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Tree Volume Increment Models of Broadleaf Species in the Uneven-Aged Mixed Caspian Forests

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Abstract: The objective was to provide a pilot increment model for major species in the Caspian forests including Common Hornbeam (*Carpinus betulus* L.), Oriental Beech (*Fagus orientalis* Lipsky) and Heart Leaved Alder (*Alnus cordata* Desf.) by routinely measured variables in forest inventories. The only published and reliable data of an accomplished inventory in the western Caspian forests have been used to construct a database including all available explanatory variables of volume increment. Potential*reducer method was applied in this research to develop tree volume increment models. Volume increment models have been well-estimated for major species according to diameter at breast height (DBH), ecological aspects (ASP) and stand density (SD). Based on coefficient of determination, the models explained between 45 to 83% of volume increment variability. The results showed a descending ranking of volume increment from alder, hornbeam to beech for trees having DBH inferior to 70 cm. The average elasticity (E%) of volume increment to ASP indicated that hornbeam trees (0.85%) were approximately two times more sensitive than beech trees (0.46%) while no sensitivity was observed in alder trees. In the same way, hornbeam trees were appeared to be a bit more sensitive (0.41%) than alder (0.32%) to SD whereas no sensitivity was observed in beech trees. Although the presented increment models can be employed for applied purposes in the western Caspian region, model enhancement is expected if more detailed and larger dataset including soil, microclimate and forest structure data are incorporated.

Key words: Ecological aspect, mixed broadleaf forest, stand density, volume increment model

INTRODUCTION

The Caspian forests of Iran are located in the north of Alborz range and south of the Caspian Sea. These commercial forests cover a narrow strip over 800 km long and 20-70 km wide ranging of altitude from the sea level to 2800 m. The Caspian forests are mixed uneven-aged consisting of broadleaf species exploited for timber production according to the forest management plans for over 40 years. No comprehensive and integrated inventory and research, however, have been preformed on the volume increment of different species in the Caspian forests (Attarod *et al*., 2007) both at the national and local levels and increment data are thus relatively scarce. Therefore, volume increment model seems to be highly useful for estimation of volume increment in various situations. Volume increment model is also useful for determining allowable cut as well as for dynamic simulation and economical optimization of forest structure (Heshmatol Vaezin, 2006).

Stand or tree volume growth model is formed by a set of logical and mathematical relationships which represents volume evolution over time or accumulated volume available at any specified time (Houllier *et al*., 1991; Zeide, 1993). However, it is easier to understand the volume growth process using its differential form, called current volume increment. Consequently, volume increment model is simply the first derivative of volume growth model which defines the volume increase of a tree or stand during a given period.

Historically, forest stand growth and increment models, e.g., yield production tables, are the first dynamic models developed in the literature. Although the stand models correspond to an overall description of the forest stand growth and increment (Peyron and Houllier, 1997), they have the following limitations:

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- Evaluation of products values according to the size classes is not permitted (Heshmatol Vaezin, 2006; Houllier *et al.*, 1991)
- Application for uneven-aged stands is almost impossible
- Calculation of tree-based competition indices e.g., social status is not possible

These limitations have led researchers to the tree-level increment models rather than to the stand-level ones. The single-tree is the most detailed models which use individual tree as the basic unit of modeling. Zeide (1993) also concluded that the safest modeling level is the individual tree.

Among the tree-level increment models, it is useful to present two classical groups of increment models, distance-dependent and distance-independent models. The difference of above-mentioned models is in the manner in which competition is incorporated. In the distance-independent model, a stand is characterized by its trees and their relative sizes regardless of the trees spatial locations. Relative simplicity and applying for a wide spectrum of forest structure (Heshmatol Vaezin, 2006) is the essential feature of this model. In contrast, distance-dependent models characterize a stand by trees, their relative sizes, as well as their spatial characteristics. Distance-independent models are often proven to be more simple and applicable for management purposes whereas the distance-dependent models are rather utilized for research purposes (Heshmatol Vaezin, 2006). Distance-independent model was used in this research regarding to the paucity of data as well as its applicability in forest management.

Volume increment is highly modeled in the literature to be predicted according to different variables. Hamilton (1969) studied the volume increment of individual trees in a 23-year-old stand of Sitka spruce (*Picea sitchensis* Carr.). Other factors being constant, he indicated that narrow crowned, upper canopy and larger trees produced timber more efficiently. Ruiter (1987) modeled the stem volume increment using evapotranspiration. Wenk (1994) developed a volume increment model in relation to age and thinning management. Gustavsen *et al.* (1998) presented a linear regression function for predicting the volume increment of peatland stands on sites drained for forestry in southern Finland using some variables such as site type, stem number, temperature, peat depth and ditch spacing.

