

SPATIAL STAND STRUCTURE ANALYSIS OF ULUDAĞ FIR FORESTS IN THE NORTHWEST OF TURKEY

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Abstract. Forest structural characteristics, which are one of the key determinants of species and habitat diversity, have also been used as a constitutive factor in sustainable forest management. This study aimed to analyse the spatial structure (Clark-Evans, segregation and species mingling) of pure fir (7 plots, 1000-1600 m a.s.l.), fir dominated (5 plots, 1000-1400 m a.s.l.) and fir-beech co-dominated (7 plots, 1000-1300 m a.s.l.) stands at the center and edge distribution of *Abies nordmanniana* ssp. *bornmuelleriana* in Sub-euxine zone of Euro-Siberian region of Turkey. The Shannon diversity of tree species was found significantly ($P < 0.01$) lower in the edge distribution (Bolu-Aladağ) (0.418 ± 0.081) compared to Yenice (0.824 ± 0.066). *Fagus orientalis* showed a clumped distribution in fir dominated stands where it is not competitive compared to *Abies nordmanniana* ssp. *bornmuelleriana* but it had a spatial association with other species in co-dominated stands. Light demanding deciduous trees such as *Quercus hartwissiana*, *Carpinus betulus* and *Populus tremula* were observed in pure groups, whereas *Pinus sylvestris* and *Pinus nigra* did not show a tendency towards clumping and had a spatial association with other species since they were located in upper stand layer. As shown in this study, spatial data in stand profiles provide new opportunities for understanding ecosystem structure and silvicultural treatments.

Keywords: Euro-Siberian, mingling, aggregation index, beech, species segregation index, stand profile

Introduction

Forest tree composition is shaped by competitive interactions among individuals in natural forests which determine the size and position of individual trees. These interactions among species are reflected in complex stand structures and highly diverse mixture of species (Hui et al., 2018). Specific structures generate particular processes of growth and regeneration, thus tree growth and the interactions between trees depend, to a large degree, on the structure of the forest (Forrester, 2019; Bastias et al., 2020). On the other hand, forest structure is not only the outcome of natural processes but is also determined to a considerable extent by silvicultural interventions (Gadow et al., 2012). Aguirre et al. (2003) define stand structure as the spatial distribution of the tree positions, the spatial mingling of the different tree species and the spatial arrangement of the tree dimensions. Spatial stand structure, which is an important facet of habitat diversity, is associated with ecological stability and species diversity (Neumann and Starlinger, 2001; Pommerening, 2002; Kint et al., 2003; Szmyt, 2012; Gao et al., 2014; Bastias et al., 2020). Therefore, forest ecosystem diversity does not only refer to species richness but to a range of phenomena that determine the heterogeneity within a community of trees, including the diversity of tree sizes and tree locations (Ni et al., 2014).

Forest stand structure is essential inputs for understanding ecosystem structure and functioning, and hence for sustainable forest management (Kint et al., 2003; Schall et al., 2018). For this reason, forest structural characteristics have been a key determinant in silvicultural methods (i.e. thinning methods). Therefore, the description of stand structural characteristics has been commonly undertaken in silvicultural researches.

Forest stand structural characteristics have been traditionally illustrated using hand-drawn profiles based on actual measurements which show the horizontal and vertical projection of the stand (hereafter stand profile) (Çoban et al., 2016, 2018). Stand profiles, which are a depiction of a section through the forest, offer good opportunities for illustrating and analyzing horizontal and spatial forest structures (Nielsen and Nielsen, 2005). In Turkey, the earliest use of stand profiles in silvicultural researches dated back to 1970's (Aksoy, 1978; Bozkuş, 1986; Yöneli, 1986; Özalp, 1989; Ertaş, 1996; Çoban, 2013). Especially, stand profile measurements were carried out in phytosociological studies. These profiles were used to characterize vertical stand structure and tree size distributions. However, the spatial pattern of trees recorded and marked in the horizontal profile has not been evaluated so far. This spatial data provide a comprehensive description of the spatial structure of a forest using indices which have been developed in the past few decades in order to quantify neighborhood competition (Aguirre et al., 2003; Hui et al., 2018). In addition, determination of the spatial pattern of tree species in mixed stands is important in gaining a better understanding of the underlying ecological processes which will provide critical information about community structure and species coexistence (Ni et al., 2014).

In this study, it was aimed to determine spatial patterns of pure and mixed stands of fir in different site conditions. It was hypothesized that (1) tree species diversity of fir forests do not differ in the center and edge distributions in Sub-euxine zone of Euro-Siberian phytogeographic region (2) *Abies nordmanniana* (Stev.) Spach. subsp. *bornmuelleriana* (Mattf.) Coode & Cullen and *Fagus orientalis* Lipsky., which have similar shade tolerance, will have the same spatial pattern in all stand types.

