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Stand Structure and Spatial Patterns of Trees in Mixed Hyrcanian Beech Forest, Iran

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Abstract: The mixed beach forests (*Fagus orientalis*) commonly dominate by shade tolerance species with irregular uneven age stand structure. The aim of this study was to analyze the stand structure and spatial pattern in order to identify specific structural patterns. Data was collected from a 16 ha permanent plot. We mapped all stems >7.5 cm in diameter at breast height on permanent plot. The six main species were divided into two groups based on density and stand structure. Group A had higher density than group B, as well as L-shaped DBH distribution of live stems. Species in group B had bell-shaped DBH distributions. Species in group A have clump spatial distribution pattern in all layers but clump intensity is more than in understory layer and size of patch clump is small in this group. This phenomenon for group A may explaining by having numerous coppice, sucker and patch regeneration in the understory layer. Middlestory and understory stems of the six major tree species were patchily distributed throughout the plot but for Alder and Maple species common pattern in canopy layer was complete spatial randomness. The distribution of Beech and Hornbeam trees were negatively associated with other species. These results suggest species differences in favorable canopy condition.

Key words: Stand structure, spatial distribution pattern, spatial association, beech forest, Iran

INTRODUCTION

Beech forests commonly dominate the intermediate elevation regions of the northern temperate zone of Iran. These forests are the most important forest communities in natural forest landscape in Iran and usually consist of several canopy tree species. In this site, including *Fagus orientalis*, *Carpinus betulus*, *Acer velutinum* and *Alnus subcordate* are the most dominant, while *Prunus spinosa* and *Diospyrus lotus* often co-occur. Because Beech forests are widespread and represent the potential natural vegetation of many areas of Hyrcanian landscape, it's of interest to identified stand structure and spatial pattern of major trees in these forests.

The spatial and temporal pattern and the consequences of that pattern for the dynamics of populations and ecosystems are two fundamental and related themes in ecology (Levin, 1992). Patterns can exist at various scales in time and space (Allen and Starr, 1982; Urban *et al*., 1987; Pickett *et al*., 1997). In nature, these patterns can appear as patches, gradients, or other kinds of spatial structures at spatial scales ranging from ecosystems to the area occupied by an individual organism (Webster and Oliver, 1992; Trangmar *et al*., 1987; Robertson *et al*., 1993; Jackson and Caldwell, 1993; Levin 1992; Gross *et al*., 1995; Miller *et al*., 1995). Accordingly, many studies have attempted to quantify the patterns of heterogeneity within plant communities. These studies described and tested the effects of environmental heterogeneity on individual plants and plant-plant interactions at scales of centimeters to dozens of meters (Caldwell *et al*., 1994; Robertson *et al*., 1993; Jacksonand Caldwell, 1993, Halvorson *et al*., 1994; Ehrenfeld *et al*., 1997).

Traditional research on plant spatial pattern has emphasized testing for departures from Complete Spatial Randomness (CSR). Tests of the CSR hypothesis have also been applied in studies of competition effects on dynamics of even aged homogeneous forests (West, 1984; Franklin *et al*., 1985; Kenkel, 1988; Kenkel *et al*., 1989) mixed species temperate forests (Collins and Klahr, 1991; Szwagrzyk and Czerwczak, 1993) semi-arid shrub dominated stands (Welden *et al*., 1990) and savanna vegetation (Skarpe, 1991). This mechanistic approach has

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been applied to describe the spatial structure of tropical and temperate forests (Maguire *et al*., 1993) and as a component of models simulating forest dynamics (e.g., Busing, 1991). The objective of this study is to identify stochastic point processes that can simulate the non-random spatial patterns of trees in mixed Beech forests, Iran. The point processes were selected to provide realistic reproduction of the observed patterns under a simple set of biologically plausible assumptions. This study assessed: (1) the characteristics of stand structure, including the stand structure of the six major species and canopy and (2) the characteristics of spatial distribution patterns of the major species. On the basis of the results of this large-scale study, we discuss the coexistence of *Fagus* and other species in the *Shastkolate* Forest permanent plot. The following questions were addressed. (1) What were the ranges of densities of trees within mixed beech stand? (2) What kinds of stand structure were observed in mixed beech stands layers? (3) Were there common spatial distribution patterns of trees in mixed beech stand? (4) Which species have negatively associated with other species in mixed beech stand?

