Commercial tree products modeling case study in Gorazbon district, Kheyroud Forest, Iran

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ABSTRACT
Reliable yield predictions are essential for sustainable forest management, with the quality of forest management plans hinges on the reliability of growth and yield predictions. Due to lack of both efficient harvest plans and product models in Hyrcanian forests, these requirements have implications for model design, implementation, and use. This study aims to estimate the percentage of different industrial products for oriental beech (Fagus orientalis Lipsky) and hornbeam (Carpinus betulus L.) at the Kheyroud Forest Research Station located in the Caspian forests of northern Iran. For this purpose at first enhancement in accuracy of district’s tariff tables were done by new clues from a new inventory. In order to determine the relation between product percentages and diameter at breast height (DBH), a set of models extracted to help forest managers predict when, where, and how much timber of hornbeam and oriental beech in each diameter class can be harvested. The results showed logs to be the most important output, reaching a peak at 100 and 115 cm diameter classes in both species, versus Bolt grade 1 & 2 reaching a minimum in these diameter classes behave conversely due to decay and harrow stems. The result of validation showed high accuracy of models in predicting commercial tree species products. In general the model is considered suitable for implementation in integrated forest sector modeling.

Introduction

The Hyrcanian forests of Iran are one of the most important relics of the so called Arctic-Tertiary forests in western Eurasia, and an important biodiversity “hot spot” (KNAPP 2005). They are located between 36° and 38° latitude in the north of the Alborz Mountains, which cover approximately 50,000 km² in the northern part of Iran, or about 15% of the total forested area and 1.1% of the country area (Sagheb Talebi et al. 2004; Sefidf et al. 2011). Many tree genera that are the last ice age survivors exist only in this area. Most of the temperate deciduous forests in western Asia have been converted into artificial plantations, secondary woodland, or agricultural and urban land, and thus these remnants of primary forests have to be considered as being irreplaceable (KNAPP 2005).

Oriental beech (Fagus orientalis Lipsky) and hornbeam (Carpinus betulus L.) are commercial species in Hyrcanian forests, which are mostly broadleaved and located at an altitude of 110–1000 m above sea level (a.s.l.). The stands are often spatially heterogeneous with large variations in tree size. These forests are intensively managed for timber production and are mostly managed under uneven-aged schemes (Marvie-Mohadjer 2012). Productions (number of workers, costs, approaches, harvesting systems) it is necessary for forest planners to be acquainted with the quality and quantity of timber present, stand volume, distribution in diameter classes, and structure of the forest ecosystem before harvesting. Therefore tools are needed for properly describing and predicting the different features of oriental beech and hornbeam stand dynamics and their influence on relevant forest attributes (Namiranian 2009).

Access to the volume of industrial and non-industrial wood products of each species in different diameter classes is essential for forest sector planning. Models that predict information about forest growth and yield enable forest planners to provide wood/ non-wood forest products on time and in the right quantity, and help enhance forest ecosystem services (Kimmins 1990; Peng 1999; Zobeyri 2001; Namiranin 2009; Pretzsch et al. 2013).

Hitherto, science-based models have been used to describe how forest stands develop (growth, mortality, and reproduction) and for predicting forest goods and ecosystem services which constitute the basis of contemporary multi-objective forest management planning (Burkhart 1990; Vanclay 1994; Rößger et al. 2011). An individual-tree model is the best type of model for describing the dynamics of uneven-aged forest stands (Bayat et al. 2012; Pukkala et al. 2013). Furthermore, in several countries formal forest sector models are being developed to serve as tools for policy analysis. The growth of uneven-aged forests in the Hyrcania has been studied previously (e.g. Heshmatol Vaezin et al. 2008; Bayat et al. 2012; Esfami and Hasani 2011), and growth and yield models for uneven-aged stands that can be used in simulations and numerical optimization have been developed (Bayat et al. 2012). But there are no models to predict the output of industrial and non-industrial wood products for oriental beech and hornbeam, which are Iran’s most important commercial trees.