O'Hara *et al.* (1999) estimated a simple linear model for predicting volume increment according to sapwood cross-sectional area in cm^2 for scots (*Picea abies* L.) and Norway pines (*Pinus sylvestris* L.) at crown base. Although volume increment have been modeled using different types of variables as mentioned previously, few models have been developed by means of routinely measured variables in all forest inventories and management plans.

Important species, Common Hornbeam (*Carpinus betulus* L.), Oriental Beech (*Fagus orientalis* Lipsky) and Heart Leaved Alder (*Alnus cordata* Desf.) form 33, 26 and 9% of growing stock of the Caspian forests, respectively (Saeed, 1995). The sole available published dataset of an accomplished inventory in the western Caspian forests (Attarod *et al.*, 2007) have been used in this study to develop the models. This research is the first of its kind in this region and provides a pilot increment model for major species. The main goal of this study was thus to obtain and compare species-specific patterns of volume increment for major species in the Caspian forest by routinely measured variables in forest inventories.

MATERIALS AND METHODS

Inventory sites: The inventory was accomplished in the summer season of 1998 in one of the forest basins of the western Caspian region (Fig. 1), North of Iran, called Shafa-Rud basin (48° 50' N, 37° 30' E). In this basin, located in Guilan province, two forest districts placed in the middle latitude profile (600-1200 meter above the Caspian sea level) were inventoried as the study areas, each one around 900 hectares (Fig. 8). Forest districts are located in different ecological aspects, northern and southern, abbreviated hereafter ASP. Average slopes in ASPs were 65%. Major species were Common Hornbeam, Oriental Beech, Heart Leaved Alder, Date-Plum Persimon (*Diospyrus lotus* L.), Coliseum Maple (*Acer cappadocicum* Gled.), Oak (*Quercus castaneifolia* C.A. Mey), Linden (*Tilia begonifolia*) and European Ash (*Fraxinus excelsior* L.). Table 1 shows the species mixing ratios (%) of southern and northern ASPs.

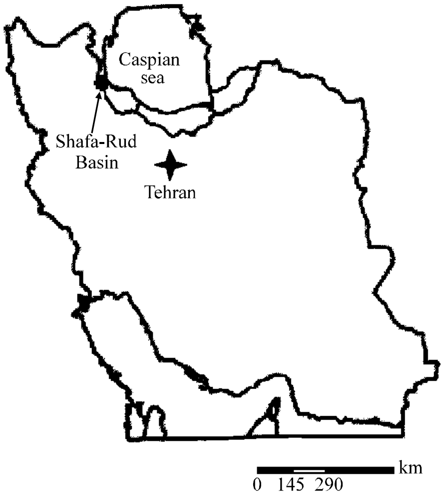

Fig. 1: Location of Shafa-Rud forest basin in the western Caspian region of Iran

Table 1: Mixing ratio (%) of species in the southern and northern aspects

Species	Beech	Hornbeam	Maple	Alder	Oak	Linden	Persimmon	Ash	Other species
Southern	7.8	25.9	13.6	11.4	11.2	6.3	15.5	3.5	6.0
Northern	29.9	33.9	8.5	8.2	---	6.0	3.1	4.8	4.4

Table 2: Descriptions of the quantitative variables

Variable (Abbreviation)	Definition	Mean	Min	Max	SD	No.	CV (%)
I_V	Volume increment (sylve ha^{-1})	0.06	0.00	0.33	0.04	360	78.89
DBH	Diameter at breast height (cm)	46.65	15.00	120.00	21.95	360	47.05
SP	Social position	0.68	0.14	1.00	0.25	360	35.94
SD	Stand density (m^3 ha^{-1})	353.96	118.63	933.98	169.08	360	47.77
ALT	Altitude (m)	761.67	450.00	1050.00	144.36	360	18.95
SLP	Slope (%)	40.00	10.00	80.00	10.00	360	20.00

Table 3: Descriptions of the qualitative variables

Variable (Abbreviation)	Definition (if variable is 1)	Mean	SD	No.	CV (%)
B	Beech	0.26	0.44	95	167.25
A	Alder	0.12	0.33	44	268.36
HB	Hornbeam	0.16	0.37	58	228.50

The main climatological parameters of the study sites were as follows the mean annual precipitation 1500 mm, the mean annual air temperature 25°C and the mean relative humidity 75-80% (Attarod *et al*., 2007). Sampling method and calculation procedures of the volume increment have been presented in the appendix.

Database construction: A database was produced using field observations of each sample plot and completed by calculation of necessary variables. We calculated some qualitative variables including species and ASP, as well as some quantitative variables of altitude (ALT), slope (SLP) and etc. (Table 2, 3).