MATERIALS AND METHODS

Study area: The study area is located at the Shastkolate educational forest in the North-East of the Hyrcanian forest, Iran (36°45' N and 41°54'E). Permanent plot located in parcel 32, district 1 with 79.9 ha. Near the study stand (at Gorgan city) mean annual precipitation is about 650±144 mm and the mean monthly temperature is highest in May (27.9°C) and lowest in November (8.71°C). The study stand is situated at an elevation between 820 and 960 m up to see level. There were no signs of human or major natural disturbance. Canopy height was typically about 30 m and Canopy cover is about 55-100%.

Field methods: In February 2005, a 16 ha (400×400 m) permanent plot was established. The forest on the 16 ha plot was well developed and contained many species within the study stand. All woody stems >7.5 cm DBH were measured to the nearest 0.1 cm and the location of all stems was mapped. The trees were tagged, identified to species level and classified according to state (living or dead) and position in the canopy by measuring height of all trees. In our analysis of spatial distribution patterns and spatial associations among the tree species, we considered layer I to be the canopy layer (height is greater than 35 m) and layers II (height between 15-35 m) and III the understorey (height is less than 15 m). The plot was divided into 64 contiguous 50×50 m quadrates and all trees coordinate were recorded. The condition of the forest floor within a quadrate was recorded by visual estimation as percentage coverage.

Data analysis: We described the stand structure of the major tree species using stem density, maximum DBH, basal area, DBH distribution. We determined the spatial distribution of each species using the number of stems in each layer. The spatial distribution of stems of major species >7.5 cm DBH in different layers was analyzed using First-order Nearest Neighbour Tests; Clark-Evans Statistic. Probably the simplest measure of spatial pattern is the first-order nearest neighbour distance; that is, the distance from an event to its closest counterpart. The measure was described in an ecological context by Clark and Evans (1954) who provide estimates of the expected nearest neighbour distance under CSR (Complete Spatial Randomness) as well as significance tests for detecting departure from CSR in spatial point processes. The Clark Evans statistic (RCE) is the ratio of the observed (r_A) nearest neighbour distance to that expected (r_E) under CSR. Under CSR, RCE ~1.0. When R_{CE}<1.0 the point process is aggregated (R_{CE} = 0 for maximum possible aggregation) and when R_{CE}>1.0 it is maximally spaced. In any given distribution the mean observed distance to the nearest neighbour is RCE times as great as would be expected under CSR (at the same density). Thus, an R_{CE} value of 0.5 would indicate that nearest neighbours are on average half as far apart as expected under CSR. Spatial associations among major tree species and stems in different layers were analyzed using Morisita's index of interspecific correlation, (Morisita, 1959). First, we considered the following function:

$$R_{\delta'} = \frac{2(q\sum_{i=1}^{q} n_{xi}n_{yi} - N_x N_y)}{q(\delta_x \times \delta_y)N_x N_y} \quad (1)$$

where

$$\delta_x = \frac{\sum_{i=1}^{q} n_{xi}(n_{xi} - 1)}{N_x(N_x - 1)} \quad (2)$$

and

$$\delta_y = \frac{\sum_{i=1}^{q} n_{yi}(n_{yi} - 1)}{N_y(N_y - 1)} \quad (3)$$

Where n_{xi} is the number of stems of species X occurring in the ith quadrate, n_{yi} the number of stems of species Y, in the ith quadrate, Nx and Ny are the total number of stems of species X and Y, respectively and q the number of quadrates. If $R_\delta \geq 0$, then

$$R_\delta = R\delta \tag{4}$$

And if $R_\delta < 0$, then

$$R_\delta = \left(\frac{q\sum_{i=1}^{q} n_{xi} n_{yi}}{N_x N_y} \right) \tag{5}$$

R_δ expresses the degree of spatial associations, taking a positive value when the distributions of the two species or layers are positively associated and a negative value when they are negatively associated. If the two species or layers are distributed independently of one other, $R_\delta = 0$. The scale of spatial associations is determined by computing R_δ values for quadrates. The size of quadrates is same at I_δ Because both I_δ and R_δ tend to vary erratically where the number of samples (stems) is small, layers II and III were pooled to increase the sample size for the analysis of spatial distributions and spatial associations (Manabe and Yamamoto (1997) and Hoshino *et al.* (2001) for use of the R_δ index in the analysis of spatial associations of tree stems).

