# A basal area increment model for individual trees in mixed continuous cover forests in Iranian Caspian forests

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**Abstract**
This study investigates basal area increment of individual trees in mixed species continuous cover forests in the north of Iran. Empirical data from the species *Fagus orientalis, Carpinus betulus, Parotia persica, Acer velutinum, Quercus castanifolia* and *Alnus subcordata* have been collected and analyzed with regression analysis. One general function for basal area increment has been estimated. Basal area increment is a statistically significant nonlinear function of the tree basal area and the competition.

**Keywords** Individual-tree model, Shastkalate forest, Continuous cover forestry, Mixed stands, Uneven-aged management, Basal area increment.

## Introduction

Iranian Caspian forests, mainly located on the northern slopes of the Alborz, are important because of environmental and economic reasons. The biodiversity in fauna and flora is high. These forests are mostly uneven-aged beach-dominated hardwood mixtures. In this paper, the ambition is to develop and test a new basal area growth function to be used in these forests.

## Material and Method

District one in Sastkalate forests, with an area of 1713 hectares, is located in Golestan province, in watershed number of 85 (36˚43´27″ to 36˚48´6″ N and 54˚21´26″ to 54˚24´57″. In order to obtain a sample of increment cores in the district, 140 circular plots, each with an area of 0.1 hectare, were chosen. In each plot, 2-3 increment cores were extracted. Trees of different species and diameter classes were selected as "witness trees". Furthermore, the diameter, height and competition of the witness trees were measured. Totally 421 sample cores in this forest have been sampled and used for modeling. The witness trees were distributed over species in the following way: *Fagus orientalis* (Beech) (93), *Carpinus betulus* (Hornbeam) (106), *Parotia persica* (Iron wood) (68), *Acer velutinum* (Maple) (67), *Quercus castanifolia* (Oak) (51) *and Alnus subcordata* (Alder) (36). The descriptive statistics are found in Table 1 (Anonymous, 2007).

Table 1. Characteristics of the data set used for basal area increment modeling

| Variable | Mean | Minimum | Maximum | Standard deviation |
|---|---|---|---|---|
| No. of trees per hectare | 211 | 10 | 750 | 117.98 |
| Stand basal area, $m^2$ $ha^{-1}$ | 26.6 | .00 | 95.97 | 12.86 |
| Tree diameter,(D), cm | 35.56 | 10 | 65 | 10.49 |
| Basal area of trees larger than the investigated trees,( $\phi$ ), $m^2$ $ha^{-1}$ | 16.113 | 0.7 | 41.8 | 0.87740 (Standard deviation for 0.1 ha plots) |

**Results**

Now, a new basal area increment function for several hardwood species in the north of Iran has been developed. The parameters are all strongly significant and the graphs show that the developments of diameter and basal area are understandable and reasonable.

**The basal area increment function and the statistical estimation**

The following functional form was selected:

$$E\left(\frac{dx}{dt}\right) \approx E\left(\frac{\Delta x}{\Delta t}\right) = ax^{\frac{1}{2}} + bx^{\frac{3}{2}} + g\phi^3 x^{\frac{1}{2}}$$

$x$ is the basal area $(cm)^2$ of a particular tree, P. $\Delta t$ is a time interval and $\Delta x$ is the change of $x$ during $\Delta t$. $D$ is the diameter of P. $x = \frac{\pi}{4} D^2$. $\phi$ is the total basal area per ha $(m^2 / ha)$ of trees larger than P. $\phi$ is estimated from the 0.1 ha plot where P is located.

$\phi = \phi(x). \frac{d\phi}{dx} \leq 0.$ There are three parameters in the function: $a > 0, b < 0, g < 0$.