The aim of this study was to develop models to predict industrial and non-industrial wood products for oriental beech and hornbeam species in each diameter class that could be incorporated into an integrated forest sector model. Some basic characteristics of the predicted models are presented.
Materials and methods

The study was carried out at the educational and experimental forest of the University of Tehran (Kheyroud Forest), which is located on the northern slopes of the Albourz ranges approximately 7 km to the east of Noshahr (Guilan Province) at 36°34’–36°37’N, 51°32E and with an altitude ranging from 0 m to 2200 m a.s.l. This broad range of altitude results in different plant communities. Kheyroud Forest has eight districts and the current research was done in the third district, Gorazbon, which covers 934.24 ha. Gorazbon district has 27 parcels, three parcels are protected, and 24 are productive and under logging (Forest Management Project of Gorazbon Section 2009).

Data collection

The dataset for modeling was produced from a list of marked and harvested tree characteristics (diameter, volume, depth of decay) in three harvesting periods, from 2012 to 2014, as assessed by renewal volume personnel from the Iranian Forest, Range and Watershed Management Organization.

After anticipate the amount of allowable cut, marking operation were performed. Marking operation is consisting of allocating the numbers to trees and measuring diameter at breast height of them. A list of marked tree characteristics – species, diameter at breast height (DBH) or 1.3 m from the ground, marked volume base in the tariff table – was produced (Namiranian 2009; Marvie-Mohadjer 2012).

By cutting and logging the marked trees, we initiated a renewal volume operation on the basis of 100% sampling. In renewal volume operation, the amount of wood with mid diameter more than 7 cm are classified as industrial wood and other pieces of wood with diameter less than 7 cm are classified as fuel wood. The length of each log and its mid diameter were marked with color in order not to interfere with the other logs. The volume of trees are calculated by sum of fuel wood and industrial volume in tree level and total of marked trees.

The total number of observed trees available to produce tree volume models based on diameter were 1263, comprising 568 F. orientalis, 632 C. betulus and with the remaining 63 made up of species such as Quercus castaneifolia, Alnus subcordata, Parrotia persica, Acer campestre, and Acer velutinum. The prediction models were based on pure stands of F. orientalis and C. betulus.

Growth and yield modeling

In this study, collected data were used to fit the following set of models:

- Individual-tree volume model base on diameter (tariff)
- Individual-tree industrial and non-industrial product models.

In order to examine the accuracy of current volume models of the region (marked volumes) we estimated the mean difference between the marked volume (Vm) and renewal volume (Vr) of trees (Equation 1) to determine the percent of difference between these two parameters (Figures 1 and 2) (diameter class is the independent variable and percent of difference is the dependent variable):

\[
\text{Percent of difference} = \frac{(V_m - V_r) \times 100}{V_m} \quad (1)
\]

Paired sample t test have been used to test the relation between percent of differences and diameter classes (Table 1). In order to produce update tariff table, power models were selected and for product models, polynomial and exponential models have been used.

Model validation

Testing models is imperative to establish their strengths and weaknesses, and to assess the range of conditions over which reliable projections can be expected. The accuracy of models with respect to prediction of total tree volume, and the percentage of industrial and non-industrial products in each diameter class for individual trees, were statistically evaluated by comparing against values from the validation sub-dataset. Twenty percent of trees were randomly selected as the validation sub-dataset and their diameter measured precisely in order to assess the models’ accuracy.

Results

The individual-tree volume models based on diameter (tariff) for both species are shown in Figures 1 and 2 (Table 1).
Table 2. Correlation of diameter and percent of differences for Fagus orientalis.

| DBH  | Differences | Percent of differences |
|------|-------------|------------------------|
| 10   | 0.325       | -0.051                 |
| 20   | 0.671       | 1                      |

**Significant correlation at 1% level.

The percent of differences between marked tree volume and renewal volume based on diameter for both commercial species are shown in Figures 3 and 4.

Paired sample t test have been used to test the relation between percent of differences and diameter classes. Results showed significant correlation between them (Table 2 and 3).

Due to comparison of marked volume and renewal volume of trees, paired sample t test have been applied and result showed, there was no significant difference between them (Table 4).

- **Individual-tree industrial and non-industrial product model.**

After harvesting, all the trees were converted into different products such as logs, bolts, wooden sleeper and others based on wood quality, decay, and type of usage. The proportion of industrial wood and fuel wood were about 82.2% and 17.7%, respectively. Product proportions over 3 years of harvest for the two commercial species are illustrated in Table 5. After cutting the trees, wood with diameter more than 25 cm and high quality classify as log, and other pieces of wood convert to different kind of bolt and rail road tie.

