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Assessment of competition indices of an unlogged oriental beech mixed stand in Hyrcanian forests, Northern Iran

MOJTABA AMIRI♥, REZA NAGHDI
Faculty of Natural Resources, Semnan University. Semnan-35131-19111, Iran. Tel.: +98-9169596900. ♥email: mojtabaamiri@semnan.ac.ir

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Abstract. *Amiri M, Naghdi R. 2016. Assessment of competition indices of an unlogged oriental beech mixed stand in Hyrcanian forests, Northern Iran. Biodiversitas 17: 306-314.* Studying on structural dynamics of natural forest ecosystems is an important subject in close-to-nature silviculture and the pertaining tending operations. The objective of this research was to analyze the competition indices of the tree species and some structural characteristics in an unlogged mixed-beech natural forest stand located in Shastkalate forest, Northern Iran. To do so, the required data was collected from a 16ha (400×400 m^2) permanent plot established in 2006. The characteristics of the trees including species, DBH, total height, stem height, crown diameter, and the distance between the stems were measured and recorded. The results indicated that alder and wild service have the highest and lowest DBH, respectively, and also beech species comprises almost half of the basal area as well as the total volume of the stand trees. The results of competition effect on the distribution of the given species tree stems and also on low (≤30 cm), medium (35-50 cm), large (55-70), and very large (>75 cm) diameter classes showed that the competition existing among individual trees decreased as their respective distances, DBH, and crown area enhanced by the increase in distance, such that the highest (R^2_{adj} = 0.79) and the lowest (R^2_{adj} = 0.38)values of competition indices (e.g. Stand density and Relative Spacing index) were, respectively, observed in ≤30 cm and >75 cm diameter classes. The data of the present research, as well, indicated that a more appropriate competition index can be selected by increasing the number of the variables applied in competition indices such as considering the distance among stems, DBH, crown area, and height. As a whole, in the present study the distance-dependent competition indices (e.g. distance-weighted size ratios and Daniel et al) presented better results.

Keywords: Competition indicators, intact forest stands, Oriental beech, Caspian Forests

INTRODUCTION

One of the challenging subjects in ecology is the mechanisms by which plants influence on each other (Bazzaz 1996; Koocheki et al. 2005). The competition existing across the surface of vegetation is one of the significant mechanisms. Also, competition is a fundamental ecological process driving succession in a forest and effects on forest composition and stand structure (Akhavan et al. 2012). Understanding competition among tree species is especially important when management goal is to mimic the dynamics of natural ecosystems (Akhavan et al. 2012). This process arises when neighboring plants share limited resources, leading to a reduction in survivorship and/or growth rate (Clements 1929; Grime 1979; Begon et al. 1996; Oliver and Larson 1996; Avery and Burkhart 2002). For this reason, competition has long been known as a primary process governing population size, community structure and diversity (Oliver and Larson 1996; Newton and Jolliffe 1998; Simard and Sachs 2004; Simard and Zimonick 2005).

Also, intra- and inter-species tree competition is a critical factor effecting on forest succession. Based on the mentioned definition, competition is the interaction among individuals leading to a reduction in the survivorship and also an increase in mortality, growth rate and regeneration of competing individuals (Connell 1983; Schoener 1983; Goldberg 1987; Keddy 1989; Grace and Tilman 1990; Begon et al. 1996; Corral-Rivas et al. 2005). In the trend of succession, competition plays an important role in species substitution (Koocheki et al. 2005), and competitive dynamics between trees is ultimately a key factor in shaping forest stand evolution (Tillman 1982; Brand and Magnussen 1988). On the other hand, Disturbance is considered as a mechanism starting a succession and able to exert a long-term effect on stands growth and succession stages by changing competition dynamics amongst trees (Weber et al. 2008). In forest succession, competition is assumed to play a major role in species replacement. Disturbance is viewed as a mechanism for initiating succession (Bazzaz 1996), which can have a long-term effect on stand development and successional pathways (Oliver and Larson 1996) by changing competitive dynamics among trees. When predicting future forest development, reconstructing past disturbance regimes and identifying changes in competitive interactions are key issues. Understanding the dynamics of forest stands with strong past anthropogenic disturbances is particularly difficult because the different types of human impact typically vary in time and space (Webber et al. 2008; Amiri et al. 2013).