Materials and methods

Site description

The study area is located in the northwest of Turkey, which is the main distribution area of *Abies nordmanniana* (Stev.) Spach. subsp. *bornmuelleriana*, hereafter will be referred as *Abies bornmuelleriana*. Stand profiles were selected from Karabük-Yenice (Çitdere) (Özalp, 1989) and Bolu-Aladağ forests (Aksoy et al., 2012) representing both center and edge distributions in Sub-euxine zone of Euro-Siberian phytogeographic region. Çitdere (6091 ha) is located in Yenice district of Karabük province which is in the western part of the Blacksea Region. It lies between 41°00'14" and 41°05'06" northern latitudes and 32°21'06" and 32°27'45" eastern longitudes. The altitude of the region ranges from 640 m a.s.l. to 1810 m a.s.l. Aladağ mountain (4502 ha) is situated between 31°33'30" - 31°38'00" eastern longitudes and 40°37'30" - 40°41'30" northern latitudes in the southern part of the Bolu province. The altitude of the mountain ranges from 750 m a.s.l. to 1840 m a.s.l. (Fig. 1).

The meteorological stations representing climate of the study areas are Karabük-Büyükdüz (1962-1970) and Bolu Şerif Yüksel Research Forests (Aladağ Mt.) (1975-1995). Mean annual precipitation and temperature were measured as 1371 mm and 6.2 °C at Büyükdüz station (1560 m), 882 mm and 5.7 °C at Bolu-Aladağ (1550 m).

Vegetation

The Euro-Siberian phytogeographical region was subdivided into Euxine, Sub-euxine and Xero-euxine zones from north to south (Zohary, 1973) since mountain

ranges create varied climate characteristics. The Euxine zone is characterized by deciduous and mixed forests from the colline to submontane zone and various mixture combinations of *Abies bornmülleriana*-*Fagus orientalis* forest in the montane zone. The Sub-euxine zone is characterized by mixed *Carpinus-Quercus* and *Pinus nigra* forests and pure coniferous forest consist of *A. bornmülleriana* on northern slopes and *Pinus sylvestris* on southern slopes in the montane belt (above 1200/1300 m) (Akman, 1995; Mayer and Aksoy, 1998). The Xero-euxine zone surrounds Central Anatolia and characterized by forest-steppe vegetation with *Quercus pubescens* as the main tree (Zohary, 1973; Mayer and Aksoy, 1998; Kurt et al., 2006).

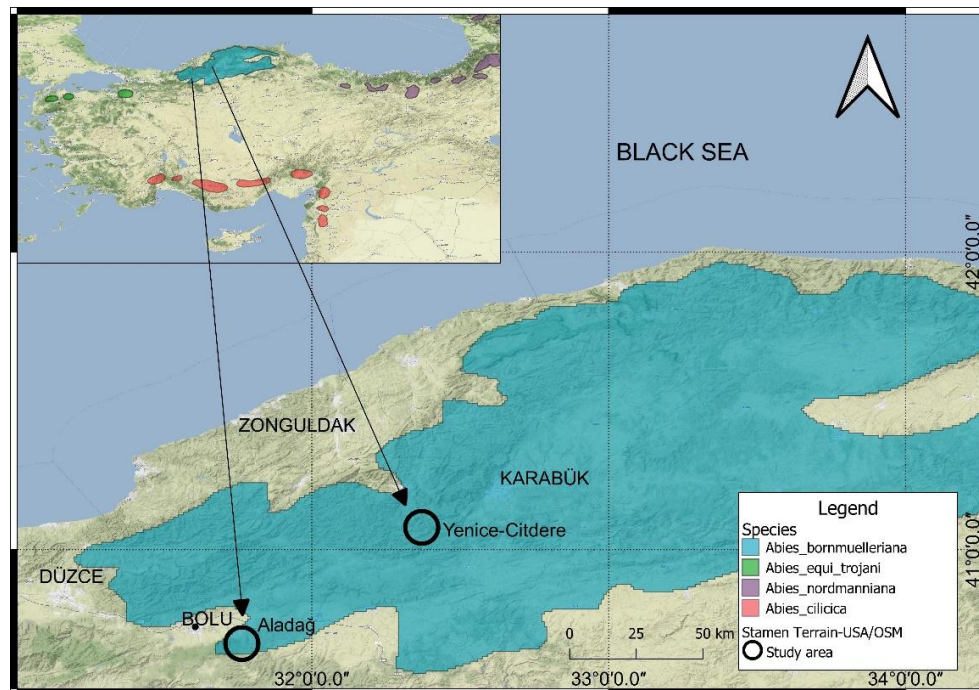


Figure 1. Location of the study area (species distributions were taken from Alizoti et al., 2011)

According to Çoban and Willner (2019), *Abies bornmuelleriana* dominated forests were classified under the alliance of *Lonicero caucasicae-Piceion orientalis* Çoban et Willner 2009, the order *Abieti nordmannianae-Piceetalia orientalis* Çoban et Willner 2019 and the class *Vaccinio-Piceetea* Br.-Bl. in Br.-Bl. et al. 1939. Mesic beech and fir-beech forests under the alliance *Fagion orientalis* Soó 1964, the order *Rhododendro pontici-Fagetalia orientalis* Passarge 1981 and the class *Carpino-Fagetea sylvaticae* Jakucs ex Passarge 1968.

Data preparation

Tree spatial data was taken from the original stand profiles of Özalp (1989) and Aksoy et al. (2012) which were used to characterize the stand structure of forest communities. Field sampling of the latter study was carried out in 1978 and vegetation data was published in 2012. Stand profiles are based on actual measurements of the positions, heights, heights of the lowest branches, and the diameters at breast height of trees over 5 m (Aksoy, 1978). In each diagram, tree positions, which were shown on millimeter papers at scale 1:200 for the whole plot, were measured with respect to a

Cartesian coordinate system. Stand profiles where *Abies bornmuelleriana* had a relative species per hectare (SPH) of at least 20% were included in the analysis. As a result, 19 stand profiles were obtained which were further grouped into pure fir (>85% fir), fir dominated (70-85% fir) and fir-beech co-dominated (20-70% fir) stands. The classification of the available data resulted in 7 stand profiles in both pure fir and fir-beech co-dominated stands and 5 stand profiles in fir dominated stands (Table 1).