Tree volume increment modeling: Increment modeling is usually based on two fundamental parts; increment model determinants and increment model specification.

The increment model determinants are classified as two main groups; potential and observed increment determinants. The potential increment is obtained in absence of any competition. For a given species, the potential increment integrates increment stages represented by age or DBH and Site Index (SI) (Zeide, 1993; Danjon and Hervé, 1994; Murphy and Shelton, 1996). Observed increment, however, is a fraction of potential increment which is realized according to different kinds of competition. In distance-independent increment models, there are generally two competition levels:

- Stand-level competition
- Tree-level competition

Stand-level competition shows the average and general degree of competition over all available stand resources, named often Stand Density (SD). SD is measured typically by some descriptive stand variables such as the number of stems, basal area, volume per hectare and Relative Density Index (RDI). Although RDI was proven to be the best indicator of SD, its calculation was difficult in uneven-aged stands (Heshmatol Vaezin, 2006) and volume per hectare was thus employed in this research.

Research on the stand-level competition has led the authors to consider also the tree-level competition. The tree-level competition explains the competition between neighboring trees on the available resources through their relative size or Social Position (SP). SP determines the place of an individual tree in the hierarchy of gaining resources and measured typically by the ratio of the tree diameter or height to maximum diameter or height of surrounding trees, the vital space. Therefore, the observed increment is a function of age or diameter, site fertility and SD as well as SP of trees.

Increment model specification is often based on three basic approaches of empirical, semi-empirical and theoretical after Pavé (1994). The semi-empirical or mixed approach selected in this research was developed to overcome the disadvantages of the empirical and theoretical approaches (Bouchon, 1995). According to Pavé (1994), due to simplicity and biological interpretation, the semi-empirical approach is proven to be effective in practice. This approach often leads to models much less complex than theoretical models but is still interpretable and consistent with the biological knowledge. In this approach, the potential and reducer functions were distinguished as Eq. (1):

$$I_V = P(DBH, SI) \,.\, R(SD, SP) \quad (1)$$

where, I_V is the volume increment, P is the potential increment function and R is the increment reducer function. SD was measured as volume per hectare and SP was calculated by Eq. (2):

$$SP = \frac{DBH}{DBH_{max}} \tag{2}$$

In which, DBH_{max} is the largest tree in each sample plot.

The potential increment is generally formulated by differentiated sigmoid functions such as Korf and Chapman-Richards models (Zeide, 1993; Pavé, 1994; Franc *et al*., 2000). Since our increment data did not cover a wide range of volume increment-diameter relationship, we were not able to fit sigmoidal models to our data. As a result, a power function was found to be the best fitting model for the relationship of volume increment and diameter as shown in Fig. 2. R function is generally formulated by an exponential function. This function equals 1 in absence of any competition and tends to zero by increasing the competition.

Fertility is often measured by dominant height at a reference age defined as SI, integrated in the potential function. However, this index is not pertinent in an uneven-aged stand. For this reason, some authors characterize fertility by a set of variables related to topography which are ASP, SLP, ALT, as well as to soil and microclimate (Seynave *et al*., 2006). Regarding the paucity of soil and microclimate data in our database, we considered solely topography variables for SI.

According to Heshmatol Vaezin (2006) and Schroder *et al*. (2002), the variables attributed to SI as ASP, SLP and ALT can be incorporated into Eq. 1 by adding a modifier function, M (ASP, SLP, ALT), as Eq. 3:

$$I_V = P(DBH).R(SD, SP).M(ASP, SLP, ALT) \tag{3}$$

Equation 3 was rearranged when the potential, reducer and modifier functions forms were integrated as Eq. 4:

$$I_V = \left(\gamma + \lambda.DBH^{\beta}\right).\exp(\mu.SD + \theta.SP).\exp(\varphi.ASP + \rho.SLP + \omega.ALT) \tag{4}$$

where, γ, λ, β, μ, θ, ϕ, ρ and ω are the model parameters.

Equation 5, linearized form, was finally produced by applying the natural logarithm (Ln) to the both sides of Eq. 4:

$$\ln(I_V) = a + b.\ln(DBH) + c.SD + d.SP + e.ASP + f.SLP + g.ALT \tag{5}$$

where, a is $[\ln(\gamma)+\ln(\lambda)]$, b, c, d, e, f and g are equal to β, 2μ, 2θ, 2ϕ, 2ρ and 2ω, respectively.

Then, multivariable regression analysis (MRA) was employed to estimate Eq. 5 by Least Square (LS) estimator.