Akhavan et al. (2012) studied the application of bivariate Ripley's K-function for studying competition and spatial association in an intact oriental beech stands in the Kelardasht region, north of Iran. The results of their research showed that the association patterns varied among different size classes across different developmental stages, likely due to shade-tolerance features, seed dispersal limitation, and intra-specific competition of beech trees. This study highlighted the importance of competition in understanding the stand dynamics of beech forests across development stages. Corral-Rivas et al. (2005) and Daniel et al. (2008), respectively, evaluated the effect of competition on basal-area growth in Durango pine stand, Mexico and Norway spruce, Toronto, Italy. Employing the competition index dynamics in the past, Weber et al. (2008) carried out a research in mixed pine and oak stands of Alpine arid regions and Vallis valley in a 30-year period. In another study, Sagheb-Talebi and Shutz (2012) studied some criteria of density in the beech saplings of various forest associations growing in the sub-mountain region near Zurich, Swiss Central Plateau. Then, three collective criteria: (i) number of saplings (N.m^2), (ii) mean distance of saplings, and (iii) crown competition factor, and one individual criterion (growth space) were investigated within the sample plots. Their findings showed that the density of beech saplings was not homogenous. The number of saplings had wide amplitude varying between 2.5 and 54.8n.m^2, and the mean distance of saplings was between 14.5 and 68 cm. The crown competition factor varied between 1 (100%) and 5 (500%) indicating a five-fold overlapping in crown space of saplings. Also, Elahi et al. (2014) surveyed intraspecific competition of *Amygdalus orientalis* which was influenced by physiographic factors (slope, aspect and altitude) in the Semiroms Tang Khoshk forest reserve. Data showed that the competition index is substantially higher on western slopes. In addition, the competition index decreased on altitudes higher than 2200-2300m, as well along with increasing the slope.

The objective of this research is to analyze the competitive indices in a mixed broad-leaf beech stand in Hyrcanian forests, Iran. The following questions were presented as the research hypotheses: Does competition effect on the stand structure? How many categories are the competitive indices divided in to, and which indices' effect is more considerable on the properties of stand structure? Species competition is a critical factor in property variations of the existing trees structure in a beech mixed stand, especially the main species of stands including beech and hornbeam.

MATERIALS AND METHODS

Study site

This study was carried out in the 89.7ha natural unlogged oriental beech (*Fagus orientalis* L.) stand in compartment 32, district 1, located at Shast Kalateh Forest in the eastern Caspian region, North of Iran on 36° 43′ 27 ″ N, 54° 24′ 57″ E (Figure 1). Elevation of the study area varies from 820 to 960 m asl., with an average monthly temperature of 15.4°C, with maximum and minimum temperature in July (28.7°C) and February (8.71°C), respectively. Mean annual precipitation is 650mm. According to the De Martonne and Emberger classifications, the climate of the study area is cold and humid, having a temperate summer with short dry season. Stand total height is about 30 m, and the canopy cover varies between 60 and 100% (Habashi et al. 2007). Soil texture is loam to clay-loam with a pH of 5.5, and the soil is classified as brown type. Mean stand density and standing volume are 235ha^{-1} and 463m^{3}ha^{-1}, respectively (Anon. 1995, 2008). The compartment consists of a natural, mixed, uneven-aged deciduous old-growth forest dominated by shade-tolerant oriental beech with minor components of other broad-leaved species including hornbeam (*Carpinus betulus* L.), velvet and cappadocian maple (*Acer velutinum* Boiss. and *Acer cappadocicum*), Caucasian alder (*Alnus subcordata*), ironwood (*Parrotia persica*), date plum (*Diospyrus lotus*), and elm (*Ulmus glabra* Huds.). The compartment experienced very limited human intervention and disturbance and had no silvicultural activity in the last 50 years since forest management plans started in Iran. Therefore, this stand could be regarded as an example of an intact and unmanaged natural forest (Habashi et al. 2007).

