.29	0.05
Silt	-0.303	0.240	0.12	0.22
Sand	-0.285	0.226	0.11	0.23
Slope	-0.728	0.578	0.69	0.01
Northness	0.491	0.390	0.31	0.05
Eastness	-0.532	-0.422	0.37	0.05
Eigen value	0.877	0.696		
Gradient length	4.802	3.743		
Trained variance %	14.1	11.2		
Cumulative trained variance %	14.1	25.3		

Figures

Figure 1

Map showing the location of the study area in the north of Iran (the circle is the exact location of Jahan-Nama Protected Area) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

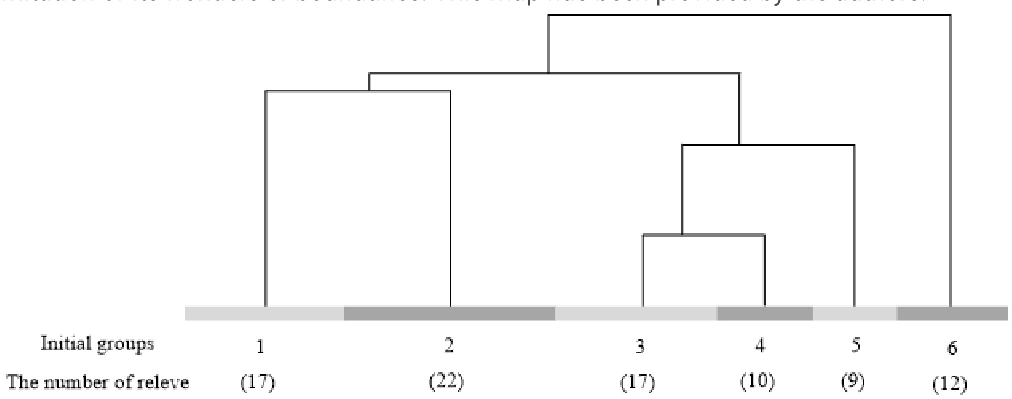

Figure 2

JNPA yew ecological units (initial groups) dendrogram (modified TWINSPAN method)

