# Fuel Load Modeling From Mensuration Attributes in Temperate Forests in Northern Mexico[1]

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## Abstract

The study of fuels is an important factor in defining the vulnerability of ecosystems to forest fires. The aim of this study was to model a dead fuel load based on forest mensuration attributes from forest management inventories. A scatter plot analysis was performed and, from explanatory trends between the variables considered, correlation analysis was carried out using the stepwise method in SAS software. Results showed that leaf load, total volume and cutting intensity largely explain dead fuel load as the dependent variable. In addition to discussing the statistical benefits of the models studied, it is concluded that inventory data from management programs are an efficient and low-cost alternative for estimating forest fuel loads.


**Keywords:** inventories, forest fires, allometric relationships.

## Introduction

All flammable plant material is considered forest fuel. Forest fuels are classified as living or dead; dead fuels are all biomass found on the ground; living fuels are comprised by herbaceous plants, shrubs and trees (Wong and Villers 2007). Dead fuels, in turn, are subdivided by weight into light or heavy fuels. They are also classified according to where they are found on a site: ground, surface or aerial fuels (Rentería and others 2005).

Forest fuel is one of the main elements involved in wildfire occurrence, and it is a very important factor to define the danger of forest fires, as the degree of danger is

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a function of the amount and type of fuel material present in each of the forest areas (Rentería and others 2005). It is known that fire intensity varies according to the fuel material. Therefore, it is essential to have updated dead forest fuel inventories. Planar intersections are one of the most common techniques; it was described by Brown in 1974, who mentions that this method can be applied to any type of forest. This technique consists of counting the intersections of woody plants in vertical planes. Based on this sampling the volume is estimated, and the weight is calculated based on the volume and the specific gravity of the woody plants.

Unfortunately, the drawback of this technique is that data must be taken *in situ*; therefore, it requires a considerable amount of time, effort and money. For this reason, the forest lands in which dead fuel quantification is carried out are few indeed. And of those that have some information available, since fuel loading is a dynamic process, after a certain time this information is out of date.

Stepwise regression is a method that facilitates relating variables with each other; this allows obtaining an equation to predict the value of the dependent variable once the values of the independent variable are known. This method is a useful, easy and fast tool to calculate dead fuels from living fuel information, and it can be used in all lands with forest inventory information, since the values for the dependent variables (dead fuel) and independent variables (mensuration data) are known.

The goal of this study is to estimate the dead fuel from living fuel information using allometric relationships, having as a hypothesis the existence of correlation between the dependent variable and the explanatory ones.

## Materials and methods

### Description of the study area

The selected study area is geographically located southwest of Durango State, Mexico. Its geographical coordinates are between 23° 07' and 23° 39' north latitude and 105° 12' and 105° 46' west longitude. It has a total area of 240,739 ha, with uneven topography in a system of plateaus associated with glens; its altitude ranges from 500 to 2,800 meters above sea level (m.a.s.l.). The soils were caused by weathering of igneous rocks. The main land uses are agriculture, livestock and forestry (Meraz 1998). Most ecosystems are common property, although some are privately owned. The climates are: C(w2), temperate, sub humid, summer rains from 5 to 10.2 percent annually; (A)C(w2), semi warm, temperate sub humid, summer rainfall from 5 to 10.2 percent annually; Cb'(w2), temperate, semi cold with fresh long summer, sub humid, summer rainfall from 5 to 10.2 percent annually; Aw1, sub humid warm, summer rainfall from 5 to 10.2 percent annually; C(w2), temperate, sub humid, summer rainfall from 5 to 10.2 percent annually (Pompa 2012), (Figure 1).