Figure 1. Location of the study site in the Hyrcanian Forests, northern Iran

Living trees measurement

Selection of the 16ha (400×400m) permanent research plot in compartment 32, District 1 Shast Kalateh forest beech stand was made according to: (i) long period without management, that is about 50 years and (ii) the permanent plot should be homogeneous regarding to the slope and aspect. The plot was divided into 64 subplots of 50×50m. All living trees with a diameter at breast height (DBH) of ≥7.5 cm (Delfan-Abazari et al. 2004) were identified by species and their DBH, total height (m), and crown height (m) were measured within subplots. The position of the trees was determined by measuring their coordinates (distance and azimuth) in each subplot (Habashi et al. *20*07; Mataji et al. 2007; Akhavan et al. 2012). Distance and height measurements were made with Laser Distance Meter (Leica Disto D5). The vertical profile of the stand was divided into three height layers (lower, medium and upper) compared to the dominant height that reached 34m. All of the measured trees were assigned to one of the four diameter size classes: small size (dbh ≤32.5 cm), medium size (32.5< dbh ≤ 52.5), large size (52.5 < dbh ≤ 72.5), and very large size (dbh ≥72.5 cm) (Sagheb-Talebi and Schutz 2002; Sagheb-Talebi et al. 2005; Eslami et al. 2007).

Selection and measurement of competition indices in the forest stands

In general, several competitive factors have been used for species competitions that are evaluated based on variables type (Tome´ and Burkhart 1989; Begin and Dobbertin 1992; Wallace et al. 1998; Bachmann 1998; Corral-Rivas et al. 2005; Alvarez et al. 2003; Daniel et al. 2008). The archival journal publications clearly show that the use of competition indices has been extensively rising in the recent years. In order to understand competitive dynamics, several competition indices have been developed through time to assess the competitive intensity occurring on either the whole stand or the individual trees. Stand-level competition indices reflect the degree of tree crowding per unit area (Husch et al. 1982), allowing to compare competitive status in different stands. Individual-based competition reflects the local density of competitors interacting with an individual tree (Tome and Burkhart 1989).

The measures of density described previously are usually employed to determine the density of a stand in general or "on average". More specific measures of density have been developed to describe the degree of competition at a given point of tree in the stand. These measures have been referred to as either point density estimates or competition indices. The basic idea of these indices is to describe the degree to which growth resources (light, water, nutrients, and physical growing space) available to an individual tree are limited by neighboring trees. The increased interest in modeling individual tree growth and yield has produced a number of competition indices, which can be broadly classified into two categories including both the distance-independent and the distance-dependent indices (Corral-Rivas et al. 2005; Daniel et al. 2008).The stand density measures discussed by far are aimed at providing an estimate of the average completion level in stands. Point density measures attempt to quantify the competition level at a given point or tree in the stand (Avery and Burkhart. 2002).

Distance-independent indices

Distance-independent measures describe the competition status of a tree or class of tree relative to all trees in the stand. The main advantage of distance-independent indices is that time-consuming measures of the tree location are not required. The main disadvantage is that these indices measure a tree's status relative to average stand conditions rather than the immediate conditions surrounding the tree (Avery and Burkhart. 2002; Daniel et al. 2008).

