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Effect of Ecological Aspects on the Quantitative Variables of Mixed Broadleaf Forests Using Multivariate Statistical Method

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Abstract: This research was performed on the commercial forests of the western Caspian region, Shafa-Rud basin, to investigate firstly the effect of ecological aspects (northern and southern) on the quantitative variables of mixed broadleaf forests using a multivariate statistical method (MANOVA). The second aim was to estimate the volume growth of Shafa-Rud forest basin. Two northern and southern aspects were chosen in the middle latitude profile (800-1200 m.a.s.l) and on each aspect, 30 circular sampling plots were selected using the random blocking method. In each sample plot, six trees were chosen according to a predefined model for sampling the radial growth using an increment borer and for measuring other quantitative variables such as height of trees and diameter at breast height (DBH). Weighted local volume tables were calculated for each of the ecological aspects and were compared using t-test. Multivariate statistical analysis, Hotelling's T^2_2 test, which was carried out on means vector of the four quantitative variables: diameter, height, bark thickness and radial growth, demonstrated that the difference in centroid of vectors was highly significant. The stand volume growths in the southern and northern aspects were found to be 9.2 and 9.5 sylve per hectare, respectively.

Key words: Ecological aspects, mixed broadleaf forests, multivariate statistical method, quantitative variables, Caspian forests

INTRODUCTION

Aspect is one of the most important ecological factors in determining different vegetative covers in forest ecosystems (Mosaddegh, 1995). The effect of ecological aspects on climate is an essential element in creating these differences. Certainly, the ecological differences of aspects have effects on the quantitative variables of forests such as the number and volume per hectare, growth and height of trees.

In the management of mountainous commercial forests of the Caspian region (North of Iran) with a high topography, the importance of the ecological aspects has rarely been considered (Attarod, 1998). The southern and northern aspects in these mountainous natural forest ecosystems have already been considered as an important ecological factor, but their significance in management have usually been ignored. In other words, for the existing forests on different ecological aspects in a forest basin, the same management policies are currently being practiced.

Investigations of the effect of aspects on the quantitative variables of managed forests help the managers to consider site condition in planning separately. This management ethics which is more harmonious with nature, in other words, close-to-nature, presents the best strategy for the sustainable use of natural forest ecosystems.

The main aim of the present study was firstly to examine the effect of northern and southern aspects on the quantitative variables of the mixed broadleaf forests such as diameter and radial growth using the multivariate statistical method. To date, statistical analyses about the effect of the southern and northern aspects on the quantitative variables of the forests are relatively scarce in this region and most of the accomplished investigations have used the univariate statistical methods (ANOVA)

Furthermore, sustainable utilization of the commercial forests is the fundamental goal in the management of these ecosystems and to achieve this, determination of the exact volume growth of forest stands is inevitable (Attarod, 1998). No documented research concerning the stand growth in the western Caspian region was available and the results of researches in other countries are currently being used to estimate the growth of forest. Therefore, the second goal of this study was to determine the stand growth of the mixed broadleaf forests of Shafa-Rud basin in Guilan province located in the western Caspian region.

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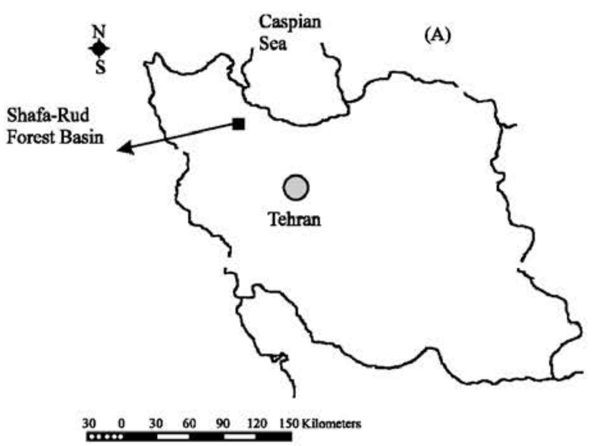
MATERIALS AND METHODS

Study sites: This research was accomplished in the summer season of 1998 in one of the forest basins of the western Caspian region, North of Iran, called Shafa-Rud basin (48°50' N, 37°30' E). In Shafa-Rud basin, located in Guilan province, the northern and southern forest districts located in the middle latitude profile (600-1200 m above the Caspian Sea level) were chosen as the study areas, each one around 900 ha (Fig. 1). Average slope in the ecological aspects was 65%. Major species were Birch (*Carpinus betulus*), Beech (*Fagus orientalis*), Persimmon (*Diospyrus lotus*), Maple (*Acer platanoides*), Alder (*Alnus glutinosa and A. subcordata*), Oak (*Quercus castaneifolia*), Linden (*Tilia begonifolia*) and Ash (*Fraxinus excelsior*).



