# Linear Regression Models to Predict Special Post Production from Logs of Deresinated Aleppo Pine (*Pinus halepensis* Mill.) Trees

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## Abstract

The goal of this study was to develop model equations to predict the production of special posts from aleppo pine (*Pinus halepensis* Mill.) deresinated trees. Resin tapping causes some changes in the wood structure around the applied tapped area as a result of the resination of wood cells. Local communities have started to use timber from deresinated aleppo pine trees to produce small-sized posts for agriculture and green house use. The experimental sample consisted of 120 logs from the Sithonia peninsula forest in northern Greece. The logs were processed in a local sawmill to produce posts of four different sizes for agriculture use. The final product was 2-m-long posts measuring 4 by 4, 5 by 5, 6 by 6, and 8 by 8 cm.

Posts measuring 4 by 4, 5 by 5, and 6 by 6 cm were to be used for field tomato cultivation and 8 by 8-cm posts were for use in vineyards.

Linear regression model equations were developed for each post product. The models predicted the number of posts produced in relation to the diameter at the middle of the log and its utilized volume. On the basis of 120 logs processed, it was possible to draw secure associations using this model. Statistical analysis showed that the mean diameter effect was the most pronounced in all models.

Forest managers and sawmills know that each cubic meter of wood does not produce the same yield in terms of lumber recovery. It is also well known that the total value of lumber from a tree depends on both external geometry and internal wood characteristics and defects (Steele et al. 1993). For an efficient forest management strategy, the end uses and the prediction of product recovery are becoming important and should be taken into consideration in forest management decision-making (Zhang and Tong 2005).

Steele (1984) identified and discussed four main factors (i.e., log diameter, length, volume, and taper) affecting lumber recovery in sawmills. Studies also have shown that a log's value recovery is related to some log characteristics (Malan 1988, Aubry et al. 1998, Beauregard et al. 2002, Liu and Zhang 2005, Petutschnigg and Katz 2005, Liu et al. 2006, Øvrum and Vestøl 2009). In all of these studies, log size (volume, diameter, and length) was found to have more impact on value recovery than other wood characteristics.

The value of lumber is also determined by the quality, size, and types of internal log defects. Depending on the nature of the end utilization, each log is sawed to minimize the occurrence of these internal defects on the resulting lumber surfaces (Bhandarkar et al. 2008).

Aleppo pine covers up to 8.7 percent of the total forest area of Greece. It grows naturally at low elevations near the sea. The multiple values of wood (building timber, boat construction timber) and nonwood (resin) products of aleppo pine are directly associated with the economy of local communities as well as the regional economy. Resin tapping of aleppo pine has been practiced in Greece from ancient times to present day (Tsoumis 1995). Annual resin tapping begins when trees are 50 to 60 years old and continues until they are 80 to 90 years old, at which time they are exhausted of resin (deresination stage). Tapping is done on the tree trunk from stump level up to 2 m.

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*Figure 1.—(1) Lumber produced at the local sawmill from deresinated* Pinus halepensis *logs; (2) lumber sawing to produce posts; (3) produced posts in different dimensions stored at the sawmill yard; (4) the posts used to support tomatoes in field cultivation.*

Resin tapping causes some changes in the wood structure around the tapped area as a result of the resination of wood cells (Papajannopoulos 1983, 1989). Thus, the mechanical properties of resinated wood are not appropriate for building and boat construction uses; additionally, the old deresinated trees may have internal decay (Papajannopoulos 1983). Local communities started to use timber from deresinated aleppo pine trees to produce small-sized posts for agriculture and green house use. Therefore, as the demand grows, and in order to serve the forest management decision-making, it is necessary to develop models to predict product recovery based on measurable deresinated timber characteristics.

The aim of this study was to develop models to predict post production from each individual log based on log characteristics that are easy to measure such as diameter and volume.

## Materials and Methods

The sample trees for this study were collected from aleppo pine deresinated stands located in the Sithonia peninsula forests of the Halkidiki region in northern Greece. The trees were exhausted of resin and were at the age for harvesting. At the stand (sample) site, 120 trees were randomly selected. The trees were cut to logs up to 2.20 m long from stump level including all the resin tapping area. Each log was marked with a number, and the diameter at the middle of the log outside bark (*D*) was measured and recorded for the study.

For each numbered log, the volume was calculated using the method of mean diameter, the Huber method, which is commonly used in Greece. The Greek Forest Service actually uses the Huber method for log volume calculation, and the log volumes had already been calculated by the local Forest Service in the raw data tally sheets.

The logs were transported to a local sawmill for further processing. At the sawmill, each log was sawn and converted into a predefined product combination. The final product of each log was 2-m-long posts with dimensions of 4 by 4, 5 by 5, 6 by 6, and 8 by 8 cm. Posts measuring 4 by 4, 5 by 5, and 6 by 6 cm were used to support plants in field tomato cultivation (Fig. 1), and 8 by 8-cm posts were used to support plants in field vineyard cultivation.