Stand density index

The number of trees per unit land area can be used as another measure of stand density. At any age, there can be a wide range in the number of trees per unit land area, so that frequency by itself is of little value. For a useful descriptive measure of stand density, number of tree must be qualified by tree size. A useful measure of density for even-aged and uneven-aged stands based on number of trees is Reineke's stand density index (Reineke 1933). This stand density index is the number of trees per unit area that a stand would have at a standard average DBH. In the metric system the standard DBH is 10 cm. Reineke (1933) defined the stand density index relationship as (Eq. 1):

$$logN = blog\overline{D_Q} + a \quad (1)$$

Where,
N = stand density (trees per hectare)
$\bar{D}$ = quadratic mean diameter (diameter of tree of average basal area)

Reineke (1933) found that the b constant was -1.605 for several species, independent of site quality and age. Other investigators note that the linear relationship expressed by the equation holds for many species and that the slop (b) differ little, although the constant a (i.e., the intercept) varies considerably. The stand density index for any stand can be determined by plotting the position of the observed number of trees/ha and the quadratic mean DBH on the stand density. The stand density index is indicated by the closest line to the plotted point, which can be found by interpolation between the index lines. Alternatively, the stand density index can also be calculated from the formula (Eq. 2):

$$\log SDI = \log N - b\ .\left(\log \bar{D}_Q - \log \bar{D}_1\right) \quad (2)$$

Where,
SDI = Reineke's stand density index, N = number of trees per unit area
D_a = quadratic mean diameter (diameter of tree of average basal area)
D_I = standard diameter
logSDI = log N-b (log D_a-log D_I)

Relative spacing

Another expression of stand density is relative spacing. The average distance between trees divided by the average height of the dominant canopy has been termed relative spacing. In other words, RS_H is the average spacing between trees, assuming square spacing, divided by the average height of the dominant trees. Relative spacing (RS) is computed as (Eq. 3):

$$RS_H = \frac{A/_N}{H_D} \quad (3)$$

Where,
A = unit area (ha)
N = number of trees per unit area (ha)
H_D = average height of dominant trees (m)

In the relative spacing index numbers will usually be round or decimal numbers such as 0.15 or 10, 11, or 12. Also, the RS index is higher when N is larger.

Basal area index

An example of a distance-independent index is the basal area index proposed by Glover and Hool (1979) (modified by Houtch et al. 2002 and Avery and Burkhart 2002):

$$G_i = \frac{\pi(\frac{D_i}{2})^2}{\pi\left[\left(\sum_{j=1}^{n} D_i/n\right)/2\right]^2} = \frac{D_i^2}{\bar{D}^2} \quad (4)$$

Where,
G_i = basal area index for *i*th tree,
D_i = diameter of *i*th tree
$\bar{D}$ = mean plot or stand diameter

Crown Competition Factor

This index developed by Krajicek, Brinkman and Gingrich (1961), Crown competition factor (CCF) is a measure of stand density rather than of crown cover. CCF reflects the area available to the average tree in a stand relation to the maximum area it could use if it were open-grown. The compute CCF values, the crown-width/DBH relationship for open-grown trees of species of interest must be established (Avery and Burkhart 2002).

On the other hand, a measure of stand density, which in final form is similar to the tree-area ratio, although considerably different in derivation, is the crown competition factor (CCF) proposed by Krajicik et al. (1961). The CCF is considered independent of site quality and stand age and can be used in both even-and uneven-aged stand (Eq.5).

$$CCF = \frac{\frac{\sum_{i=1}^{n}\left(\pi.mcw_i^2\right)}{4}}{S} \quad (5)$$

Where,
CCF = Crown competition factor,
mcw = maximum crown width
S = Crown area

Distance-dependent indices

Distance-dependent indices attempt to describe a tree's competitive status based on the immediate conditions surrounding the tree. Distance-dependent indices fall into three broad classes (Avery and Burkhart 2002): area overlap indices, distance-weighted size ratios, and area potentially available or polygons indices (Figure 2). These competition indices provide an estimate of the degree to which growth resources (e.g., light, water, nutrient, and physical growing space) may be limited by the number, size, and proximity of neighbors. The actual competition processes among trees are much more complex than can be described by a reasonably simple mathematical index. However, these indices have been found useful for predicting tree mortality and growth. A large number of distance-independent competition indices have been developed. These indices are described in three classes: (i) area-overlap measurement, (ii) distance-weighted size ratio indices, and (iii) area-available (or polygon) indices.