Including or excluding of independent variables was accomplished by the stepwise procedure. In this study, the modeling was performed using MRA analysis and stepwise method of SPSS/11 software.

RESULTS AND DISCUSSION

Models estimation

Beech model: Figure 3 shows the relation of volume increment of beech trees with diameters in ASPs, partially related to SI. The difference amplified by DBH increasing

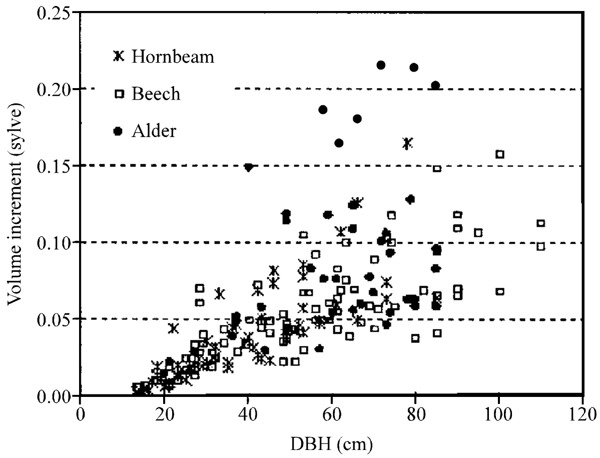

Fig. 2: Scattergram of volume increment and DBH for beech, hornbeam and alder

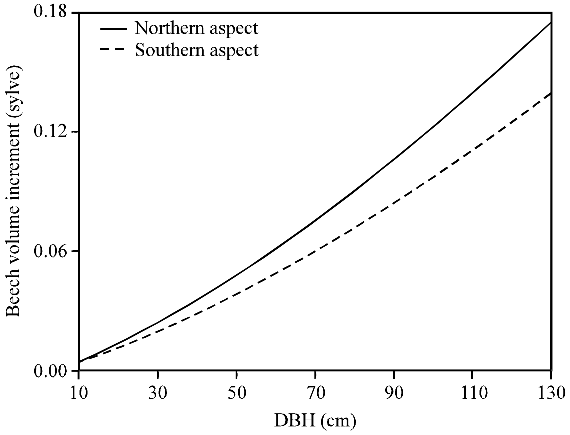

Fig. 3: Relation of beech volume increment with diameter in ecological aspects (ASP)

Table 4: Estimation result of volume increment model for beech

Variable	Variable impact	Unstandardized coefficients (B)	Standardized coefficients (β)	t-student statistic	VIF
a	Constant	-8.373	---	-26.57**	---
b	DBH	1.362	0.86	16.85**	1
e	ASP	-0.229	-0.11	-2.18*	1

$^{**}p<0.01$; $^{*}p<0.05$, $R^2 = 0.76$/Adjusted, $R^2 = 0.75$, Standard Error of Estimate SEE = 0.42, df = 92, F = 144.45, $\ln (I_V) = -8.373+1.362.\ \ln(\text{DBH}) -0.229,\ \text{ASP}$

was found to be 26% higher in northern aspect at all diameters. The higher beech volume increment in the northern aspect can be explained by climatological factors particularly by higher relative humidity, lower temperature and more fertility of sites. It should be noted that frequency of beech trees in the northern aspect were expectedly much higher than that of the southern (Fig. 3).

No sensitivity was detected in the volume increment of beech trees related to SD, elucidated either by shade-tolerance of beech trees or the limited range of SD in the present database. According to Table 2, SD varied from around 118 to 933 sylve per hectare (Coefficient of Variation # 48%). Therefore, the non-sensitivity of beech volume increment to SD can be rather explained by its tolerance to shade (Marvi Mohadjer, 2007).

Moreover, the standardized coefficients of DBH and ASP showed that the impact of DBH on beech volume increment is approximately 8 times of that of ASP (Table 4).

Hornbeam model: Figure 4A shows the relation of volume increment of hornbeam trees with diameters according to ASP. The higher volume increment of hornbeam trees in the northern aspect can be mainly due to the fertility of northern aspect typically higher than that of southern aspect as well as to the forest type. For instance, hornbeam trees of the northern aspect in association with beech trees grow better than hornbeam trees of the southern aspect in association with Oak trees.

Enlarged by DBH increasing, the volume increment of hornbeam trees was found to be 54% higher in the northern aspect compared to the southern at all diameters. Using volume increment elasticity to ASP, the volume increment of hornbeam trees (0.85%) was found to be almost 2 times more sensitive than that of beech trees (0.46%). Note that elasticity (E%) is calculated via the ratio of the percent change in a dependent variable (I_v) to that of an independent variable (ASP).