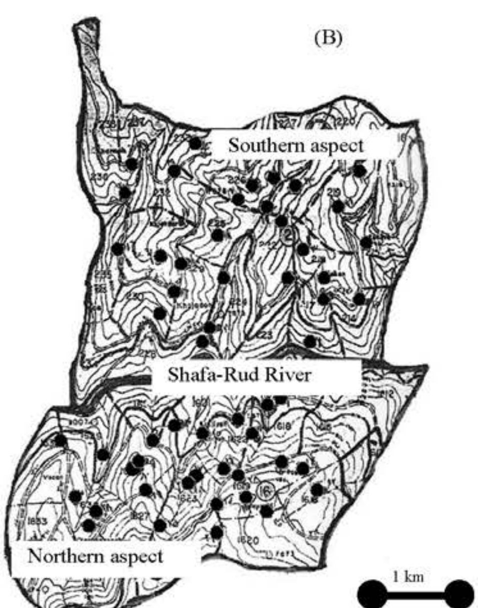


Fig. 1: Locations of Shafa-Rud forest basin in the western Caspian region (A), the Northern and Southern ecological aspects. Sample plots shown as black circles on the topography map (B). Note that the basin has been divided into 17 districts (not shown all districts here)

The main climatological characteristics of the study sites were: mean annual precipitation: 1500 mm, mean annual air temperature: 25°C and mean relative humidity: 75-80% (Shafa-Rud Forest Company, 1970a, b).

Data collection: 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. 1).

In each sample plot, six trees were selected randomly according to a predefined model (Fig. 2) for sampling the radial growth using increment borer and for measuring other quantitative variables. According to the model, the selected trees were:

- The nearest tree to the center of the sample plot
- The largest diameter (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 (Attarod, 1998).

In addition to the growth and bark sampling of the selected trees, diameter at breast height (DBH) and height of all trees in the sample plots were measured.

Tariff: Weighted Tariff tables (local volume table) for each forest district were completed using Eq. 1 and Chuka local volume table (Attarod, 1998).

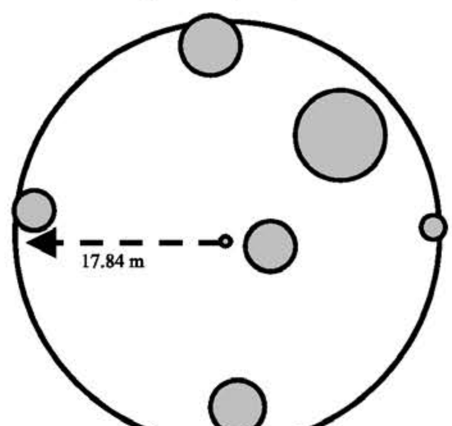


Fig. 2: Schematic representation of a sample plot and the predefined model for trees selection: ● Basal area of the selected trees

$$V_i = \frac{\sum_{i=1}^{n}(n_{ik}V_{ik})}{\sum_{i=1}^{n} n_i} \quad (1)$$

in which i is diameter class, K is tree species, n_i is the number of trees in the i[th] diameter class, V_i is weighted Tariff in i[th] diameter class (sylve), V_{ik} is volume of a tree of K[th] species in the i[th] diameter classes from Chuka volume table (sylve) and n_{ik} is the number per hectare of K[th] species in the i[th] diameter classes. Note that Chuka local volume table is a currently used local table for estimating the volume of the trees in Guilan province prepared by Shafa-Rud Forest Company (1970a, b).

Measurement of the radial growth (L): After smoothing the annual rings on the increment cores using a sand paper and soaking them in water for one hour, radial growth of trees in ten recent years were measured (Asli and Ether, 1969-1970; Loetch and Haller, 1964).

Calculating of the bark coefficients (K): It was measured separately for all of species using Eq. 2:

$$K = \frac{\sum_{i,j=1}^{n} d_{OB_{ij}}}{\sum_{i,j=1}^{n} d_{UB_{ij}}} \quad (2)$$

where, d_{OB} and d_{UB} are the diameter over bark and diameter under bark, respectively, by assuming that $d_{UB} = d_{OB} - 2e$ (Zobeiri, 1993), i (1, 2, ..., n) is the number of trees in each diameter class, j (1, 2, ..., n) is the number of diameter classes and e is the bark thickness.