RESULTS

Floristic and physical characteristics: In the 16 ha permanent plot, we found nine tree and shrub species with a DBH >7.5 cm: *Fagus orientalis*, *Carpinus betulus*, *Acer velutinum*, *Acer cappadocicum*, *Alnus subcordata*, *Ulmus glabra*, *Prunus spinosa*, *Diospyrus lotus* and *Parrotia persica*. We counted 4901 living stems (292 ha^{-1} stems) and 314 dead stems (18.7 ha^{-1} stems) with a total basal area of 55.2 m^2 ha^{-1} (living) and 24.3 m^3ha^{-1} (dead). Here we considered only the living stems of the six main species that each made up >95% of the total stem density: Fagus orientalis Lipsky, *Carpinus betulus*, *Parrotia persica*, *Alnus subcordata*, *Acer velutinum* and *Diospyrus lotus* (Table 1). Most of the ground surface was covered by *Ruscus hyrcanus*, although bare rock and exposed mineral soil occurred locally.

Size and stand structure: Stand parameters varied among the major tree species (Table 1). *A. subcordata* had the largest mean DBH and basal area, whereas *F. orientalis* had the highest stem density. The DBH distributions of living stems of *D. lotus*, *A. velutinum* and *A. subcordata* were bell-shaped. The mode of *A. subcordata* was 60-70 cm and that of *A. velutinum* was 20-30 cm and for *D. lotus* was 10-15 cm (Fig. 1). Live stems of *F. orientalis*, *C. betulus* and *P. persica* exhibited reverse J or L-shaped distributions. Canopy layers varied among species (Table 2). The four species had stems in all layers but *D. lotus* hadn't stems in layer I and 68.3% this species stems is related on layer III. *A. subcordata* had far fewer stems in layer III than in layers I and II. *P. persica* had more stems in the lowest layer and *A. velutinum* had more stems in the layer II.

Spatial distribution pattern: Dispersion maps of individual stems of Beech and species in each layer illustrate their spatial distributions (Fig. 2). Stems of four species in the plot were clumped in canopy, middle and understorey layers, but *A. subcordata* and *A. velutinum* were complete spatial randomness pattern and $R_{CE}>1$ illustrate maximum space between stems. In the canopy layer, *A. velutinum* stems were aggregated in a large sized clump (4518 m^2) *P. persica* was clustered in large sized clump (8885 m^2) and *A. subcordata*, *C. betulus* and *F. orientalis* were aggregated in small clump (552 and 400 and 144 m^2). Because we found few *A. subcordata* stems in the understorey, we did not analyze the data for this species. Understorey stems of *F. orientalis* were aggregated in small patch (41 m^2) and *P. persica* were (32 m^2) patches, whereas stems of *A. velutinum* and *A. subcordata* were aggregated in intermediate (1038 and 862 m^2) clumps.

Table 3 shows spatial distribution analysis in three layers with use of Clark and Evan (1954) indices.

Spatial association: In permanent plot, *F. orientalis* and *C. betulus* stems were negatively associated with *A. subcordata* and *A. velutinum* stems, although the relation was stronger with *A. subcordata*. The sole exception to this result was that *C. betulus* was

Table 1: Stand parameters of living stems >7.5 cm DBH for major tree species in the 16 ha permanent plot of the Shastkolate Forest Iran

		DBH (cm)				
Species	Stem density (ha^{-1})	Mean±SD	Maximum	Height (m)	Basal area (m^2 ha^{-1})	Crown diameter (m)
F. oreintalis	107.5	33.84±30.01	150	21.29	17.30	6.16
C. betulus	71.5	29.19±23.9	112	21.03	8.00	6.02
P. persica	76.4	22.45±16.4	98	15.03	4.60	6.64
A. subcordata	2.5	62.99±21.6	119	32.25	0.87	5.90
A. velutinum	8.5	38.6±28.6	154	24.29	1.53	5.66
D. Lotus	23.7	12.4±4.3	40	13.39	0.32	6.36