Although beech trees of northern aspect enjoy more favorable ecological conditions, they suffer from more intense intra-specific competition defined by Purity Index (PI). Calculated as the volume ratio of beech trees to all species, PI varied from 0.12 in southern versus 0.40 in northern aspect. As the higher PI of beech trees in the northern aspect was resulted in less volume increment, the influence of favorable conditions of northern aspect on beech volume increment was mitigated (Heshmatol Vaezin, 2006). By contrast, the influence of northern aspect on volume increment of hornbeam trees with much less difference of PI in ASPs was higher compared to beech trees.

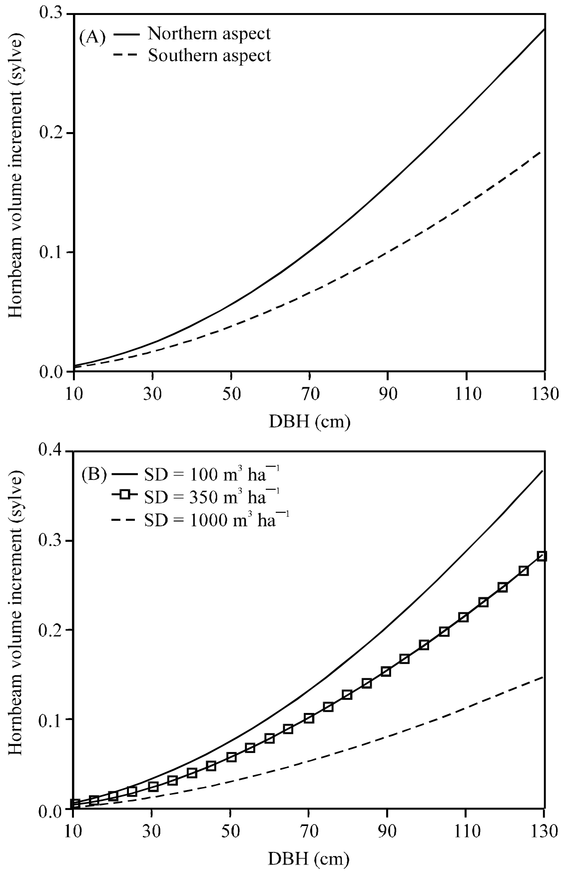

Fig. 4: (A) Hornbeam volume increment against DBH in ecological aspects (ASP) and (B) against DBH in low (100 m³ ha⁻¹), intermediate (500 m³ ha⁻¹) and high (1000 m³ ha⁻¹) forest densities

Figure 4B shows the relation of volume increment of hornbeam trees against DBH classified according to SD, low (100 m³), intermediate (500 m³) and high densities (1000 m³). Volume increment in the low density forest was found to be 1.6 times higher than that of the high density forest in all diameters. In fact, availability of needful resources for increment especially sun light in forest ecosystems which is inversely related to SD can be a key

Table 5: Estimation result of volume increment model for hornbeam

Variable	Variable impact	Unstandardized coefficients (B)	Standardized coefficients (β)	t-student statistic	VIF
a	Constant	-9.048	---	-23.14**	---
b	DBH	1.680	0.89	15.75**	1.03
e	ASP	-0.430	-0.23	-3.72**	1.25
c	SD	-0.001	-0.19	-3.10*	1.27

**$p<0.01$; *$p<0.05$, $R^2 = 0.83$, Adjusted $R^2 = 0.82$, Standard Error of Estimate (SEE) = 0.38, df = 54, F = 89.86, In (I_V) = -9.048+1.680. In (DBH) -0.001. SD -0.430. ASP

Table 6: Estimation result of volume increment model for alder

Variable	Variable impact	Unstandardized coefficients (B)	Standardized coefficients (β)	t-student statistic	VIF
a	Constant	-7.604	---	-8.70**	---
b	DBH	1.320	0.73	5.82**	1.18
c	SD	-0.001	-0.26	-2.03*	1.18

**$p<0.01$; *$p<0.05$, $R^2 = 0.45$/Adjusted, $R^2 = 0.43$, Standard Error of Estimate (SEE) = 0.50, df = 41, F = 17, In (I_V) = -7.604+1.320. In (DBH) -0.001 SD

factor for increment of the semi-shade tolerance species such as hornbeam (Marvi Mohadjer, 2007).

According to Table 5, apart from DBH which showed the highest impact on hornbeam volume increment, ASP and SD both had roughly the same impact on it.

Alder model: Figure 5A shows the relation of volume increment of alder trees against diameters in the forests with low (100 m^3), intermediate (500 m^3) and high densities (1000 m^3). Volume increment of alder trees in the low density forest was found to be around two times of the high density forest.