Table 1. Details of sample plots and their classification (species less than 10% of relative species per hectare (SPH) in any of the plots were not shown)

Plot	Group	Altitude (m)	Aspect	Slope (°)	<i>Abies bornmuelleriana</i>		<i>Fagus orientalis</i>		<i>Carpinus betulus</i>		Total SPH
					SPH	Rel. freq.	SPH	Rel. freq.	SPH	Rel. freq.	
A1	Pure fir	1120	NNW	22	500	86	80	14			580
A4		1030	WNW	17	820	93					820
A5		1600	NNW	6	700	100					760
A6		1200	N	19	460	88	60	12			520
A7		980	SSE	7	660	92					720
A8		1510	NNE	23	580	97	20	3			600
A9		1060	S	8	840	95					880
C6	Fir dominated	1120	NNW	13	680	83	140	17			820
C7		1350	SSW	32	1220	72	160	9	180	11	1700
A2		1300	NNW	27	460	74	160	26			620
A3		980	NNW	31	620	72	120	14	60	7	860
A10		1400	NNE	40	840	81	160	15			1040
C1	Fir-beech co-dominated	1120	ENE	13	240	48	220	44			500
C2		1030	SSE	21	340	31	640	58	40	4	1100
C3		1180	NNW	17	360	44	460	56			820
C4		1400	NNW	20	180	20	580	74			780
C5		1250	NE	27	320	52	260	41			620
C8		1090	NNE	6	500	54	400	43			920
C9		1300	NNW	10	529	35	784	51			1529

Pure forests occurred between 1000 and 1600 m a.s.l., fir dominated forests 1000-1400 m a.s.l. and fir beech co-dominated forest between 1000 and 1300 m a.s.l. Pure forests were also found on steeper slopes compared to other units (Fig. 2).

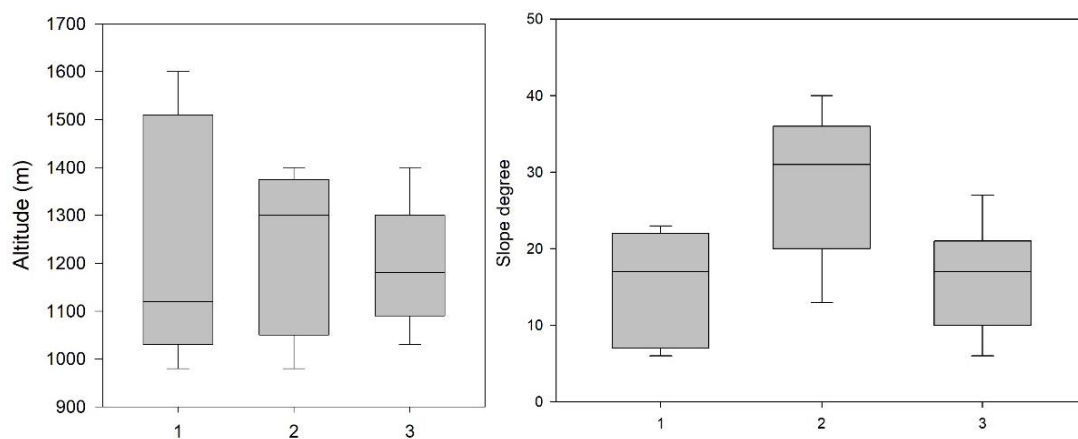


Figure 2. Altitude and slope ranges of forest types (1: Pure fir, 2: Fir dominated, 3: Fir beech co-dominated)

Computed indices

In order to analysis spatial structure of the stands, following distance-dependent indices, also known as spatially explicit indices were used.

Species mingling (M_i)

Mingling (M_i) is defined as the proportion of neighbours which do not belong to the same species as the reference tree (Gadow, 1993; Földner, 1995). The distribution of the M_i values, in conjunction with the species proportions within a given tree population, allows a detailed study of the spatial diversity within a forest. With four neighbours, indices have five possible values: 0.00, 0.25, 0.50, 0.75 and 1.00. While higher values show different species intermingled, small values indicate pure groups. For instance, a value of $M_i = 0$ is obtained if the neighbouring species belong to the same species, whereas $M_i = 1$ when all neighbouring trees are different than reference tree (Eq. 1).

$$M_i = \frac{1}{n} \sum_{j=1}^n v_{ij} \quad (\text{Eq.1})$$

where n is the number of the nearest neighbours, $v_{ij} = 1$ if the species_j ≠ species_i and $v_{ij} = 0$ otherwise.

Aggregation index of Clark-Evans (CE)

Clark-Evans index (CE) expresses the extent to which a forest deviates from the stands with a complete randomised spatial distribution of trees (Eq. 2). It uses distances between nearest neighbours and it is measured for all individuals located on the plot (Clark and Evans, 1954). The values are restricted to the range between 0 and 2.15 and values lower than 1 indicate clumped distribution, while regularity is assumed if the values are over 1. While complete regular hexagonal distribution results in the highest index of 2.15, random distribution equals to 1 (Neumann and Starlinger, 2001).

$$CE = \frac{1}{n} \sum_i r_i^2 \sqrt{p} \quad (\text{Eq.2})$$

where r_i is the distance from one tree to his next neighbour and r is density of tree per square meter.