Sawing schemes were not set up especially for this study; sawmill operators used their normal schemes. The sawmill operators were instructed to include in the final product only posts free of defective (decayed) wood. Thus, when the sawmill operators finally cut the log into lumber, they had to clear the lumber from decayed wood. The remaining lumber was cut into posts according to its width. The decision for the dimensions of each post was made by the operator in charge. For example, if the final width of the lumber was 9 cm, the operator in charge would produce one 5 by 5-cm post and one 4 by 4-cm post.

Thus, the production of 4 by 4-, 5 by 5-, and 6 by 6-cm posts was a combination product. The ratio of each post dimension product was decided during the sawing process by the operator, according to the external shape of each log and its internal wood characteristics and defects (decays). The production of 8 by 8-cm posts was not a combination product and only this dimension was produced from each log. In total, 24 logs were used for the production of 8 by 8-



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*Table 1.—Descriptive statistics.*

| Variable | No. of logs | Mean | SE | SD |
|---|---|---|---|---|
| Diameter at the middle of the log in meters ($D_m$) | 120 | 0.4372 | 0.0096 | 0.1059 |
| Volume of the log ($V_{log}$), $m^3$ | 120 | 0.349 | 0.0167 | 0.1833 |
| No. of posts | | | | |
| 4 by 4 (*Y*44) | 34 | 3.32 | 0.522 | 3.042 |
| 5 by 5 (*Y*55) | 23 | 14.35 | 3.861 | 18.517 |
| 6 by 6 (*Y*66) | 61 | 11.03 | 1.016 | 7.937 |
| 8 by 8 (*Y*88) | 24 | 8.92 | 1.184 | 5.800 |
| Utilization percentage for posts | | | | |
| 4 by 4 (perc_44) | 34 | 3.188 | 0.515 | 3.006 |
| 5 by 5 (perc_55) | 23 | 15.870 | 3.705 | 17.773 |
| 6 by 6 (perc_66) | 61 | 23.422 | 1.835 | 14.333 |
| 8 by 8 (perc_88) | 24 | 27.312 | 2.977 | 14.588 |

cm posts. Figure 1 shows parts of the sawing process of the logs at a local sawmill.

The volume of the produced posts from the log was then calculated, and the coefficient of production was calculated as the ratio of the product's volume to the volume of the log multiplied by 100. The coefficient of production (perc) was calculated for each post dimension (perc_44, perc_55, perc_66, perc_88).

To predict the number of posts per log for each post dimension in association with the measured diameter at breast height and the calculated coefficient of production, it was important to determine and build models. Simple linear models (linear regression models) in the form $Y$ (number of produced posts) $= f(D_m$, perc) were selected. The development of model equations for each post dimension was $Y = a + b \cdot D_m + c \cdot \text{perc}$, where $Y$ is the number of posts, $D_m$ is the diameter at the middle of the log in meters, and perc is the percentage of the utilized wood from the log. The statistical analysis was performed by using the computer statistical program SPSS 12.0 (Norusis 2003).

## Results and Discussion

The mean diameter, the volume per log, the produced posts per dimension, the percentage of the utilized wood (perc) for each post dimension, and the relevant descriptive statistics are presented in Table 1.

The fitted results of the linear regression models are shown in Table 2. Model 1 is for the 4 by 4-cm posts, Model 2 for the 5 by 5-cm posts, Model 3 for the 6 by 6-cm posts, and Model 4 for the 8 by 8-cm posts.

Table 3 shows that all regression models have large correlation coefficients as well as coefficients of determination. All the models performed very well, and the variance explained by the models varied from 78 percent for the 4 by 4-cm posts to 94 percent for the 8 by 8-cm posts. The Durbin-Watson statistic is ranked from 1.665 to 2.062, which falls within the range from 1.5 to 2.5. Thus, the assumption of residuals independence is satisfied for all calibrated models.

Table 4 shows the coefficients of models and their significance denoting very strong models. Multicollinearity is not a problem for the models because the tolerance statistic varied between 0.62 to 0.95 and was much greater than 0.1, which is considered the threshold for multicollinearity problems. The variance inflation factor also varied between 1 and 2, and it was certainly less than the threshold value of 5 (Van Laar 1991).

The three-dimensional scatterplots in Figure 2 show the strong linear relationship that exists between the dependent variable (number of posts) and the independent variables, diameter at the middle of the log and the percentage of log utilization.