Area overlap indices

Area-overlap indices are based on the concept that there is a competition influence zone around each tree. Typically, this area over which the tree is assumed to compute for site resources is represented by a circle whose radius is a function of tree size. The area overlap competition index proposed by Gerrard (1969) is as follows: (Eq. 6)

$$CI_i = \frac{1}{A_i}\sum_{j=1}^{n} a_j \quad (6)$$

Where,
CI_i = Competition index for subject tree i
A_i = area of competition circle for subject tree i
n = number of competition,
a_j = area of overlap of the *j*th competitor

The basic premise of Gerrard's index is that the competitive stress sustained by a tree is directly proportional to the overlapping area of its competition circle with those of its neighbors and inversely proportional to the area of its own competition circle. Area overlap indices are based on the idea that each tree has a potential area of influence over which it obtains or competes for site factors (Opie 1968). All trees whose areas of influence overlap with a subject tree's area of influence are considered competitors (Figure 2.A).

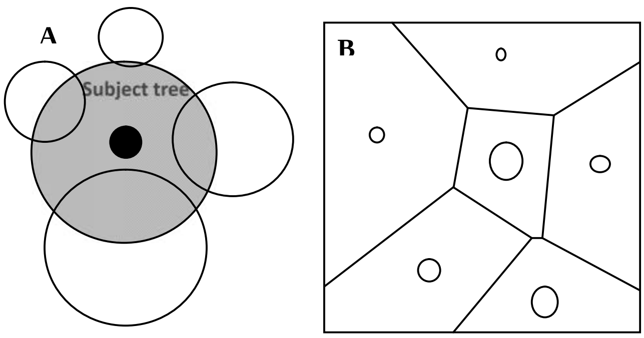

Figure 2. Examples of distance-dependent indices: A. Area overlap concept adapted from Clutter et al. 1983; B. Area potentially available or polygons adapted from Daniels et al. (2008) and Husch et al. (2002).

Distance-weighted size ratios

Distance-weighted size ratios are calculated as the sum of the ratios between the dimensions of each competitor and those of the subject tree, weighed by a function of inter tree distance (Tome and Burkhart 1989). An example is the Competition index proposed by Hegyi (1974).

$$G_i = \sum_{j=1}^{n} \frac{D_j / D_i}{L_{ij}} \quad (7)$$

Where,

C_i = Competition index for subject tree

D_j = diameter of *j*th competitor

D_i = diameter of subject tree

L_{ij} = distance from subject tree to *j*th competitorn = number of competitors

Hegyi (1974) defined n as the number of trees within a fixed radius of the subject tree. Daniels (1976) modified the index defining n as the number of trees within a fixed-angle gauge sweep.

The index of area potentially available

The mentioned index utilizes polygons created by the intersections of the perpendicular bisectors of the distance between a subject tree and its competitors (Figure 2.B). The polygon area, as calculated from the coordinates of the vertices, is the area potentially available for tree growth (Brown 1965). Moor et al. (1973) modified the index, so that the division was weighed by tree size (Eq. 8):

$$I_{ij} = \frac{D_i^2}{D_i^2 + D_j^2} L_{ij} \quad (8)$$

Where I_{ij} = distance from subject tree to weighed midpoint between subject tree and competitor

D_i = diameter of subject tree

Dj = diameter of *j*th competitor

L_{ij} = distance between subject tree and *j*th competitor

As mentioned above, numerous indices have been developed. Each index is derived based on a certain assumption about how the competitive process is manifested. Daniels (1976) suggests that the utility of an index be judged base on correlation with observed tree growth and computational simplicity. Several publications have investigated the efficacy of these measures for predicting individual tree growth (Alemdag. 1978; Noone and Bell 1980; Martin and Ek 1984; Daneils et al. 1986; Tome and Burkhart 1989; Biging and Dobbertin 1995; Avery and Burkhart 2002, Van Laar and Aka 2007).