Species segregation index (S)

The Pielou Index (S) (Pielou, 1977) compares the observed number of mixed pairs with the one expected under random conditions, independently of their spatial pattern (Eq. 3). Values of the S index vary between -1 and 1. If $0 < S < 1$ indicates that the nearest neighbours are always same species (spatial separation or segregation of species) and if $-1 < S < 0$, spatial association between two species is observed (Kint et al., 2003). In the plots more than two species, segregation index is calculated by comparing one species against all others.

$$S = 1 - \frac{N.(b+c)}{m.s + n.r} \quad (\text{Eq.3})$$

N is the numbers of all pairs of trees, m and n are the number of individuals of A and B respectively, r and s are the number of times species A and B are found as the nearest neighbours of a reference tree (Pommerening, 2002).

Species related Shannon index

The Shannon index (Shannon and Weaver, 1949) which describes species diversity was calculated based on SPH. The Shannon index takes the relative abundance of different species into account rather than simply expressing species richness. The Shannon index is affected by both the number of species and their evenness.

$$H = -\sum_{j=1}^n p_j \cdot \ln(p_j) \quad (\text{Eq.4})$$

where p_j is relative frequency of tree species and n is number of tree species.

All of the values mentioned above were calculated using CRANCOD 1.4 (Pommerening, 2012) and stand profile figures were produced using the package ggplot2 (Wickham, 2009). Statistical significance of groups in terms of measured parameters was tested using Systat SigmaPlot (SigmaPlot 14 trial version, www.systatsoftware.com). When the Shapiro-Wilk test showed the homogeneity and Brown-Forsythe test Equal Variances ($p > 0.05$), Student's t-test was applied to the data. Pearson Product Moment Correlation was used to measure the strength of association between pairs of variables.

Results

Tree species diversity

Fir and beech mixed forests of Yenice were found to have significantly ($P < 0.01$) higher diversity of tree species (0.824 ± 0.066) compared to Aladağ (0.418 ± 0.081). There was not a statistically significant difference between fir dominated (0.702 ± 0.103) and fir-beech co-dominated stands (0.798 ± 0.065). *Fagus orientalis* was the most common tree species in the mixture in both regions. Species such as *Carpinus betulus*, *Pinus sylvestris*, *Pinus nigra*, *Taxus baccata*, *Sorbus torminalis*, *Populus tremula* and *Quercus hartwissiana* had a scattering occurrence in the mixtures (less than 10% relative SPH). *Quercus hartwissiana* joined stand mixture only in Yenice region. Also, tree species diversity decreased with the ratio of fir ($r(18) = -0.69$, $p < 0.01$) (Table 2).

Spatial structure of stands

Mean distance to the first neighbour of all trees was 2.06 ± 0.16 , 1.88 ± 0.19 and 2.07 ± 0.16 for pure fir, fir dominated and fir-beech co-dominated stands. When segregation of species was compared among stand types, there was a segregation ($S > 0$) between accompanying species in fir dominated stands (Fig. 4c). This means low numbers of mix pairs of the nearest neighbours. On the other hand, low spatial associations both on plot and species level were found in the co-dominated and pure stands except for plots C3 and C9 (Figs. 3 and 4b, d). Unlikely, *Abies bornmuelleriana* spatially associated with other species whereas *Fagus orientalis* segregated in the plot C2 (Fig. 4a) where *Carpinus betulus* and *Quercus hartwissiana* admix. In that plot,

Fagus orientalis form pure groups. In general, light demanding coniferous trees (*Pinus nigra* and *Pinus sylvestris*) had spatial association with other species, whereas light demanding deciduous trees (*Quercus hartwissiana*, *Carpinus betulus* and *Populus tremula*) highly segregated and clumped. A positive correlation was found between altitude and segregation index ($r(19) = 0.58$, $p < 0.01$) means that a spatial association and low mixtures occur among different species at higher altitudes.

Clark-Evans Aggregation index at plot level showed a regular distribution ($CE > 1$) of trees except for plots A8, C2 and C9 (Figs. 3 and 4a, d, e) which have a low clumping trend. However, when species were evaluated separately, all of the species showed a clumping distribution except *Abies bornmuelleriana*. It had a low clumping only in fir-beech co-dominated stands where *Fagus orientalis* had also similar pattern. Other trees were much more clumped compared to main dominant species. Increasing fir ratio caused a regular distribution for *Abies bornmuelleriana* and a strong clumping distribution of *Fagus orientalis* in fir dominated stands except for plot A10 (located on a steep slope at 1400 m) where *Abies bornmuelleriana* also had a low clumping degree (Fig. 3). A negative correlation was found between fir ratio and CE index of Beech ($r(15) = -0.70$, $p < 0.01$) showing clumping distribution pattern in fir dominated stand. Besides, increasing altitude caused a significant decrease in beech CE index ($r(15) = -0.52$, $p < 0.05$).