The value of parameter $a$ is a function of the species which P belongs to. (The values of $a$ for different species can be determined via the regression function found below.) The parameters were determined via regression analysis, along the lines of Pindyck and Rubinfeldt (1998). In the regression analysis, $\Delta t$ was 10 years and the values of $x$ were approximations of the average x- values during the ten years. The following basal area increment function was estimated. (Below the coefficients, the t-values are given).

$$E\left(\frac{dx}{dt}\right) \approx E\left(\frac{\Delta x}{\Delta t}\right) = \underset{(42.115)}{1.3468}\, x^{\frac{1}{2}} - \underset{(-16.260)}{0.0000487}\, x^{\frac{3}{2}} - \underset{(-4.118)}{0.0000061632}\, \phi^3 x^{\frac{1}{2}}$$

$$- \underset{(-2.802)}{0.0791} K_F x^{\frac{1}{2}} - \underset{(-11.042)}{0.3116} K_C x^{\frac{1}{2}} + \underset{(5.028)}{0.2286} K_Q x^{\frac{1}{2}} - \underset{(-26.290)}{0.9932} K_P x^{\frac{1}{2}}$$

$K_F, K_C, K_Q, K_P$ are the dummy variables, $K_i \in \{0,1\}\ \forall i$, representing different species. (Error term calculations is not included in this short manuscript.)

If $(K_F = 0, K_C = 0, K_Q = 0, K_P = 0)$, then the function holds for maple and alder.

If $(K_F = 1, K_C = 0, K_Q = 0, K_P = 0)$, then the function holds for beech.

If $(K_F = 0, K_C = 1, K_Q = 0, K_P = 0)$, then the function holds for hornbeam.
If $(K_F = 0, K_C = 0, K_Q = 1, K_P = 0)$, then the function holds for oak.
If $(K_F = 0, K_C = 0, K_Q = 0, K_P = 1)$, then the function holds for iron wood.

All estimated parameter values were significantly different from zero (at the 95% level). Many of the parameters were determined with very high precision, which is shown by the t-values. The regression analysis also gave the following information, which, together with the analysis of residual diagrams, shows that the suggested functional form fits the empirical data very well: $R = 0.975, R^2 = 0.951, R^2_{adj} = 0.950, F = 1144$. The standard deviation of the estimate is 112.055 (with ten years prediction) and the number of observations = 421.

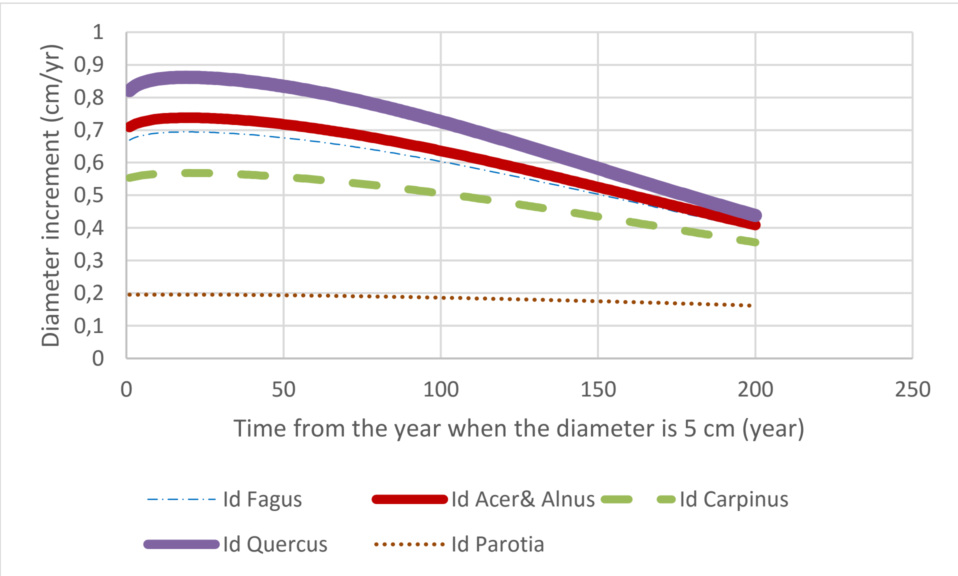


Figure 1. Diameter increment as a function of time for different species without competition.