RESULTS AND DISCUSSION

Quantitative characteristics of stand

The permanent plot consists of 10 species including beech, hornbeam, ironwood, alder, velvet maple, Cappadocia maple, lime, date plum, mountain elm, and wild service. The results of the present research indicate that alder and wild service have the highest and lowest DBH, respectively. Beech and ironwood with 116 and 77 stems, respectively, have the highest number per hectare, while Cappadocia maple, lime, mountain elm, and wild service each have only one stem per hectare (Table 1). Beech contains half of the basal area per hectare of the whole trees (17.2 m^2). Alder and lime with average heights of 31.3 m and 14.1 m are, respectively, the tallest and shortest among the whole stand trees. Beech and date plum have the highest and lowest crown area per hectare with 106.5 m^2 and 37.6 m^2, respectively. The least and most distance among tree stems refer to beech (4.5 m) and alder (69 m), and as for lime, mountain elm, wild servie, and Cappadocia maple, due to their small number per hectare, the average distance among trees was disregarded (Table 1).

Based on diameter classes, Table 2 exhibits the quantitative characteristics of trees in the studied permanent plot. Trees in diameter classes of <30 cm and 55-70 cm have, respectively, the largest and smallest number per hectare, whereas for the other quantitative characteristics of the studied stand including basal area, volume, average height, crown area, and average distance among stems, the very large diameter class >75 cm showed the highest values (Table 2).

Competition indices of stand

Based on the type of variables applied, the results obtained from the relation between basal area growth and competitive indices indicate that among the distance-independent indices, Reinke density and relative spacing indices own the highest R^2-adjust, respectively (Table 3). There is no statistically significant relation between the values obtained from the two mentioned indices and basal area growth. The results, also, show that among the distance-dependent indices, Daniel et al. (2008), Hegyi (1974), and Rouvinen and Kuuluvainen (1997) indices have the highest R^2-adjust.Thus, the above-mentioned indices have a lower square mean error, compared to the other indices. For the indices of crown area such as relative spacing, closed crown, and crown competitive coefficient, R^2-adjust, as well, increased by adding more variables; for instance, the value R^2-adjust is higher than those of the closed crown and crown competitive coefficient having a lower R^2-adjust and consequently a higher square mean error (Table 3).

The results presented in table 4 indicate that the R^2 and root mean square error values differ based on the type of variable and diameter classes used in different indices. As observed in table 4, the larger the number per hectare of trees in a stand is, the higher the R^2 value for the applied index is. It can, thus, be said that due to the large number per hectare of the stems, young and middle-aged diameter classes (35-50 cm and ≤30 cm) have a higher R^2 compared to 55-70 cm and >75 cm diameter classes. However, considering the type of the applied variable in the index, R^2 and root mean square error values of the given index are, as well, varied (Table 4).

Table 1.Structural characteristics of the living trees on the studied permanent research plot, based on species

Species name	DBH (cm)	Density (n.ha)	Basal area (m^2)	Height (m)	Volume (m^3)	Crown area (m^2.ha)	Average distance between of stem (m)
Beech	47	116	17.2	28.7	264	106.5	4.50
Horn beam	40.5	62	8.07	27.4	113.8	92.7	6.84
Ironwood	28	77	4.7	20.7	49	91.5	5.37
Date Plume	13.5	21	0.29	20.4	2.67	37.6	9.30
Velvet maple	48	9	1.6	28.5	25.8	94.6	15.75
Alder	69	3	0.94	31.3	15.8	86.7	25.85
Cappadocia maple	39	1.3	0.09	20.1	1.6	61.2	37.70
Lime tree	48	0.21	0.02	14.9	0.2	48.8	-
Elm	22	0.31	0.01	16.5	0.14	35.4	-
Wild service	12	0.06	0.003	15.2	0.09	48	-

Table 2. Main structural characteristics of the living trees on the studied permanent plot based on DBH classes