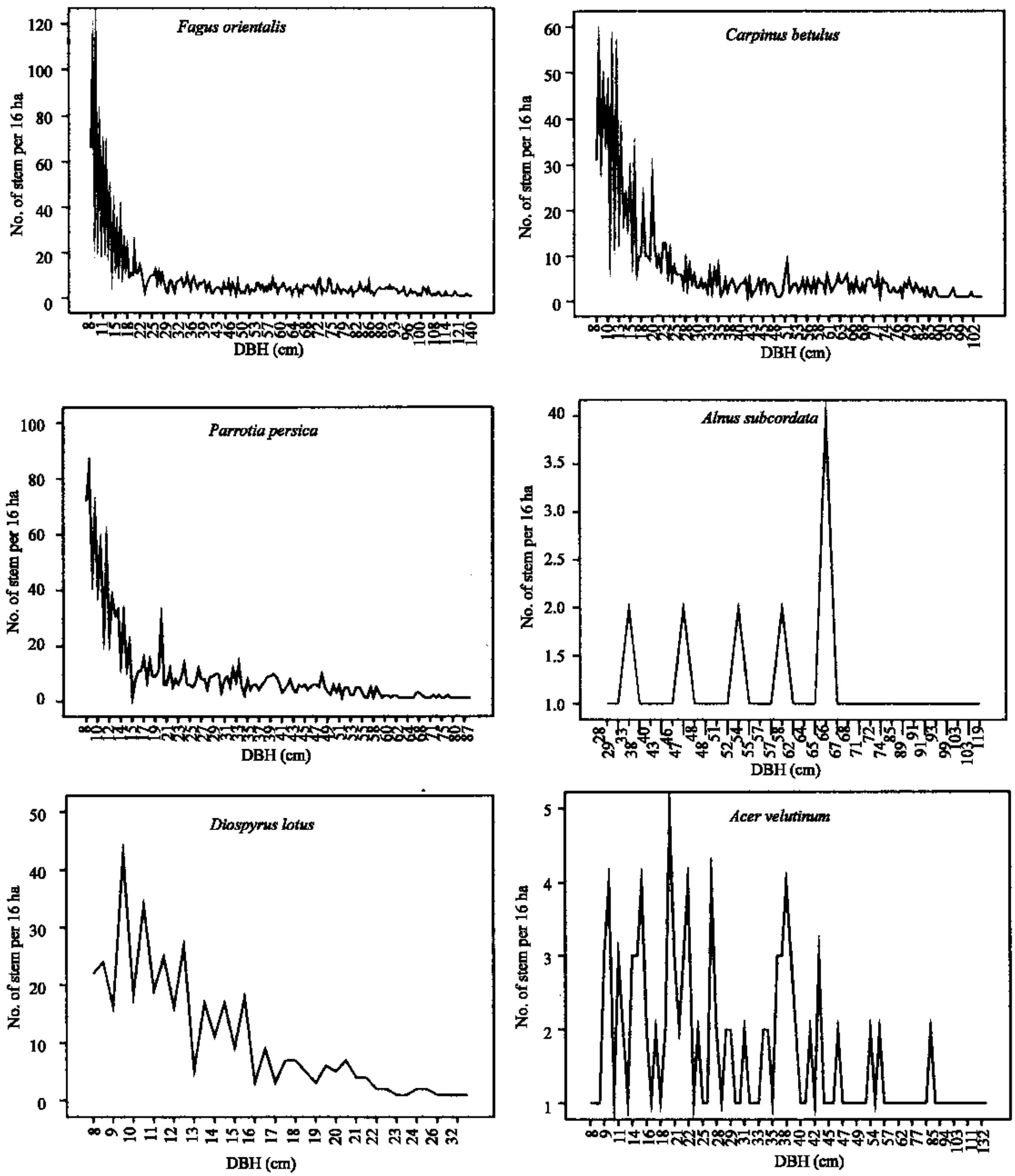

Fig. 1: The Stand structure and DBH class distributions of the major tree species in the 16 ha permanent plot of the Shastkolate Forest Iran

distributed independently of other species specification *A. velutinum* and *P. persica* in big quadrate size. *A. subcordata* were positively associated with *D. lotus* in quadrates 145000 m^2 but were negatively associated with other species in the smallest quadrates. Stems of *A. velutinum* were

Table 2: Density (ha^{-1}) by canopy height of living stems >7.5 cm DBH for major tree species in each layer in the 16 ha permanent plot of the Shastkolate Forest, Iran

	Layer[a]					
	I		II		III	
Species	No.	%	No.	%	No.	%
F. oreintalis	17.70	16.5	47.2	43.9	42.50	39.6
C. betulus	5.90	8.2	43.4	60.7	22.20	31.1
P. persica	0.48	0.6	31.7	41.5	44.20	57.9
A. subcordata	1.10	45.2	1.3	52.4	0.05	2.4
A. velutinum	0.95	11.2	6.0	70.6	1.50	18.2
D. Lotus	0.00	0.0	7.5	31.7	16.20	68.3