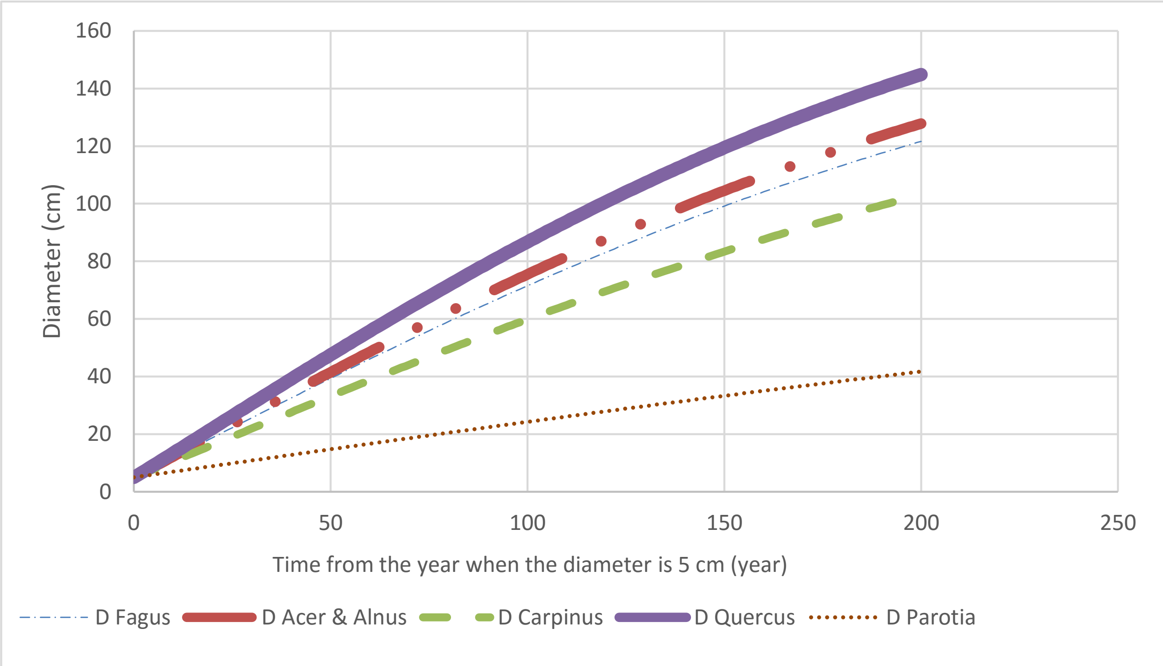


Figure 2. Diameter development as a function of time for different species without competition.

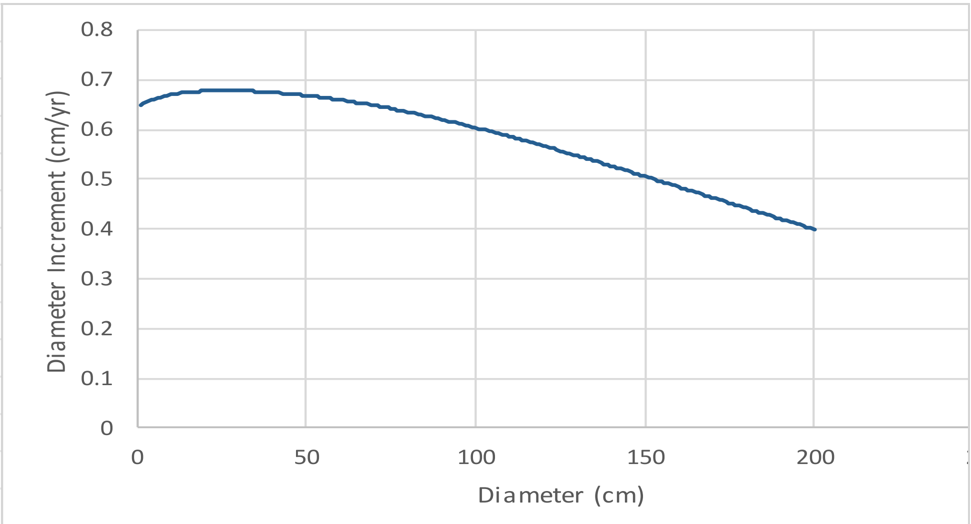


Figure 3. Diameter increment as a function of diameter for beech in case $\phi$ =max (20-1/6*D, 0)