The linear regression models fitted the data well, and the residual plots indicated a high order in terms of the predicted variables (Fig. 3). The residual analysis of the four models in Figure 3 shows that there were no obvious patterns or clustering, the residuals were homoscedastic, and the variance remained the same for every combination of values of the independent variables. The assumption of normality was another issue that had to be tested in order to secure that the calibrated models are statistically sound. The statistical criteria of Komogorov-Smirnov and Shapiro-Wilk shown in Table 5 appear statistically nonsignificant at the $\alpha = 0.05$ level except Model 4 for which the criteria appeared significant. This very slight departure from normality was not a big problem and thus did not interfere with the regression analysis.

## Conclusions

This study illustrated the effect that log characteristics such as mean diameter and percentage of wood utilization

*Table 2.—Linear regression model equations to predict post production.*

| Model | Equation |
|---|---|
| 1 | $Y44 = -8.874 + 19.197 \cdot D_m + 1.079 \cdot \text{perc\_44}$ |
| 2 | $Y55 = -34.604 + 73.156 \cdot D_m + 0.847 \cdot \text{perc\_55}$ |
| 3 | $Y66 = -18.639 + 45.143 \cdot D_m + 0.432 \cdot \text{perc\_66}$ |
| 4 | $Y88 = -15.459 + 39{,}117 \cdot D_m + 0.232 \cdot \text{perc\_88}$ |

*Table 3.—Statistical summary for models.*

| Model | *R* | $R^2$ | Adjusted $R^2$ | SE of the estimate | Durbin-Watson |
|---|---|---|---|---|---|
| 1 | 0.886 | 0.785 | 0.760 | 1.494 | 1.665 |
| 2 | 0.941 | 0.886 | 0.866 | 4.589 | 2.062 |
| 3 | 0.956 | 0.914 | 0.911 | 1.884 | 1.987 |
| 4 | 0.972 | 0.944 | 0.939 | 1.406 | 1.576 |

*Table 4.—Model coefficient parameter estimations and collinearity diagnosis.*[a]

| Model | Parameters | Coefficients | SE | *t* | Tolerance | VIF[b] |
|---|---|---|---|---|---|---|
| 1 | $a_1$ | −8.874 | 1.969 | −4.508 | | |
| | $b_1$ | 19.197 | 3.219 | 5.964 | 0.622 | 1.608 |
| | $c_1$ | 1.079 | 0.139 | 7.739 | 0.622 | 1.608 |
| 2 | $a_2$ | −34.604 | 6.356 | −5.444 | | |
| | $b_2$ | 73.156 | 11.719 | 6.242 | 0.950 | 1.053 |
| | $c_2$ | 0.847 | 0.105 | 8.066 | 0.950 | 1.053 |
| 3 | $a_3$ | −18.639 | 1.391 | −13.400 | | |
| | $b_3$ | 45.143 | 2.671 | 16.901 | 0.863 | 1.159 |
| | $c_3$ | 0.432 | 0.019 | 22.403 | 0.863 | 1.159 |
| 4 | $a_4$ | −15.459 | 1.377 | −11.223 | | |
| | $b_4$ | 39.117 | 2.320 | 16.858 | 0.959 | 1.043 |
| | $c_4$ | 0.232 | 0.022 | 10.617 | 0.959 | 1.043 |

[a] All model parameters were highly significant (Sig. < 0.000).
[b] VIF = variance inflation factor.



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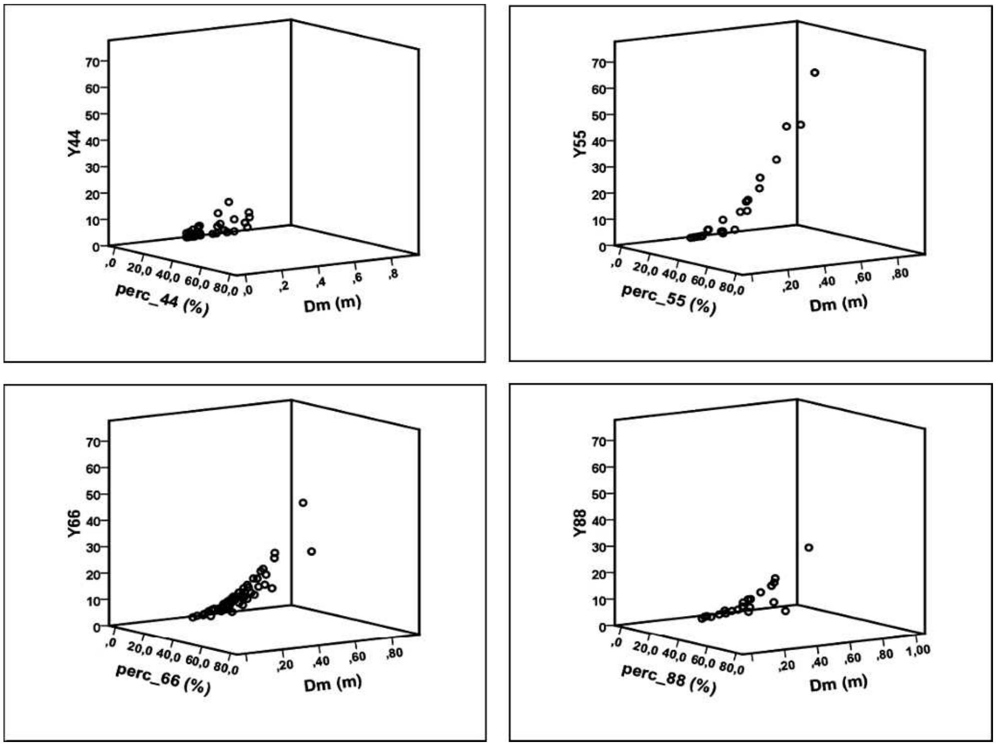