Calculation of the diameter growth and the stand volume growth: Diameter growths and volume growths of all species were calculated separately according to the procedures shown in Table 1 and 2, (Asli and Ether, 1969-1970; Attarod and Bayramzadeh, 2003) 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 growth in the studied period (ten years) (cm), w and W are the annual growths 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 growth of the diameter over bark in the period and the diameter over bark in half of the period ($W = \alpha + bx$) was found and applied due to unavailability of trees in some diameter classes.

In Table 2, T is the tariff of the forest, dVi and (dVi)′ are the volume and corrected volume differences, respectively, I_1 is the growth in volume resulted in 1 cm diameter growth (sylve), W is the annual growth of diameter over bark estimated by the mentioned linear equation, I_v is the annual growth of an individual tree, N/ha is the number of trees per hectare and I_{V_i} is the total annual volume growth for each diameter class. The total annual volume growth of a species was finally calculated as

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

and the total annual volume growth of each aspect (I) was computed as the sum of annual volume growths of all species.

Computation of Lorey's mean height ($\bar{h}_L$) and diameter of average basal area ($d_{\bar{g}}$): Lorey's mean height and diameter of average basal area, more appropriate factors than mean height and mean diameter to understand the site index in uneven-aged forests, were computed by Eq. 3 and 4, respectively (Zobeiry, 1993):

$$\bar{h}_L = \frac{\sum_{i=1}^{n}(g_i \times h_i)}{G} \quad (3)$$

$$d_{\bar{g}} = (4\bar{g})^{1/2} / \pi \quad (4)$$

Table 1: A sample table of the calculation procedure of diameter growth 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 2: A sample table of the calculation procedure of volume growth 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)

in which $\bar{h}_L$ is Lorey's mean height, g_i and h_i are the basal area and height of an individual tree, respectively, G is the total basal area of all trees involved in the computation of Lorey's mean height, $\bar{g}$ is the average basal area per hectare computed by the Eq. 5:

$$\bar{g} = G_{ha} / N_{ha} \qquad (5)$$

where, G_{ha} and N_{ha} are the diameter of the average basal area and the number of trees per hectare, respectively.

Statistical analysis: T-test and t-test with paired comparisons were employed to examine the mean difference of radial growths and mean difference of tariffs in the aspects, respectively. Hotelling's T_2^2 test was carried out to test the null hypothesis of equality of mean vectors between the ecological aspects. The mean of four measured variables of sample trees, diameter (D) in centimeters, height (H) in meters, bark thickness (E) in centimeters and radial growth of trees (L) in millimeters, were merged to produce the means vector in each ecological aspect. Bartlett's test was employed prior to the before-mentioned tests to examine the null hypothesis of equality of the population covariance matrices as a precondition for the strict validity of Hotelling's T^2_2 test as well as t-test (Zali and Jaafari Shabestari, 1984; Hosseinzadeh, 1986a, 1986b). Correlation matrices among cited variables were calculated and examined in the two aspects.

RESULTS AND DISCUSSION

Correlation matrices of the variables in the ecological aspects: Correlation matrices among the four variables in each ecological aspect demonstrated that there are significant correlations among diameter, height and bark thickness in each aspect, however; no significant correlations between radial growth and the other mentioned variables were observed. Radial growth may have correlations with other forest parameters not considered in this research. Followings are the correlation matrices of the northern and southern aspects (** = p<0.01; ns = non-significant):

Southern aspect

$$\begin{array}{cccc} D & H & E & L \end{array}$$
$$\begin{bmatrix} 1 & 0.789^{**} & 0.449^{**} & 0.107^{ns} \\ 0.789 & 1 & 0.588^{**} & 0.095^{ns} \\ 0.449 & 0.588 & 1 & -0.015^{ns} \\ 0.107 & 0.095 & -0.015 & 1 \end{bmatrix}$$

Northern aspect

$$\begin{array}{cccc} D & H & E & L \end{array}$$
$$\begin{bmatrix} 1 & 0.732^{**} & 0.300^{**} & -0.072^{ns} \\ 0.732 & 1 & 0.588^{**} & -0.087^{ns} \\ 0.300 & 0.588 & 1 & -0.060^{ns} \\ -0.072 & -0.087 & -0.060 & 1 \end{bmatrix}$$

Local volume tables (Tariff): In the present study, local volume tables more adapted with the studied forest districts were completed. The weighted Tariffs (local volume table) of the mixed broadleaf forests were completed as Table 3. Chuka local volume table is currently being used by the forest managers (Shafa-Rud Forest Company, 1970a, b) for all managed forests in Shafa-Rud basin to estimate the growing stock, nevertheless the calculated tables in this research are certainly able to estimate volume of trees and volume growth more accurately than Chuka table since they were prepared according to the characteristics of the forest in each aspect such as species mixing ratio. Comparison of the two tariffs by t-test with paired comparison showed a significant difference between them at 5% level of significance ($\chi^2_{\text{Calculated}} = 0.051$, $t_{\text{Calculated}} = 10.9$). It implies that calculating a weighted volume table for each of the northern and southern ecological aspects in the studied basin is indispensable to estimate precisely the stand growing stock prior to utilization.