In the comparable ecological conditions, SD seems to be more critical factor for increment of light-demander species like alder rather than shade and semi-shade tolerance species such as beech and hornbeam, respectively (Marvi Mohadjer, 2007). However, using volume increment elasticity to SD, the volume increment of hornbeam trees (0.41%) was found to be a bit more sensitive than that of alder trees (0.32%), likely related to the social status of hornbeam and alder. In fact, alder often occupies dominant storey whereas hornbeam places in co-dominant or intermediate storey in the Caspian forests. Figure 5B indicated that SD affects more strongly co-dominant species, hornbeam, rather than dominant species, alder, as also mentioned by Heshmatol Vaezin (2006).

Moreover, an inverse exponential relation of volume increment of hornbeam trees to SD was also observed in Fig. 5B attributed to a progressive adaptation of hornbeam trees to shortage of light as mentioned by Zeid (1993).

Based on standardized coefficients, the impact of DBH on alder volume increment is approximately 3 times of that of SD (Table 6). No sensitivity of alder volume increment was observed to ASP. This fact shows that an increased volume increment of alder trees in the northern aspect encouraged by more relative humidity and fertility may be compensated by an increased volume increment caused by more availability of sun light in the southern aspect.

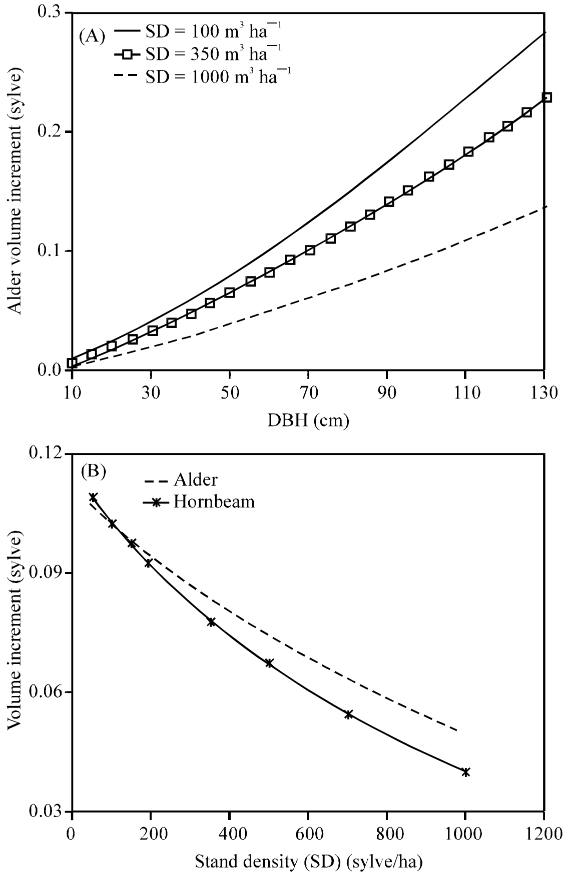

Fig. 5: (A) Alder volume increment versus DBH. SD was grouped into three classes as low (100 m^3 ha^{-1}), intermediate (500 m^3 ha^{-1}) and high (1000 m^3 ha^{-1}) forest densities and (B) volume increment-SD relation for alder and hornbeam trees

Species volume increment: Figure 6 shows the relation of volume increment versus diameter for the three species. Volume increment in larger diameter (>70 cm) showed a descending ranking from hornbeam, alder to beech trees, respectively. Hornbeam and beech volume increment

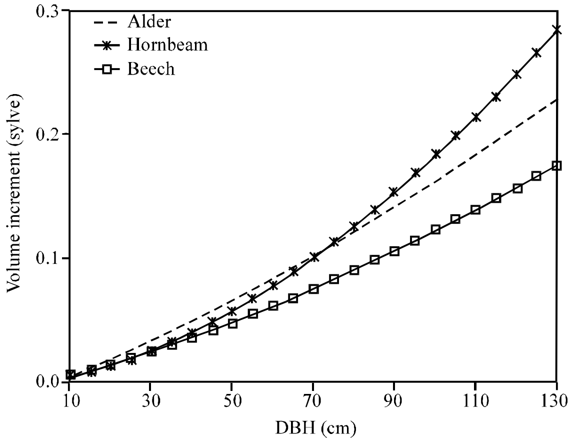

Fig. 6: Volume increment of beech, hornbeam and alder against DBH at the same stand density (SD) and ecological aspects, 350 m^3 ha^{-1} and northern aspect, respectively