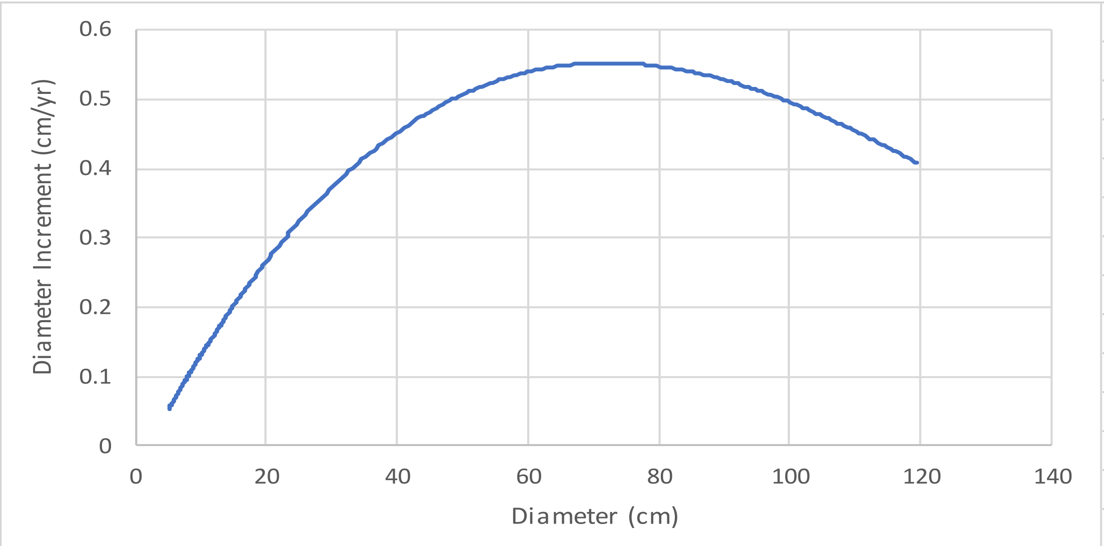


Figure 4. Diameter increment as a function of diameter for beech in case $\phi$ =max (60-1/2*D, 0)

**Discussion**

The function that was estimated in this analysis has similarities to functions estimated by Bayat et al (2013) and by Schütz (2006). The function estimated in this paper includes competition in a way that makes sure that the basal area increment is strictly positive only between basal area levels between zero and the maximum level. The new function leads to stable solutions, which is not always the case with other types of increment functions.

**Conclusions**

Now it is possible to predict basal area and diameter developments of 6 different hardwood species under different levels of competition in mixed forests in Iran.

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**References**

-Anonymous, 2007. Forestry Planning of Shastkalateh, District No. 1., Published by Natural Resources and Watershed Management Office at Golestan province, Gorgan, Iran, 517p (In Persian).

- Bayat, M., Pukkala, T., Namiranian, M. and Zobeiri, M. 2013. Productivity and optimal management of the uneven-aged hardwood forests of Hyrcania. European Journal of Forest Research, 132:851-864.

- Pindyck, R.S., and Rubinfeld, D.L. 1998. Econometric Models and Economic Forecasts, 4th edition, McGraw-Hill/Irwin.

- Schütz, J-P., 2006. Modelling the demographic sustainability of pure beech planter forests in Eastern Germany, Annals of Forest Science, 63: 93-100.