*Figure 2.—Three-dimensional scatterplots show the strong linear relationship between the dependent variables (number of posts) and the independent variables diameter at the middle of the log and the percentage of log utilization.*

had on predicting the number of posts produced from deresinated aleppo pine logs. On the basis of 120 logs processed, it was possible to draw secure associations regarding the number of posts produced, the mean diameter, and the percentage of wood utilization of the logs. The results of the statistical analysis show that the mean diameter effect was the most pronounced in all models. The model equations are suitable for use by forest managers

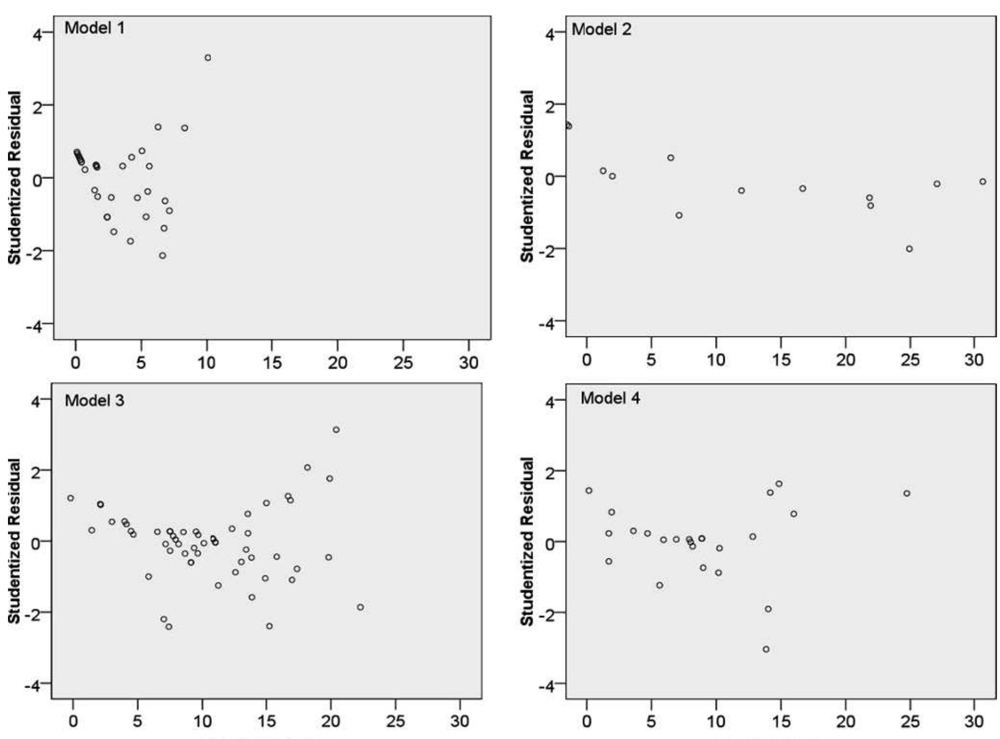


*Figure 3.—Residual analysis of the studentized residual versus the predicted variable of the calibrated models.*



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*Table 5.—Tests of normality of the residuals for the four models.*

| Model | Kolmogorov-Smirnov | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|
| | Statistic | df | Sig. | Statistic | df | Sig. |
| 1 | 0.130 | 20 | 0.200 | 0.967 | 20 | 0.683 |
| 2 | 0.132 | 14 | 0.200 | 0.971 | 14 | 0.892 |
| 3 | 0.109 | 58 | 0.082 | 0.966 | 58 | 0.100 |
| 4 | 0.205 | 23 | 0.013 | 0.906 | 23 | 0.034 |

and by sawmills as a reliable tool to predict the number of posts produced from each log derived from aleppo pine forests in Sithonia peninsula (Halkidiki region) of northern Greece. Nevertheless, further studies are recommended using samples of deresinated aleppo pine logs from other areas in Greece in order to test the general applicability of the model equations produced from this study.

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