[a]Layer I: Canopy with height is greater than 35 m, Layer II: middlestory canopy with height between 15-35 m, Layer III: Understory canopy with height less than 15 m

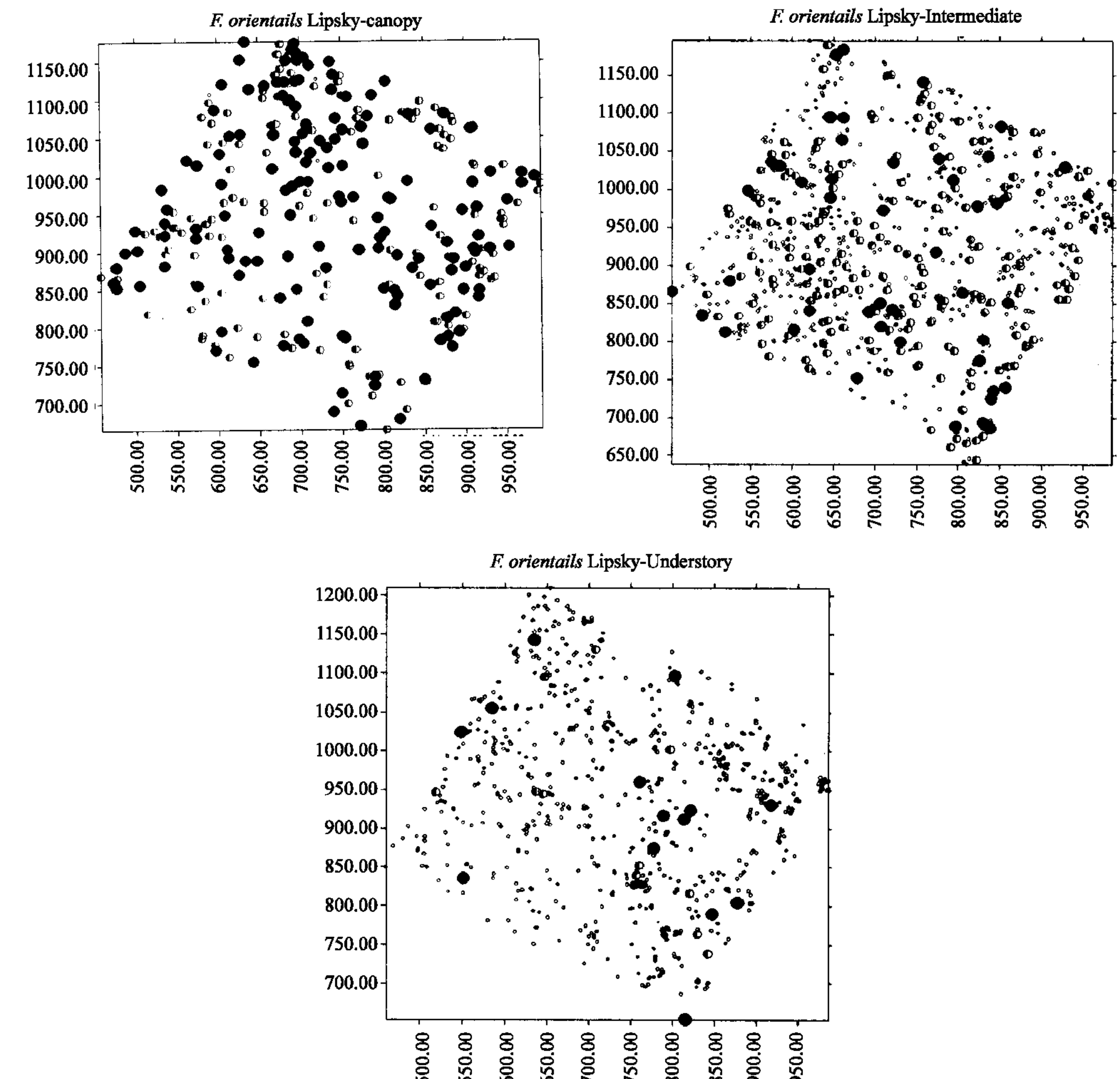

Fig. 2: Distribution of individual stems of Beech tree in the 16 ha permanent plot of the Shastkolate Forest, Iran. Large circles: stem with DBH greater or equal than 80 cm; Medium circle: stems with DBH greater or equal than 40 cm and less than 80 cm; Small circles: stems with DBH greater than 40 cm. Scale in meters