Ultimately, in order to estimate the percent of products in marked trees based on diameter classes, 10 equations have been extracted and are illustrated in Tables 6 and 7 and Figures 5 and 6.

**Model validation**

A validation sub-dataset of 113 oriental beech and 125 hornbeam trees were randomly selected and tested by paired sample t test. The result of comparison for training and validation data in the two species are presented in Tables 8 and 9.

For log and bolt, the performance of models were acceptable. But, about saw, subsidence performance of models were not acceptable and this is the result of buttress and decay in trees stem and trunk.

**Discussion**

Due to lack of efficient wooden product models in tropical forest, production of growth and yield models with different level of accuracy has been frequently assessed.

### Table 4. Results of paired sample t test.

| Species         | d.f. | Significance level | SD     | SEM    |
|-----------------|------|-------------------|--------|--------|
| Fagus orientalis| 567  | 0.077             | 0.021  | 0.0986 |
| Carpinus betulus| 630  | 0.466             | 0.0104 | 0.0654 |

**Significant differences at 1% and 5% level.

### Table 5. Wooden products volume in 3 years.

| Species           | Log (m³) | Grade 1 bolt (m³) | Grade 2 bolt (m³) | Saw subsidence (m³) | Sum (m³) |
|-------------------|----------|-------------------|-------------------|---------------------|----------|
| Fagus orientalis  | 2281.12  | 150.373           | 615.125           | 171.405             | 795      |
| Carpinus betulus  | 1085.75  | 174.242           | 394.948           | 119/122             | 557      |

### Table 6. Estimation of Fagus orientalis products based on diameter classes.

| Products (%) | Equation (R²) |
|--------------|---------------|
| Log          | P = -0.0083 d³ (cm) + 1.9387 d (cm) - 34.518 | 0.9614 |
| Grade 1 bolt | P = 0.0034x² - 7406x + 46.057 | 0.9527 |
| Grade 2 bolt | P = 0.0046x² - 1.0785x + 76.152 | 0.9296 |
| Saw subsidence | P = 13.587e⁻⁰.³³³³³x | 0.9008 |

### Table 7. Estimation of Carpinus betulus products based on diameter classes.

| Products (%) | Equation (R²) |
|--------------|---------------|
| Log          | P = -0.0115 d³ (cm) + 2.3048 d² (cm) - 40.669 | 0.9595 |
| Grade 1 bolt | P = 0.0071 d³ (cm) + 1.4543 d² (cm) + 85/781 | 0.9124 |
| Grade 2 bolt | P = 0.0029 d³ (cm) - 0.4437 d² (cm) - 18/829 | 0.9151 |

### Table 8. Model validation for Fagus orientalis.

| Species         | d.f. | Significance level | SD     | SEM    |
|-----------------|------|-------------------|--------|--------|
| Fagus orientalis| 25   | 0.05              | 1.288833 | 0.252761 |
| Grade 1 bolt    | 25   | 0.05              | 0.46076  | 0.903635 |
| Grade 2 bolt    | 25   | 0.05              | 0.128833 | 0.252761 |
| Saw subsidence  | 25   | 0.00              | 0.8729142 | 0.171926 |

**Significant differences at 5% level.
In this research, in order to improve marking operation accuracy, the percent of differences in each diameter class was calculated. As illustrated in Figures 3 and 4 the percent of overestimation is more than underestimation, which showed marked trees volume is more than renewal volume base on diameter. Point’s distribution in low diameter classes is more sporadic. This is the result of the presence of far

**Figure 5.** Estimation of *Fagus orientalis* products based on diameter classes.

**Figure 6.** Estimation of *Carpinus betulus* products based on diameter classes.

**Table 9.** Model validation for *Carpinus betulus*.

| *Carpinus betulus* product | d.f. | Significance level | SD   | SEM  |
|----------------------------|------|--------------------|------|------|
| Log                        | 23   | 0.143              | 1.082 | 0.2209583 |
| Grade 1 bolt               | 23   | 0.038              | 1.009 | 0.2061479 |
| Grade 2 bolt               | 23   | 0.634              | 1.3588138 | 0.277361 |
| Saw subsidence             | 23   | ~0.00              | 0.8729142 | 0.1711925 |