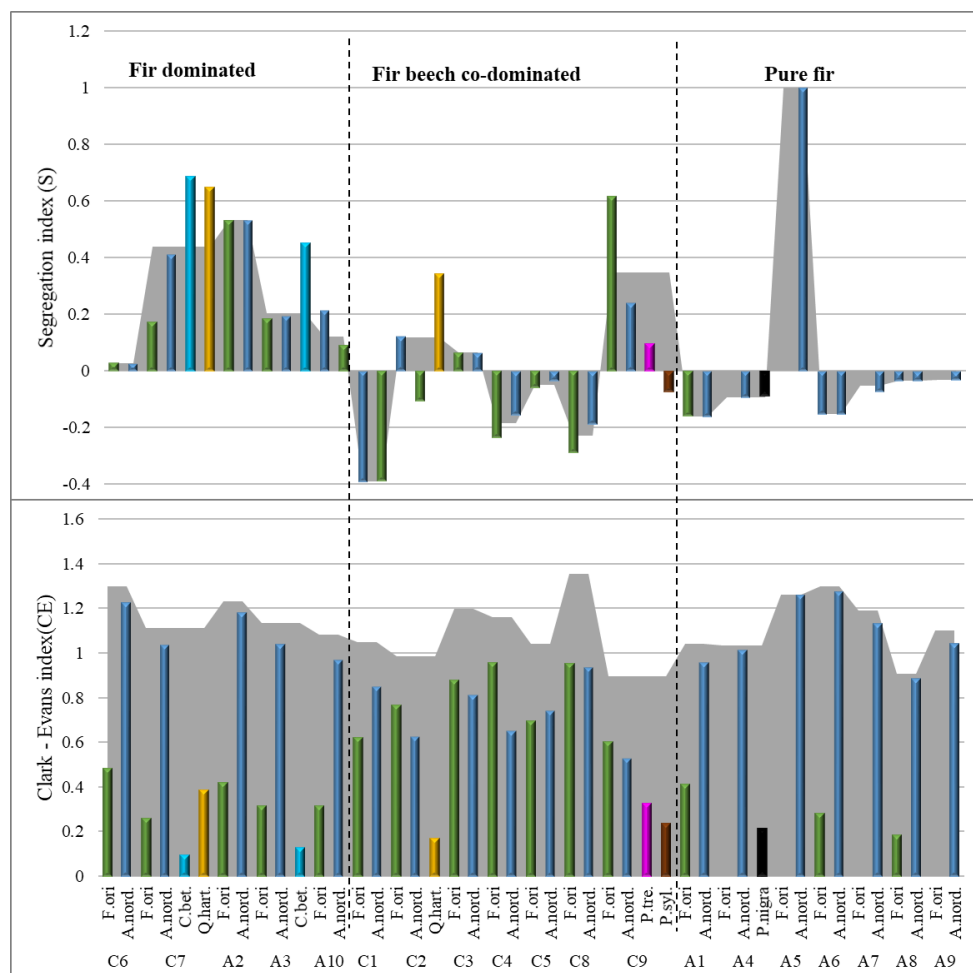


Figure 3. Species segregation (S) and Clark-Evans aggregation (CE) index in plots (gray area represent plot mean; F.ori: *Fagus orientalis*, A.nord.: *Abies bornmuelleriana*, C.bet.: *Carpinus betulus*, Q.hart: *Quercus hartwissiana*, P.trem.: *Populus tremula*, P.syl: *Pinus sylvestris*)