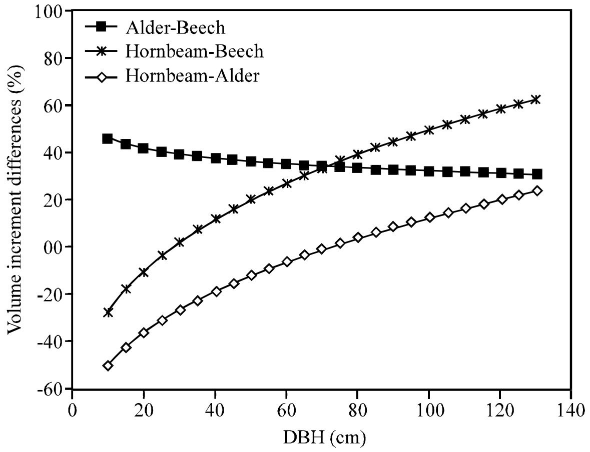

Fig. 7: The percent of volume increments differences of beech, hornbeam and alder versus DBH at the same stand density (SD) and ecological aspects, 350 m^3 ha^{-1} and northern aspect, respectively

curves were almost overlapped up to 35 cm. Then, hornbeam curve diverged rapidly whereas beech curve deviated moderately with diameter. Alder volume increment showed, however, a separated curve from the beginning and diverged steadily.

The percent of volume increment differences among the species was shown in Fig. 7. In Fig. 7, alder-beech refers to the percent of volume increments difference of alder and beech trees. Hornbeam-beech and hornbeam-alder were defined as the same mentioned way. The least difference variation of volume increments was observed between alder and beech, shown a positive difference within a range of 30 to 45%. It suggests that alder volume increment was in average 36% higher than that of beech trees. This result is supported by previous studies that light demander species e.g. alder, grow faster than shade tolerance species like beech (Marvi Mohadjer, 2007).

Difference of volume increment belonged to hornbeam and beech varied from -30 to +60%. Figure 7 shows that beech trees grow faster than hornbeam up to 30 cm while an inverse trend was seen after 30 cm and no volume increment difference was observed at 30 cm. Since hornbeam trees are more demander in light than beech, the volume increment of hornbeam is usually higher than that of beech trees (Gersonde and O'Hara, 2005; Paquette *et al*., 2007). In small diameters (<30 cm), however, hornbeam volume increment appeared to be lower than that of beech, related likely to higher tolerance of small beech trees, up to 30 cm, to shelter.

Volume increment difference of hornbeam and alder changed from -50 to +25%. More volume increment of alder trees up to 70 cm can be due to more light demanding of alder compared to hornbeam (Marvi Mohadjer, 2007). Since the longevity of alder trees is lesser than that of hornbeam, in large diameters (>70 cm), alder volume increment becomes less than that of hornbeam.

In addition, Fig. 7 showed that the volume increment of hornbeam-beech was 1.6 times of that of hornbeam-alder in average.

Applications to the Caspian forest managers: Regarding the lack of volume increment models for the Caspian forests, annual allowable cut is currently determined using the following ways:

- Using the increment data obtained from accomplished researches in other countries that have rather similar forests to the forest ecosystems in the Caspian region
- Estimation of volume increment as a percentage of growing stock
- Ignore the volume increment

Although, the presently used ways may produce important consequences:

- Calculation of annual allowable cut is not accurate and mostly tends to its lower limit
- Forest potential increment has been ignored
- There is no way to take into account differences in volume increment of species for determination of optimum mixing ratio

Although the presented models have some deficiencies, particularly due to paucity of database in soil, microclimate as well as forest structure, they can be usefully applied for volume increment estimation which is much more precise than current procedure for volume increment estimation in Iran. Nevertheless, the presented models should be validated before applying for prediction.

In addition, they could be utilized for economical researches on optimum growing stock, N-diameter distribution, felling cycle and species mixing ratio. Comprehensive and integrated increment inventories at the national level should be accomplished in the Caspian forests for monitoring, estimating and modeling of the volume increments of different species.

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APPENDIX

Sampling method: Thirty circular fixed-sized sample plots with a 0.1 ha area were determined on the topography map in each ecological aspect using random blocking method, a more practical and accurate method in such studies (Zobeiry, 1993) (Fig. 8).

In each sample plot, six trees were selected randomly according to a predefined model (Fig. 9) for sampling the radial increment using increment borer and for measuring the other quantitative variables (Attarod *et al.*, 2007; Attarod and Bayramzadeh, 2003). According to the model, the selected trees were:

- The nearest tree to the center of the sample plot
- The largest diameter at breast height (DBH) tree in the sample plot
- Four trees situated in the four main directions of a sample plot with a maximum distance from the center.

In addition to the increment and bark sampling of the selected trees, DBH and height of all trees in the sample plots were measured.