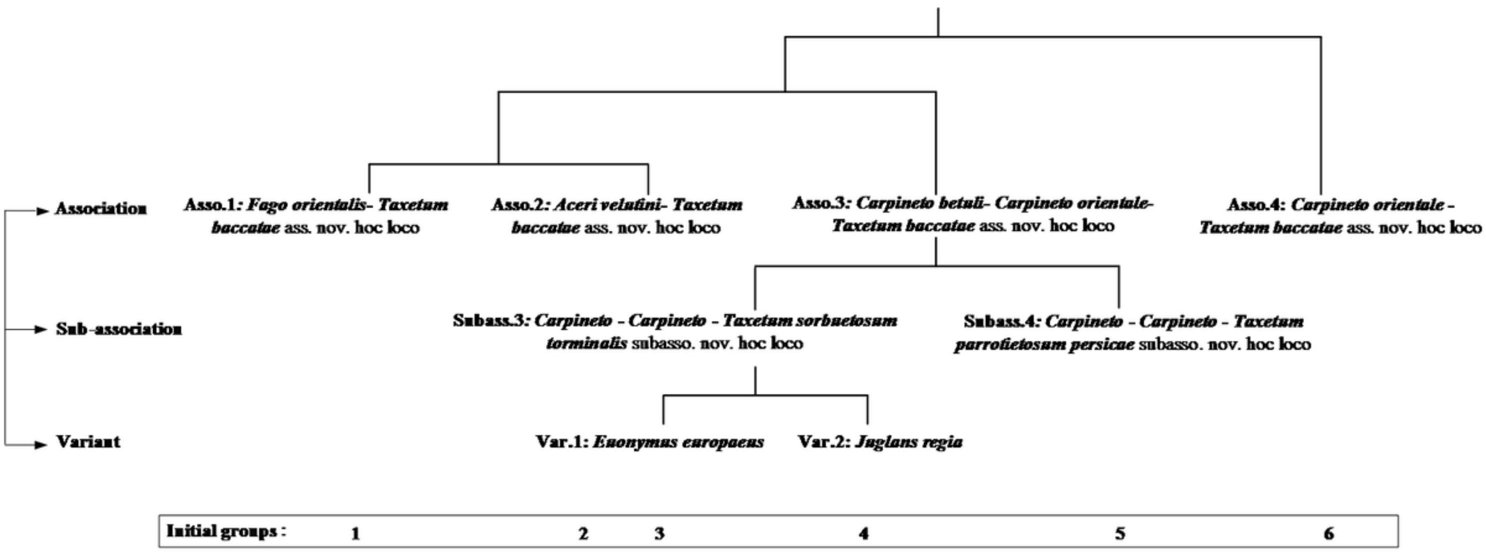

Figure 3

JNPA yew syntaxa dendrogram (Braun-Blanquet hierarchical method. Phytosociological ranks are indicated by horizontal lines.

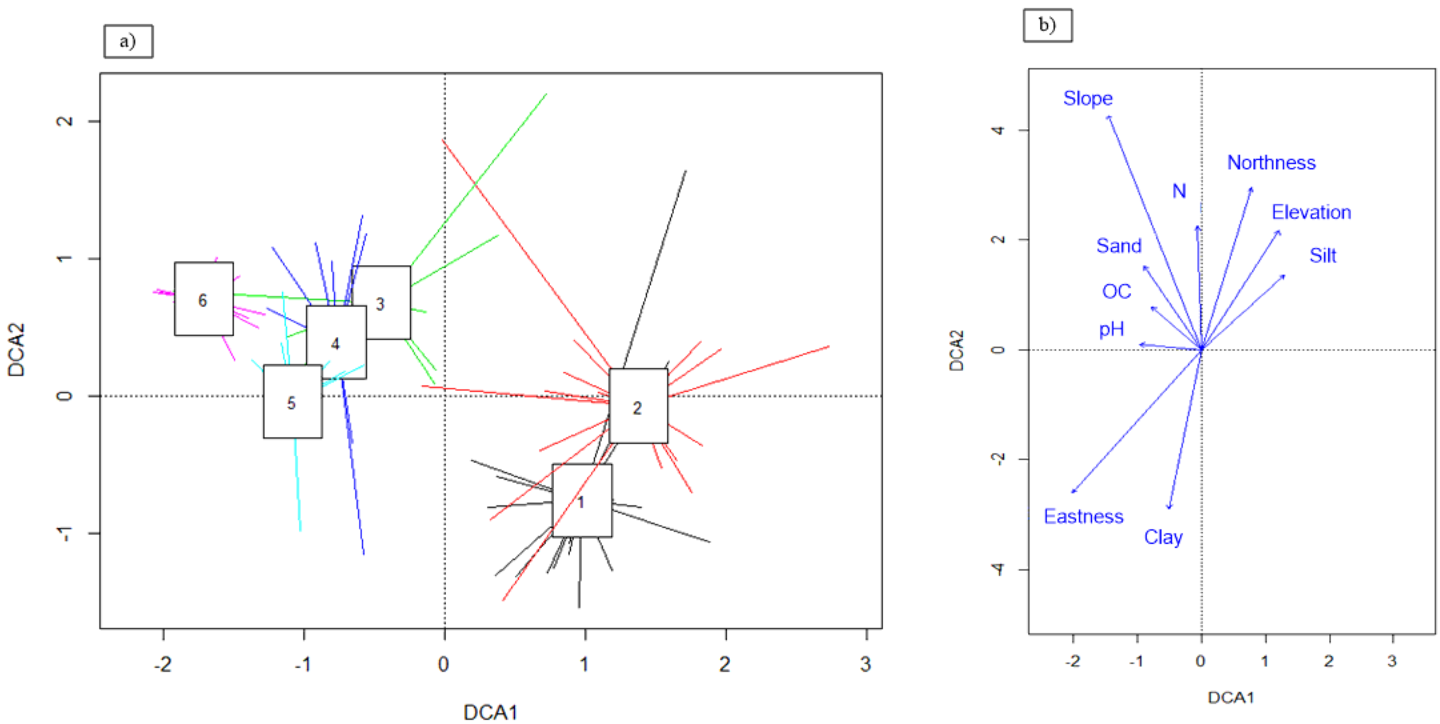

Figure 4

DCA of the JNPA yew communities (a) and correlation of environmental variables with two first axes.