Diameter classes (cm)	DBH (cm)	Density (n.ha)	Basal area (m^2)	Height (m)	Volume (m^3)	Crown area (m^2.ha)	Average distance between of stem (m)
≤30	19.7	117.2	4.35	17.64	37.55	54.10	3.82
35-50	42.24	40.3	5.74	24.98	70.28	73.35	7.92
55-70	62.5	24.6	7.7	28.9	109.2	89.6	9.6
>75	107.34	25.8	16.34	36.3	253.3	187.8	12.56

Table 3. Analysis of competitive indices in the permanent plot based on structural characteristics

Competition index	Variable type	R^2_{adj}	RMSE	F-Value	P-Value
Stand density (Rienkeh Index)	n.ha, DBH	0.73	0.48	6.54	0.002
Relative Spacing index	Crown area, n.ha and Height	0.66	0.52	1.7	0.03
Basal area index	DBH	0.28	0.54	1.34	0.34
Crown Closure index	Plot size, Crown width	0.42	0.58	5.28	0.22
Crown Competition Factor	Maximum crown width, Plot size	0.49	0.47	3.9	0.04
Area overlap indices (Gerrard's index)	Crown area, Distance	0.347	0.46	1.27	0.52
Distance-weighted size ratios (Hegyi 1974; Rouvinen and Kuuluvainen1997)	DBH, Distance	0.57	0.49	2.82	0.023
area potentially available index (Brown 1965; Moor et al. (1973)	DBH, Distance	0.66	0.54	5.45	0.027
Alvarez et al. (2003)	Distance, Crown area	0.39	0.46	1.38	0.43
Daniel et al. (2008)	Distance, Crown area, Height	0.63	0.50	5.54	0.034

Table 4. Analysis of competitive indices in the permanent plot based on diameter classes

Diameters classes (cm)	≤30		35-50		55-70		75[	
Competition index	R^2_{adj}	RMSE	R^2_{adj}	RMSE	R^2_{adj}	RMSE	R^2_{adj}	RMSE
Stand density	0.79	0.54	0.61	0.53	0.48	0.54	0.38	0.61
Relative Spacing index	0.62	0.58	0.55	0.51	0.37	0.46	0.26	0.51
Basal area index	0.21	0.58	0.34	0.35	0.385	0.44	0.48	0.51
Crown Closure index	0.19	0.70	0.22	0.52	0.35	0.46	0.54	0.49
Crown Competition Factor	0.24	0.66	0.26	0.52	0.42	0.49	0.46	0.40
Area overlap indices (Gerrard's index)	0.34	0.45	0.38	0.51	0.46	0.49	0.56	0.50
Distance-weighted size ratios (Hegyi 1974; Rouvinen and Kuuluvainen 1997)	0.58	0.48	0.52	0.46	0.4	0.57	0.35	0.62
Index of area potentially available (Brown 1965; Moor et al. 1973)	0.53	0.50	0.46	0.58	0.38	0.59	0.29	0.64
Alvarez et al. (2003)	0.68	0.51	0.57	0.49	0.51	0.50	0.43	0.64
Daniel et al. (2008)	0.73	0.34	0.67	0.45	0.64	0.52	0.78	0.47