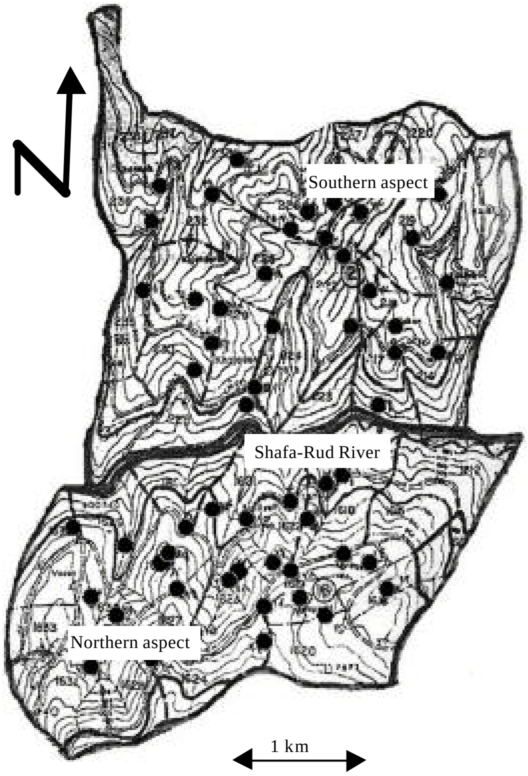

Fig. 8: Southern and Northern ecological aspects in Shafa-Rud forest basin. Sample plots shown as closed circles on the topography map

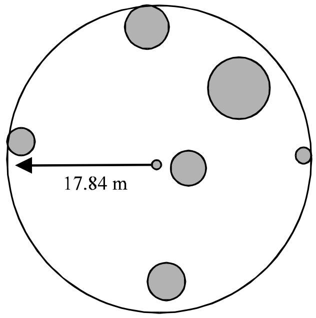

Fig. 9: Schematic representation of a sample plot and the predefined model for trees selection: (◉) Basal area of the selected trees

Measurement of the radial increment (L): After smoothing the annual rings on the increment cores using a sand paper and soaking them in water for one hour, radial increment of trees in ten recent years were measured (Loetch, 1964; Attarod *et al.*, 2007).

Calculation of the diameter increment (W): Diameter increments of all species were calculated separately

Table 7: A sample table of the calculation procedure of diameter increments of a species

i	n_i	$\bar{d}_{OB}$	$\bar{d}_{UB}$	$\bar{L}$	$w = 2\bar{L}/10$	$W = K.w$	$x = \bar{d}_{UB} - \bar{L}$	$X = K.x$
15	2	15	13.79	2.76	0.552	0.589	11.03	11.78
…	…	…			…	…	…	…
110	1	110	104.92	2.5	0.5	0.534	102.42	109.38

(The data shown are as an example only)

Table 8: A sample table of the calculation procedure of volume increments of a species

i	T (sylve)	dV_i	$(dV_i)'$	I_1	W	I_V	N/ha	I_{V_i}
15	0.12		0.035	0.007	0.637	0.004	6	0.024
20	0.19	0.070	0.105	0.021	0.634	0.013	7	0.091
…	…	…	…	…	…	…	…	…
110	…	…	…	…	…	…	…	…

(The data shown are as an example only)

according to the procedures shown in Table 7, (Attarod *et al*., 2007) in which i is the diameter class, n_i is the number of trees in the i^{th} diameter class, $\bar{d}_{OB}$ and $\bar{d}_{UB}$ are the means of diameter over bark and under bark (cm), respectively. $\bar{L}$ is the mean radial increment in the studied period (ten years) (cm), w and W are the annual increments of diameters under bark and over bark in the period (cm), respectively, x and X are the diameters under bark and over bark in the half of the period, respectively.

Note that a linear correlation between annual increment of the diameter over bark in the period and the diameter over bark in half of the period (W = a+bx) was found and applied due to unavailability of trees in some diameter classes.

Calculation of volume increment (I_V): For calculation of volume increment, weighted tariff tables (local volume table) for each forest district were used after Attarod *et al.* (2007). Table 8 shows the calculation procedure of volume increment for each species. In Table 8, T is the tariff of forest, dV_i and $(dV_i)'$ are the volume and corrected volume differences, respectively, I_1 is the increment in volume resulted in 1 cm diameter increment (sylve), W is the annual increment of diameter over bark estimated by the mentioned linear equation, I_V is the annual increment of an individual tree, N/ha is the number of trees per hectare and I_{V_i} is the total annual increment in volume for each diameter class. The total annual increment in volume of a species finally was calculated as:

$$\sum_{i=n}^{i=1} I_{V_i}$$

and the total annual increment in volume of each aspect (I) was computed as the sum of annual increments in volume of all species.

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