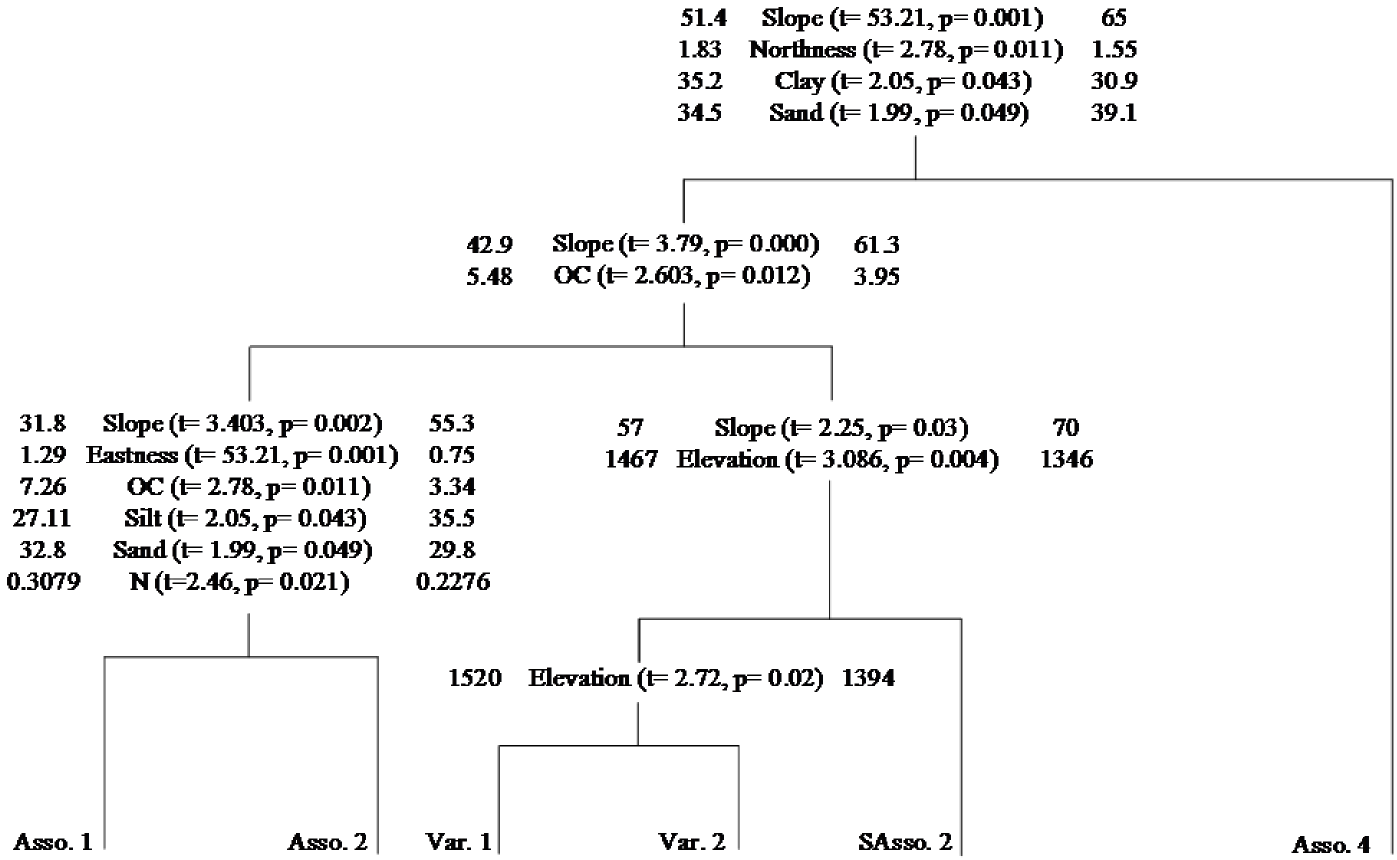

Figure 5

Dendrogram of JNPA syntaxa with environmental differences between two clusters at each Braun-Blanquet community levels. Only significant variables are shown with their mean values (on both sides) and significant as well as t values (in parenthesis)