Discussion

The present study was carried out in a mixed-beech natural unlogged forest in the Hyrcanian broad-leaf forests. The existing differences for competition over the stand area were obtained by measuring the competition indices on the surface of the tree stems presenting an acceptable compatibility. Studying on competition and spatial structure of trees in a natural oriental beech stand located in Kelardasht (Northern Iran), Akavan et al. (2012) reported similar results. These findings are consistent with the results reported by Sagheb-Talebi and Shutz (2012) and Akhavan et al. (2012). On the other hand, the spatial structure existing in a natural ecosystem interpreted by ecology science can provide a number of indices to more appropriately determine and comprehend natural processes such as competition. In a previous study, Amiri et al. (2013) conducted a research on dynamics of structural characteristics beech mixed stand in the same region and reported the density and volumeof the stand to be 278n.ha^{-1} and 472 m^{2}ha^{-1}, respectively. Beech owned the highest volume of living trees (55.8%) and deadwood (62%) among other species. The present structure of natural and intact forests is the outcome of some complicated interactions among trees having a varied history combined with the effect of a number of factors namely site, climate, and natural distractions such as longevity, competition, storm, fire, pests and diseases, snow and frost, and flood (Akhavan et al. 2012). Information about the spatial patterns of trees having varied dimensions and competition conditions can be useful for regenerating the past structure of stand and interpreting the evolutionary stages forming the distribution pattern of trees. Based on the performed investigations, most of species in plant communities have a clump pattern (Denyslow 1980; Ludwig and Reynolds 1989; Nakashizoka 1989; Alavi et al. 2005; Mattaji et al. 2008). In another study on a permanent plot in the Shaskalateh forest of Gorgan, it was reported that the distribution pattern of most existing tree species including beech, hornbeam, and ironwood was, as well, clump. In some cases, the distribution pattern of date plum, in gaps created by the felling of large trees, is also considered as clump (Amiri 2013).

Hegyi (1974) and Lorimer (1983) analyzed the trend of variations in competition indices over the surface of stand, tree stems, and diameter classes. The results indicated that by the increase in tree size (due to increase in diameter, height, crown area, basal area, and the spacing between trees), competition stress initially increased but then reduced. This is possibly due to the unequal conditions of tree species in different diameter classes, such that in all diameter classes, the number of stems for beech and hornbeam is larger than that of the other existing species across the permanent plot under study. Since the major part of stand number per hectare is in diameter class<30 cm, the mentioned condition is more severe for all the measured tree stems having the given diameter class. It can, therefore, be said that due to the large number per hectare of stems, competition is more severe in the above-mentioned diameter class (Table 4).

To introduce the target tree, the DBH of existing trees in distance-independent indices was used. Since DBH is pertaining to basal area, it is expected that the mentioned indices have a strong relation with basal area. Thus, most of the competition indices in which DBH was influential showed a higher R^2. Root mean square error was higher in large and very large classes, compared to low and medium diameter ones, which is possibly due to their high variability. DBH is used in most competition indices (Hegyi 1974; Lorimer 1983). The spatial indices using DBH showed a good performance as a main prediction variable (e.g. Rouvinen and Kuuluvainen 1997) and were different with the other competition indices. The advantage of the given indices over the other ones is possibly due to the relation between the diameter growth of the target tree and its diameter. Holmes and Reed (1991) reported that such a correlation may be created as a result of competition pressure. However, the diameter of a tree is more dependent on its age and competition history than on the community status of tree in stand (Fox et al. 2007). When the distance-independent competition indices were used with regression relation and without competition index, they showed no statistically significant relation. The given results are corresponding with the results reported by Begin and Dobberrtin (1995) indicating that there was no significant relation between the models of diameter growth and height. Thus, the results of the present study showed that the main point is to use the type of variables in competition indices which determine the index effectiveness. This means that all the counted trees equally intervene in competition survey in spite of their size and closeness to one another. The results of distance-independent basal area and relative space exhibited more significant values. Since, none of the overlapping indices of area-effect showed a significant relation in terms of the growth model of basal area. The results of ratio-size indices introduce the application of DBH, along with other characteristics, as an effective distance-dependent index.

Since no human interventions have been yet reported to occur in the studied stand, a long-term period is required to study the growth and dynamics of forest structure. Furthermore, one of the important aims of establishing permanent plots in intact forests is to regularly monitor the characteristics of stand structure over time, which can be used as a precious tool when the competition amongst tree species is to be investigated. The results revealed that competition is an effective factor on the dynamics of forest stands structure, in particular on the immature stands of beech and hornbeam. Considering the distribution of number in diameter classes and the presence of inter- and intra-species competition in forest, it is recommended that the results of the present research be employed as a pattern for the other beech forest stands in the north of Iran and also implementing proper management operations. Therefore, the information derived from these untouched stands could be used as a key reference for future studies in terms of developing management programs, silvicultural interventions, and likewise plantation.

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