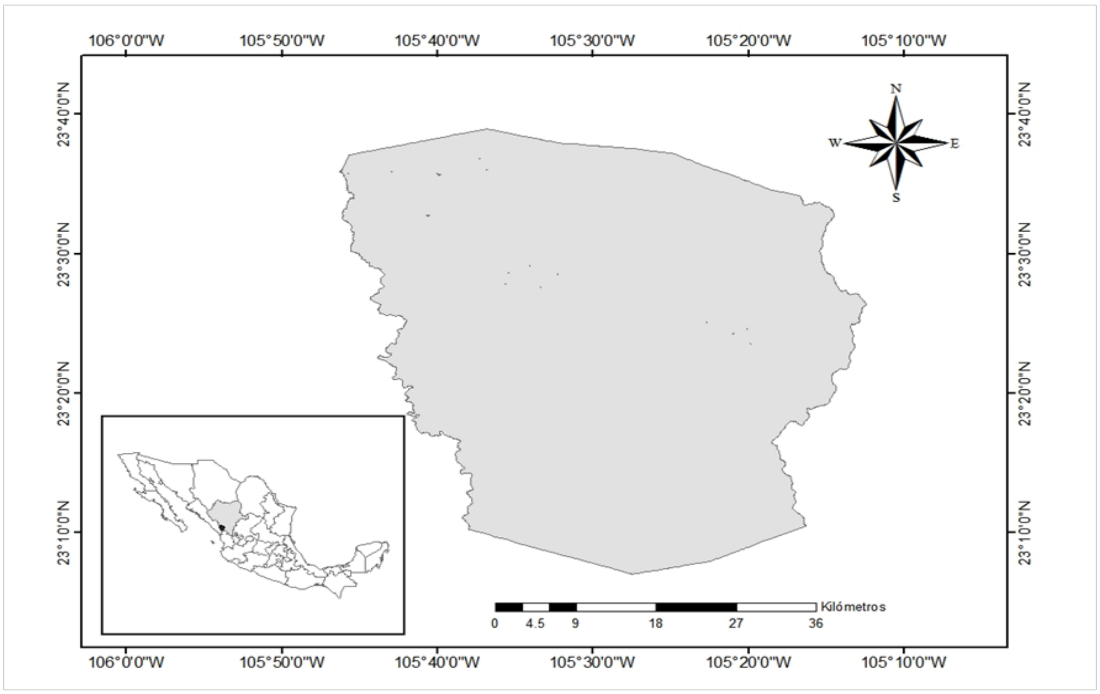


**Figure 1 –** *Ejido Pueblo Nuevo, Durango, Mexico.*

## Methodology

First, the following mensuration data was collected: leaf litter load ($Mg/ha^{-1}$); light, medium and heavy woody fuels ($Mg/ha^{-1}$): slope (percent); average *Pinus* height (m); average removal ($m^3$); oak and pine squared diameter (cm); pine and oak cutting intensities (percent); oak, conifers and leafy tree percentages; physical stocks of each species (number of individuals); total IMA and productivity level of the stands obtained from the forest management inventory of Ejido Pueblo Nuevo, Durango. Using this information, a scatter plot analysis for dead fuel material was performed using each one of the living fuel variables, in which trends with a greater relationship to the dead fuel load were identified. Once the variables with greater contribution were identified, they were processed using the stepwise method in SAS software in order to analyze the spatial relationships of the dependent variable (dead fuel) with the independent variables (living fuel).

The models used to estimate the dead fuel load were as follows (Table 1):

**Table 1** - *Models used to estimate the fuel load*

| | **Model** |
|---|---|
| (1) | L=$\beta_1$*$S$+$\beta_2$*H+$\beta_3$*R+$\beta_4$*SD+$\beta_5$*PCI+$\beta_6$*ACI |
| (2) | T=$\beta_1$*L+$\beta_2$*QSD |
| (3) | SWF=$\beta_1$*L+$\beta_2$*QCI |
| (4) | WHFL=$\beta_1$*PSD |
| (5) | SWF=$\beta_1$*$T$OC+$\beta_2$*QSD |
| (6) | c3=$\beta_1$*$T$OC+$\beta_2$*QSD |
| (7) | c2=$\beta_1$*$T$OC+$\beta_2$*QSD |
| (8) | c1=$\beta_1$*$Q$SD |

where β1, β2, β3, β4, β5, β6 are regression parameters, L is leaf litter load (Mg/ha$^{-1}$), S is slope (%), H is average Pinus height (m), R is average removal (m$^3$), QSD is *Quercus* squared diameter (cm), PCI is *Pinus* cutting intensities (%), ACI is average *Pinus* cutting intensities (%), T is total load (Mg/ha$^{-1}$), SWF is sum of light, medium and heavy wood fuel load (Mg/ha$^{-1}$), QCI is *Quercus* cutting intensities (%), WHFL is woody heavy fuels load (Mg/ha$^{-1}$), PSD is *Pinus* squared diameter (cm), TOC is total of other conifers (number of individuals), and C1, C2, C3 are categories of woody fuel loads with 1, 10 and 100 h of TR, respectively (Mg/ha$^{-1}$).