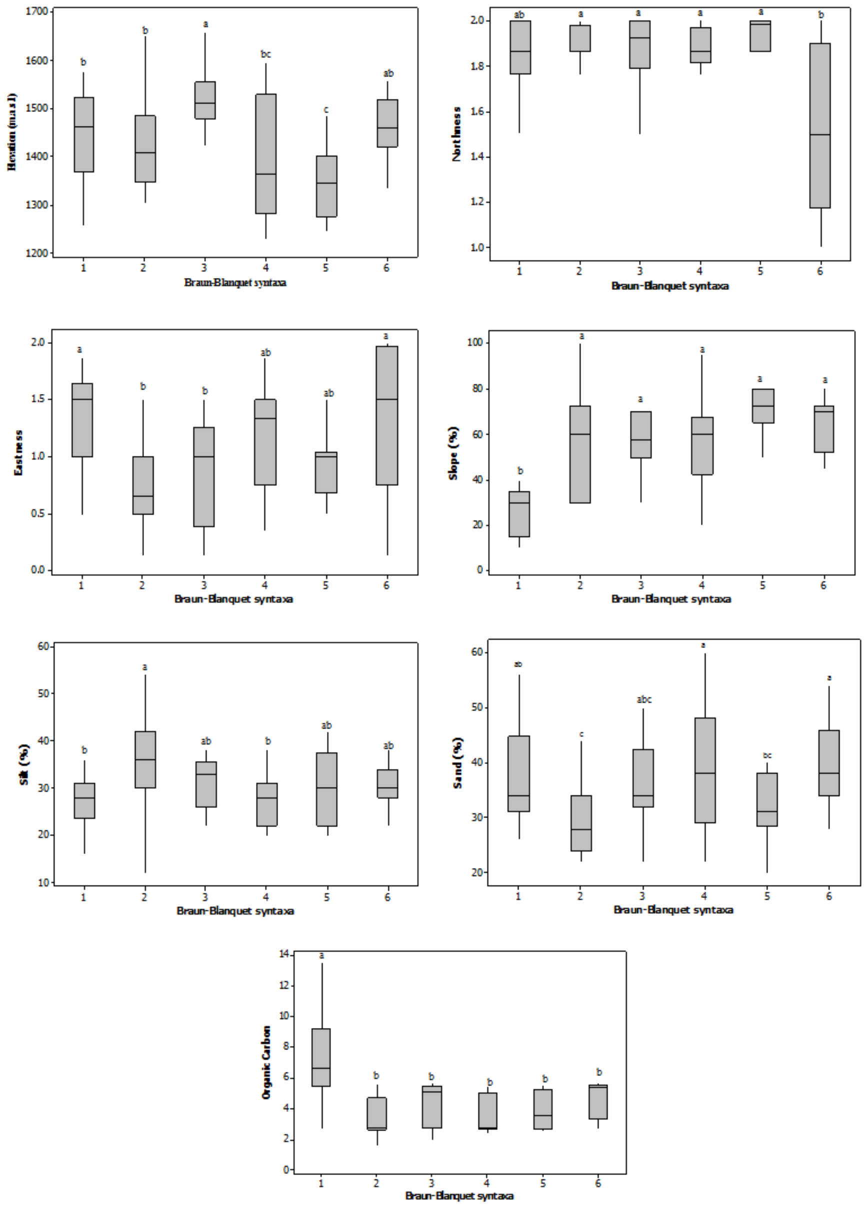

Figure 6

Multiple comparisons of environmental variable among JNPA syntaxa. Significant in one-way ANOVA and tukey post-hoc test (p<005) are displayed by different letters (a-d). Box plots show interquartile range (25- 75% of values), central lines are median value and whiskers refer to the range of values without outliers.