Comparison of the mean radial growths in the ecological aspects: Mean radial growth of trees in ten recent years in the southern and northern aspects were 22.6 and 23.7 mm,

Table 3: Weighted tariffs of the southern and northern ecological aspects

I	Diameter classes (cm)	Tariff of southern aspect (sylve)	Tariff of northern aspect (sylve)
1	15	0.119	0.175
2	20	0.188	0.292
3	25	0.324	0.474
4	30	0.528	0.723
5	35	0.799	1.037
6	40	1.137	1.416
7	45	1.543	1.861
8	50	2.016	2.372
9	55	2.556	2.949
10	60	3.163	3.591
11	65	3.838	4.300
12	70	4.581	5.073
13	75	5.390	5.913
14	80	6.267	6.818
15	85	7.210	7.789
16	90	8.221	8.825
17	95	9.300	9.928
18	100	10.446	11.069
19	105	11.659	12.329
20	110	12.939	13.629

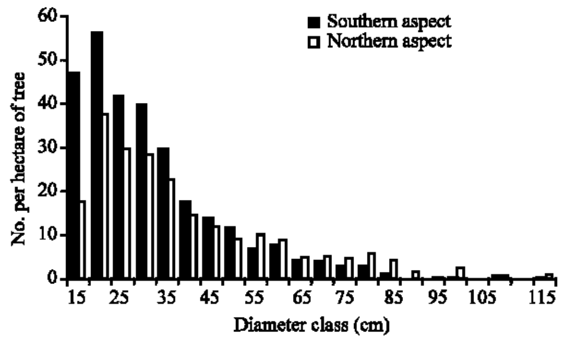


Fig. 3: Distribution of trees in diameter classes (cm) in the Southern and Northern ecological aspects

respectively. Comparing the radial growth means by t-test showed a significant difference between them at 5% level of significance ($\chi^2_{Calculated}$ = 11.1 and $t_{Calculated}$ =3.47). It demonstrated that the ecological differences at the two northern and southern aspects in Shafa-Rud basin such as climatological factors might have effects on the growth of trees.

Figure 3 shows the distribution of trees in diameter classes in the two aspects. The northern aspect has larger diameter trees than those of the southern. Furthermore, the diameters of average basal areas for the southern and northern aspects were calculated to be 28.3 and 33.5 cm, respectively. The study concluded that the significant difference between radial growths of the two aspects could not be attributed to the unequal distributions of trees in different diameter classes of the ecological aspects. Correlation matrices also produced no significant correlation between the radial growth and diameter as well as between the radial growth and height.

Lorey's means height, diameters of average basal area and Bark coefficient: Calculation of Lorey's mean height and diameter of average basal area with 869 trees in southern and with 666 trees in the northern aspects showed higher values in the northern aspect than that in the southern. Lorey's mean height in the northern aspect was 25 m in comparison with the 22.9 m in the southern. Similarly, the diameter of average basal area of the northern aspect was 43.9 cm. This parameter was computed to be 35.3 cm in the southern aspect. The results indicated a higher site index in the northern than that of the southern.

Bark coefficients were also computed in the southern and northern aspects as 1.04 and 1.05, respectively. The higher value of bark coefficient in the southern aspect can be attributed to the higher amount of solar radiation, higher air temperature and also the presence of thick-barked species such as Oak in this aspect.

Multivariate comparisons (MANOVA): The means vectors of the four variables: diameter, height, bark thickness and radial growth were compared using Hotelling's T^2_2 test and results showed that the differences in the centroid of vectors were highly significant at 5, 1 and 0.1% levels of significance. The means vectors and Hotelling's T^2_2 value were as follows:

$$\bar{X}_{Southern} = \begin{bmatrix} \bar{D} \\ \bar{H} \\ 2\bar{E} \\ \bar{L} \end{bmatrix} = \begin{bmatrix} 22.6 \\ 44.1 \\ 2.0 \\ 31.3 \end{bmatrix}$$

$$\bar{X}_{Northern} = \begin{bmatrix} \bar{D} \\ \bar{H} \\ 2\bar{E} \\ \bar{L} \end{bmatrix} = \begin{bmatrix} 23.7 \\ 48.9 \\ 1.6 \\ 26.4 \end{bmatrix}$$