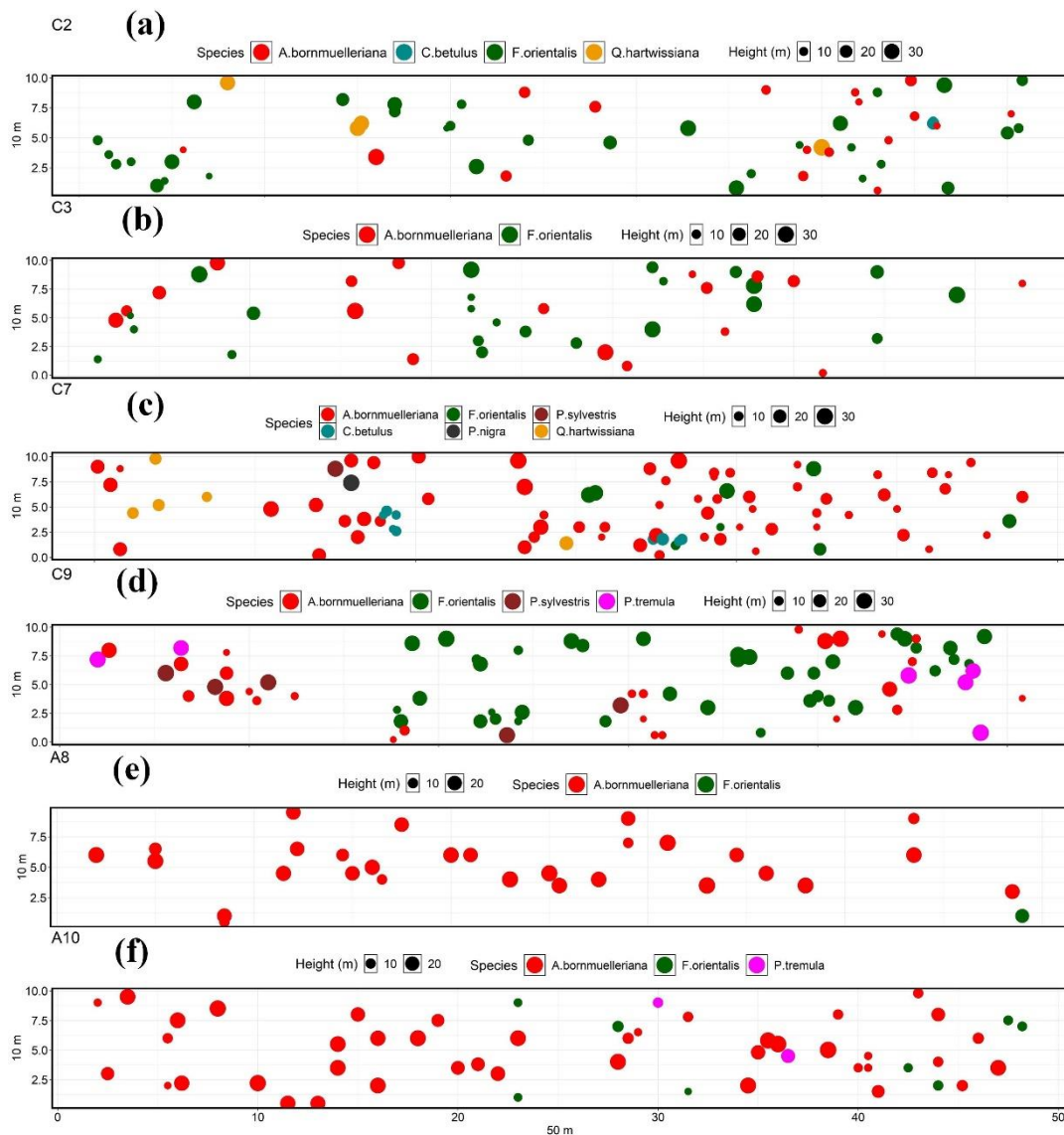


Figure 4. Some of the horizontal stand profiles mentioned in the text (sizes of the circles represent tree heights)

The Mi distribution clearly reveals that *Abies bornmuelleriana* and *Fagus orientalis* have an opposite behaviour in fir dominated and co-dominated stands. *Abies bornmuelleriana* does not form pure groups in fir-beech co-dominated stands where it occurs from low to complete mixtures, but *Fagus orientalis* can also occur in pure groups (17-40 %) (Figs. 4a, b, d and 5). On the other hand, *Abies bornmuelleriana* predominantly occurs either in pure groups (20-60%) or low to medium mixtures in fir dominated stands. Here, *Fagus orientalis* occurs from medium to complete mixtures with other deciduous trees but not in pure groups (Figs. 4c, f and 5). In addition, correlation analysis showed a negative correlation between fir ratio and species Mi ($r(18) = -0.80$, $p < 0.001$) and Shannon diversity ($r(18) = -0.69$, $p < 0.01$) which means that abundant fir ratio decrease mixture and tree species diversity (Table 2). However, increasing beech ratio causes a regular distribution of beech ($r(15) = 0.69$, $p < 0.01$) and high mingling of species ($r(15) = 0.66$, $p < 0.01$) in the stand.

Pinus sylvestris is surrounded by mostly different species in line with CE and S indexes. Since small clusters or individuals of species (i.e. *Carpinus betulus* and *Quercus hartwissiana*) were always surrounded by different species, Mi index does not reveal pure groups of species, instead a low mingling value (Figs. 4c and 5). However, using CE, S and Mi indexes give detailed information about the spatial distribution of all species.