**Significant differences at 5% level.**
flung branches in thin trees stem, lack of culturing operations in natural forests, and selection of bad quality trees in some marking operations. In investigation by Inche Borouni (2013) Videlicit renewal volume of trees was more than marked volume in scatter points. So they suggest that producing updated tariff table by using new clues from 100% inventory or 3p method to accurately predict tree diameter is an essential activity. On the other hand, after paired sample t test, the results showed no significant difference between these two variables. This is well in line with the results of this study, which report however small dispute has been watched between two parameters, there is no significant differences between them. But regard to importance of renewal volume operation in determination of owner interest rate, imposition, product trade, and by considering accurate principle of exploitation, adjustment of this errors is necessary (Soleimanian et al. 2009). Some authors after assessment of current volume tables calculate significant differences between two mentioned volumes. Sheykholeslami et al. (2010) investigated that in hycranian forests there are tariff table for different species but they don’t predict the volume of standing trees in high precision such as tariffs for Parrotia Persica and Carpinus Betulus. One of the most important results of this problem is presence hollow and indirect stems in these trees which make prediction difficult.

Our models and analyses show the best models which is fit to relation between DBH and total volume (renewal) of trees in both of commercial tree species is power model and correlation coefficient determined about 0.887 for oriental beech and 0.922 for hornbeam. In investigation by Hasanzad et al. (2012) in order to assess the relation between DBH and total volume of oriental beech, parabolic models have better performance. In compare with other models with correlation coefficient of 0.95. In another research by Poorshakoori and Hasanzad (2005) the result indicate that parabolic models show the best performance and correlation coefficient is 0.97. These results are similar to the current study.

In this research the difference between current and new tariff table after paired sample t test were not significant but these small discrepancy have to be refine. In low diameter classes differences were small and by increasing the amount of diameter it grows. This is because of the lack of accurate tariff table in prediction of the thick and standing trees.

With increasing diameter and age of trees the amount of decay in stems increases, which decreases stem quality and thus negatively impacts the production of industrial wood products. So in higher diameter classes it can be observed that the amount of fuel wood increases and the production of logs decreases. Disregard of decay is the most important proof for dispute between current and new tariff. In other words, by increasing the amount of diameter, industrial volume increased and fuel wood is decreased but in high diameter again condition reverse. In Poorshakoori and Hasanzad (2005) also these result have been indicated. Until 65–85 diameter industrial volume reached to peak but after this diameter decreased and this is well in line with current study results. In investigation by Inche Borouni (2013) hornbeam tariff table showed high accuracy but tariff table of oriental beach needs to refine by new clues from a new inventory of forest trees.

In research by Lee and Guilding (2002) significant differences between available and predicted tariff table have been observed also in Gel and Bella (1995) and Ringvall and Kruys (2005) the necessity of update tariff tables is explored.

In order to determine the most appropriate models to predict commercial tree products, the relation between diameter and the percent of different industrial and non-industrial products, linear, power, exponential, polynomial, and logarithmic models have been compared. Power and polynomial models were found to be the most appropriate. The lowest correlation coefficient have been illustrated in saw subsidence and highest determined for logs in both species. The amount of logs in oriental beech reached to peak in 115 diameter classes and for hornbeam in 100 diameter classes which indicate these diameter classes are the most important diameters for producing industrial wood products. After these diameter classes the amount of logs fall down and other products will be replace. Other products reach to mean in this diameter classes but in high diameter the amount of logs decreased because of the presence of decay and other product grow. In Poorshkooori and Hasanzad (2005) researches parabolic models have the best performance in determine the relation between DBH, industrial wood, and fuel wood with correlation coefficients of 0.97 and 0.97, respectively. In other research on Fagus orientalis stands, parabolic model has been shown for relation between volume and DBH with correlation coefficient of 0.999 (Fallah et al. 2000). In other research, such as Soleimanian et al. (2009) and Sheykholeslami et al. (2010), predictions for the percentage of fuel wood and saw subsidence are imbalanced. It is because of decay or buttress in trunk of commercial tree species. These indicated results are similar to the results of this study.

Conclusion
Forest growth models have become indispensable tools for forest managers. Clearly models are useful, but they could be more useful. To realize their full utility, models need to become more accurate, and need to become an integral part of the forest management system. Model predictions should be monitored to reveal any discrepancies between predicted and realized outturns. This feedback loop provides the basis for a system of continual improvement both in growth modeling and in forest management.

Disclosure statement
No potential conflict of interest was reported by the authors.

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