T^2_2=32.4 and $F_{4,\,355}$=8.05

A separate site condition planning therefore presents the best management policy for the southern and northern aspects in Shafa-Rud basin. In the running management policy in this basin, there is no concern about the effect of the southern and northern aspects on the quantitative variables of forests (Attarod, 1998). In other words, the same management policy has currently been practiced to all the existing forests on northern and southern ecological aspects. A site condition planning represents the most appropriate strategies for the sustainable use of natural forest ecosystems.

Moreover, in forestry investigations in Iran, univariate statistical methods (ANOVA) are usually used to analyze the variability of one factor. However, multivariate statistical methods are to analyze the variability of many variables at the same time (MANOVA) (Moghaddam *et al*., 1993). Given the complexity of the multivariate statistical methods for forest managers in Iran, they often avoid applying MANOVA techniques. The interaction among various variables in forest ecosystems highly recommends that multivariate statistical methods should be used to attain more reliable and scientific results in the management of forest ecosystems.

Mixing ratios and volume growths in the ecological aspects: Species mixing ratios of the two aspects are shown in Fig. 4. These species form the main composition of commercial forests in the Caspian region. Present results showed the number per hectare of trees in the southern aspect as 289.7 and 222, respectively. Besides, 94 and 84% of trees in the southern and northern aspects were less than 60 cm in diameter, respectively (Fig. 4).

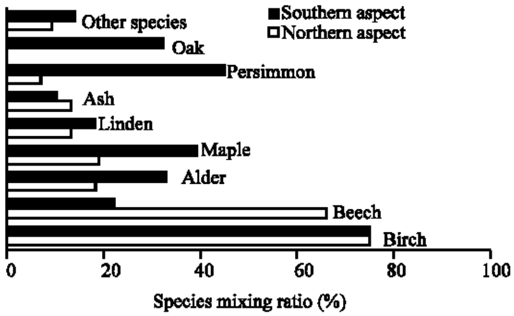


Fig. 4: Species mixing ratios of the Southern and Northern ecological aspects

Table 4: Volume growths (sylve ha^{-1}) of all species in the northern and southern ecological aspects

Species	Southern aspect (sylve ha^{-1})	Northern aspect (sylve ha^{-1})
Birch	1.24	2.26
Beech	0.57	3.05
Alder	2.30	1.47
Maple	0.39	1.25
Linden	0.97	0.70
Ash	1.72	0.43
Persimmon	0.66	0.14
Oak	1.14	-----
Other species	0.18	0.25
Total	9.17	9.55

Volume growth of the forest in the southern aspect was found to be 9.2 sylve per hectare, slightly lower than that of the northern (9.5 sylve per hectare) (Table 4). This research was the first of its kind in Shafa-Rud forest basin (Attarod, 1998) since there was no investigation concerning the growing stock of species.

Presently, to calculate the annual allowable cut, the managers of Shaf-rud Forest Company either use volume growth data obtained from the accomplished researches in other countries having rather similar forests to the forest ecosystems in Iran or ignore the growing stock. Neither method seems sound and reasonable (Attarod and Bayramzadeh, 2003). A comprehensive and integrated research will definitely be required to estimate the stand volume growth of Shafa-Rud forest basin as well as that of Guilan province, the western Caspian region.

The percent volume growths per hectare for the southern and northern aspects were estimated to be 3.1 and 2.9%, respectively. The percent volume growths per hectare of Kheirudkenar forests in Mazandaran province, the central Caspian region, was reported to average around 2% by Zahedi-e-Amiri (1991). Although the composition of the commercial forests of Iran in the narrow line of the Caspian region is almost the same, climatological differences at different latitudes as well as soil properties may have produced different volume growths values.

CONCLUSIONS

We examined the effect of the southern and northern ecological aspects on the quantitative variables of commercial forests of the Caspian region, north of Iran using a multivariate statistical method. Means vectors of the four variables namely diameter, height of trees, bark thickness and radial growth in ten recent years compared by Hotelling's T^2_2 test exhibited a highly significant difference. Volume growths were calculated to be 9.2 and 9.5 sylve per hectare in the southern and northern aspects, respectively. Local volume tables (Tariffs) of the two southern and northern aspects were completed and compared with t-test and a significant difference was observed between them. No significant correlations were observed between radial growth and diameter, height and bark thickness in the northern and southern aspects.

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