Table 3: Spatial distribution analysis parameters of living stems>7.5 cm DBH for major tree species in the 16 ha permanent plot of the Shastkolate Forest- Iran

Species	Parameter	Canopy layer	Middler layer	Understorey layer
F. oreintalis	Point analyzed	294.00	789.00	718.00
	Average NN distance	12.02	6.72	6.39
	Clark and Evan's R	0.38	0.34	0.30
C. betulus	Point analyzed	98.00	729.00	372.00
	Average NN distance	20.03	6.91	7.85
	Clark and Evan's R	0.39	0.36	0.27
P. persica	Point analyzed	7.00	528.00	740.00
	Average NN distance	94.26	8.66	5.68
	Clark and Evan's R	0.45	0.35	0.28
A. subcordata	Point analyzed	19.00	20.00	0.00
	Average NN distance	23.50	29.36	0.00
	Clark and Evan's R	2.31	0.25	0.00
A. velutinum	Point analyzed	15.00	99.00	26.00
	Average NN distance	67.22	17.01	32.22
	Clark and Evan's R	0.91	0.33	0.32
D. lotus	Point analyzed	0.00	124.00	271.00
	Average NN distance	0.00	13.33	8.17
	Clark and Evan's R	0.00	0.27	0.25

distributed independently of the *D. lotus* and *P. persica* in quadrates 12500 m^2 but were negatively associated the smallest quadrates. *D. lotus* was strong negatively associated with *P. persica* in all quadrates.

DISCUSSION

Stand characteristics: In many mixed Beech forests, *Fagus* sp. are found at a much greater density than other species (Saniga and Schutz, 2001; Rademacher *et al*., 2004; Leibundgut, 1993). In the study stand, the density of *F. orientalis* was much higher than that of *C. betulus*, *A. subcordata* and *A. velutinum* although *A. subcordata* and *A. velutinum* occupied the largest basal area. Total dead wood volume is similar to other reported from Hyrcanian mixed beech forest (Habashi *et al*., 2005).

Stand structure: Beech forests (*Fagus orientalis*) represent the most important forest communities in natural forested landscapes in Hyrcanian forest, Iran (Mohajer, 2005). In Beech forest of central Europe mean density of living trees >7 cm DBH amounted to 263 ha^{-1} and about one-third of the trees (95 ha^{-1}) occurred in the upper canopy layer (Oheimb *et al*., 2005). In our study, mean density of living trees>7.5 cm DBH amounted to 107.4 ha^{-1} and 16.5% of the trees (17.7 ha^{-1}) occurred in the upper canopy layer. On the basis of our results, we divided the species into two groups. The species in group A were *F. orientalis*, *C. betulus* and *P. persica* and in group B were *D. lotus*, *A. subcordata* and *A. velutinum*. The species in group A were the most common, characterized by continuously reverse L-shaped DBH distributions (live stems). Stand structure of beech forest most dominant with L-shaped DBH distributions (Mohajer, 2005; Oheimb *et al*., 2005). The species in group B had bell-shaped DBH distributions (live stems). Group A species dominated the canopy layer and very most stems in the middle layer understorey layer too. Despite their low density in the understorey, however, their longevity may allow for continued coexistence of these two species groups in the canopy layer. In *Rusco-Fagetum* association, *Diospyrus* is usually more abundant in understorey (Asadollahi, 2001) and in mixed beech forest studied *Diospyrus* trees occurred in understorey canopy layer (68.3%). Group A's dominance of the understorey may be due to shade tolerance, a characteristic of *Fagus* species.

Spatial distribution pattern and spatial association: Individuals of many tree species in various forest communities tend to be patchily distributed (Denslow, 1980; Taylor and Qin, 1988; Nakashizuka, 1989; Manabe *et al*., 2000). We found a similar situation in this study site; stems of four species in each layer had clumped distributions and the size of the clumps differed among species and canopy layers. *Alnus subcordata* and *Acer velutinum* had complete spatial randomness pattern in out site that reflected pioneer species. In this study, spatial associations varied among intra- and inter-specific cohorts in stand structure. Some of species such as *Alnus subcordata* were negatively associated with other species in small quadrate size but were positively associated with other species in their big quadrate size. *F. orientalis* stems were negatively associated with all other species. *D. lotus* stems was occupied in layer II and III and had strong negatively associated with *P. perica* that occupied same layer.

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