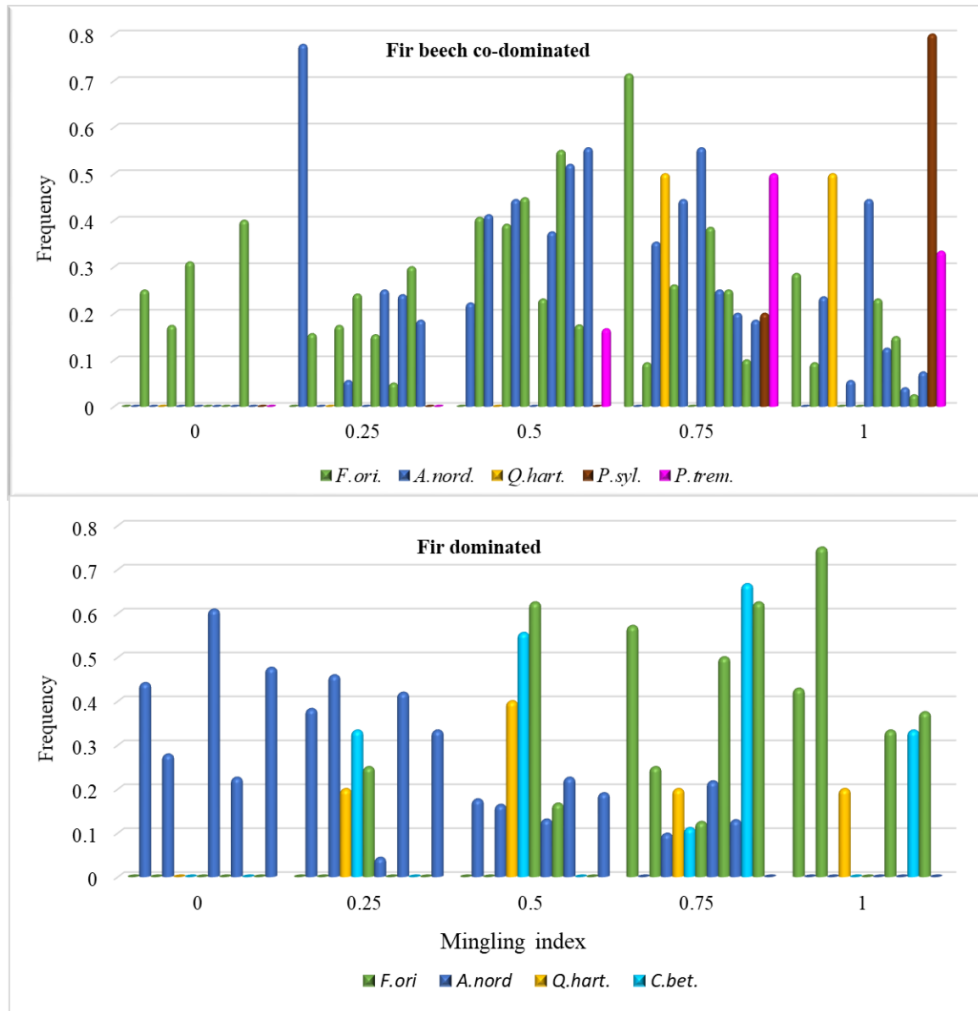


Figure 5. Species mingling (Mi) index of species in fir beech co-dominated and fir dominated stands (F.ori: *Fagus orientalis*, A.nord.: *Abies bornmuelleriana*, P.syl: *Pinus sylvestris*, P.trem.: *Populus tremula*, Q.hart: *Quercus hartwissiana*, C.bet.: *Carpinus betulus*)

Table 2. Pearson product moment correlation between indices and other parameters (* $P < 0.05$, ** $p < 0.01$, *** $P < 0.001$; CE: aggregation index of Clark-Evans, S: species segregation index, Mi: species mingling)

	Fir ratio	Beech ratio	CE)	S	Mi	Beech CE	Fir CE	Beech Mi	Fir Mi	Shannon index
Altitude	0.06	-0.13	-0.09	0.58**	-0.027	-0.52*	0.13	-0.21	0.21	0.09
Slope (°)	-0.035	-0.452	-0.265	0.042	0.083	-0.267	-0.247	0.389	-0.016	0.19
Fir ratio			0.18	0.31	-.80***	-0.70**	0.63**	0.86***	-.97***	-.69**
Beech ratio			-0.05	-0.34	0.66**	0.69**	-0.41	-0.87***	0.93***	0.40

Discussion and conclusions

Northern Anatolia exhibits a great variety of forest types composed of many tree species owing to differing edaphic, climatic and topographical factors (Çoban and Willner, 2019). Mountain ranges extending east-west direction cause both altitudinal and horizontal differences in forest communities. For instance, the isolation effect of high mountains increases continental effect which is reflected in the dominance of coniferous forest at the expense of deciduous trees towards inland (e.g. Aladağ Mountain). For this reason, deciduous mixed forests are mostly replaced by pure or fir dominated montane coniferous forests on north facing slopes, while southern slopes are dominated by *Pinus sylvestris* dominated forests in Sub-euxine zone (Aydın et al., 2008). The current study showed a significantly lower tree species richness in fir and beech forests of Aladağ mountain (0.418 ± 0.081) compared to Yenice (0.824 ± 0.066). Accordingly, tree species richness of Yenice forest was given as 24 containing 20 deciduous trees (Özalp, 1989) and 15 containing 12 deciduous trees on Aladağ (Aksoy et al., 2012). This reveals a decrease in the numbers of tree species in forest composition from north to south due to decreasing annual temperature and precipitation. Thus, the first hypothesis was not supported by the results of this study since tree species diversity was significantly lower in fir stands of Aladağ mountain located in the edge of sub-euxine zone. However, species richness is only one component of forest biodiversity which comprises genetic and ecosystem diversity (Simberloff, 1999). According to Pommerening (2002), spatial stand structure, which is an important factor in determining habitat and species diversity, is linked to the ecological stability of forests. For this reason, determination of forest structural attributes are suggested for an effective forest management (Latham et al., 1998; Ehbrecht et al., 2017; Vilà-Cabrera et al., 2018; Pöldveer et al., 2020).

Spatial pattern is a matter of concern within silviculture since regular distribution provides maximal space and optimal growing conditions, while a clustered distribution causes increment loss (Pretzsch, 1995; Neumann and Starlinger, 2001; Del Río et al., 2016). Spatial distribution of tree species in mixed forest is determined by many factors related to habitat heterogeneity and environmental requirements of species. Besides, species with differing tolerances to environmental factors are confined to their own niche which causes clumped distribution (Pielou, 1961). Segregation between two species occurs when one species is more likely to be found near its own species. According to Pielou (1961), if both species are aggregated it does not necessarily follow that they will be segregated from each other. Thus, one of the species may have clumped pattern whereas other has regular pattern also means segregated distribution. Therefore, segregated distribution reveals that at least one of the species has been effected from habitat patchiness or familial clumping. Segregated and aggregated stands present group mixture of two species (Pielou, 1961). This situation was revealed with the comparison of CE and S indexes in the fir dominated forest where clumped pattern of *Fagus orientalis* (Beech $CE < 1$) and regular pattern of *Abies bornmuelleriana* (Fir $CE > 1$) revealed a segregated pattern between two species (Figs. 3 and 4f). Similarly, *Quercus hartwissiana*, *Populus tremula* and *Carpinus betulus* had clumping pattern with segregated and clumping distribution ($S > 1$, $CE < 1$). On the other hand, clumped and unsegregated distribution of both species in fir-beech co-dominated forest means more or less single mixtures of both species. According to Neumann and Starlinger (2001), both CE and S are describing microstructure by focusing on the distances between single trees or sample points to trees, respectively. Besides, mingling index

describes mutual positioning of different species or intermingling (Szmyt, 2012; Pöldveer et al., 2020). In this study, differing spatial patterns were determined among species. *Fagus orientalis*, which is the most common tree species co-occurring with *Abies bornmuelleriana*, had both regular and clumping distribution depending on the stand type. In contrast, a regular distribution of *Abies bornmuelleriana* was found in pure fir and fir dominated stands which were also supported with the correlation between fir ratio and fir CE ($r(18) = 0.63$, $p < 0.01$). Such variations might be caused by both habitat heterogeneity and silvicultural characteristics of the species. Petritan et al. (2015) explained the regular distribution of fir overstorey trees by their smaller crown radii compared to beech and the different crown shape, which allow them to grow closer together. On the other hand, *Abies bornmuelleriana* and *Fagus orientalis* are characterised as shade-tolerant species and can thrive under sheltered conditions for a long time. However, fir has a lower assimilation capacity which reflects its greater shade tolerance and ability to grow assimilation tissue under lower lights conditions than beech. For this reason, beech reacts much faster to changes in light intensity and adapts better in gap openings (Čater and Levanič, 2013). Besides, the behaviour is not totally fixed and shade tolerance within species may be affected by site quality (Carter and Klinka, 1992). Shade tolerance of both dominant species provided a high degree of spatial mingling in fir-beech co-dominated forest. *Fagus orientalis* showed segregation and low mingling values in fir dominated forest but the spatial association with other species in fir-beech co-dominated stands. This might be caused by habitat heterogeneity or beech are not so competitive in fir dominated sites where it can only thrive in groups. Özel and Ertekin (2012) indicate that the mixture rates of fir increase depending on altitude in NW Anatolia. Hence, *Fagus orientalis* is confined to the most suitable niches as determined by the correlation between altitude with CE of beech ($r(15) = -0.52$, $p < 0.05$) and with S ($r(19) = 0.58$, $p < 0.01$) which indicate increasing clumping pattern at higher altitudes. Bulušek et al. (2016) indicated that clumped spatial pattern of beech was positively influenced by increasing altitude, extreme conditions of the site as well as by stand density in European beech (*Fagus sylvatica* L.) stands. Thus, the second hypothesis was not supported by the results of this study since the spatial pattern of *Fagus orientalis* does not solely depend on shade tolerance but site condition or stand type which effect its competition capacity.

The main differences in the spatial pattern were determined between light demanding deciduous trees and shade tolerant species. In stands dominated by both shade tolerant species, light demanding deciduous trees such as *Quercus hartwissiana*, *Carpinus betulus* and *Populus tremula* were observed in pure groups. This finding was also supported by Petritan et al. (2012) who highlighted that oak in beech dominated stand has a greater chance of survival when co-occurring in groups. In contrast, light demanding *Pinus sylvestris* and *Pinus nigra* did not show a tendency towards clumping and had a spatial association with other species. Because, these species always situated within the overstorey layer and excluded from suppress of shade tolerant species such as *Abies bornmuelleriana* and *Fagus orientalis*. Indeed, *Pinus sylvestris* and *Pinus nigra* situated in the upper stand layer in all stand types (Özalp, 1989). In addition, pioneer characters of these species allowed early establishment in the successional stage. As a result, light demanding coniferous trees which showed a random distribution and spatial association with other species. Whereas other light demanding deciduous trees showed segregated and clumped distribution.

In conclusion, the diversity of spatial patterns in pure and mixed stands arise as a result of the species identity of dominant species (Petritan et al., 2015) and habitat heterogeneity. However, species with identical characteristics can create varied patterns depending on the dominated species and site quality. In this respect, spatial and structural patterns of diverse forests must be determined for developing appropriate silvicultural methods. Stand profiles, which are based on actual field measurement, are useful tools for analysing both structural and spatial characteristics of the forest using spatial and structural indices. Especially, if the sizes (diameter and height) of each tree were given in the profile, competition between tree species can be calculated with different indices. Thus, as indicated by Kint et al. (2003), the impact of management and/or competition on stand structure can be evaluated details. Stand profiles, which were sampled from different forest types, provide new opportunities using spatial pattern analysis. According to Yılmaz et al. (2019), analysing the spatial structure of forests reveals competition relationships among trees which make valuable contributions to silvicultural treatments. Especially, detection of tree spatial patterns and structural attributes in a forest stand can provide critical information on occurring dynamics, and steer management decisions (Carrer et al., 2018). Therefore, old or new stand profiles can be used to develop appropriate silvicultural methods for various stand types using spatial pattern analysis. At this point, terrestrial laser scanner technology, which provides many individual tree attributes with high accuracy, can be used to obtain stand profile data (Yurtseven et al., 2019).

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