The criteria used to evaluate the model is based on a numerical analysis that compares three statistical parameters commonly used in forestry: 1) bias ( $\overline{E}$ ), which evaluates the model deviation with respect to the values observed; 2) the root mean square error (RMSE), which analyzes the accuracy of the estimates, and 3) adjusted coefficient of determination ($R^2_{adj}$), representing the portion of variance explained by the model, taking into account the number of its parameters. Their expressions are:

Bias:

$$\overline{E} = \sum_{i=1}^{n} (y_i - \hat{y}_i) / n \qquad (1)$$

Root mean square error:

$$RMSE = \sqrt{\sum_{i=1}^{n} \left(y_i - \hat{y}_i\right)^2 / (n-p)} \tag{2}$$

Adjusted coefficient of determination:

$$R^2_{\text{adj}} = 1 - (n-1) \cdot \sum_{i=1}^{n} (y_i - \hat{y}_i)^2 / (n-p) \cdot \sum_{i=1}^{n} (y_i - \bar{y}_i)^2 \tag{3}$$

Where: $y_i$ , $\hat{y}_i$ and $\bar{y}$ are the observed, estimated and average values of the dependent variable, respectively; $n$ is the total number of observations used to adjust the model and $p$ is the model's number of parameters.

## Results and discussion

According to the fit statistics values obtained by using the stepwise method, the independent variables that mostly explain the influence of dead fuel loads are: pine and oak cutting intensities; total actual stocks of pine, oak and other leafy trees and leaf litter depth (Table 2).

**Table 2** – *Estimated dead fuel models from living fuels*

| Model | Parameters | Estimate | Standard error | Adjusted parameters RMSE | $R^2_{adj.}$ |
|---|---|---|---|---|---|
| (1) | $\beta_1$ | -0.084 | 0.018 | 4.363 | 0.761 |
| L=$\beta_1$*$S$+$\beta_2$*H+$\beta_3$*R+$\beta_4$*SD+ | $\beta_2$ | 0.377 | 0.071 | | |
| $\beta_5$*PCI+$\beta_6$*ACI | $\beta_3$ | 31.250 | 5.375 | | |
| | $\beta_4$ | 0.162 | 0.027 | | |
| | $\beta_5$ | -0.066 | 0.015 | | |
| | $\beta_6$ | -2.149 | 0.393 | | |
| (2) T=$\beta_1$*L+$\beta_2$*QSD | $\beta_1$ | 1.053 | 0.173 | 15.635 | 0.683 |
| | $\beta_2$ | 0.413 | 0.044 | | |
| (3) SWF=$\beta_1$*L+$\beta_2$*QCI | $\beta_1$ | 1.120 | 0.128 | 17.100 | 0.371 |
| | $\beta_2$ | 0.104 | 0.027 | | |
| (4) WHFL=$\beta_1$*PSD | $\beta_1$ | 0.308 | 0.026 | 14.818 | 0.269 |
| (5) SWF=$\beta_1$*$T$OC+$\beta_2$*QSD | $\beta_1$ | 0.106 | 0.018 | 5.729 | 0.554 |
| | $\beta_2$ | 0.149 | 0.009 | | |
| (6) c3=$\beta_1$*$T$OC+$\beta_2$*QSD | $\beta_1$ | 0.052 | 0.009 | 2.847 | 0.520 |

| | | | | | |
|---|---|---|---|---|---|
| | $\beta_2$ | 0.068 | 0.004 | | |
| (7) c2=$\beta_1$*TOC+$\beta_2$*QSD | $\beta_1$ | 0.052 | 0.009 | 2.847 | 0.520 |
| | $\beta_2$ | 0.068 | 0.004 | | |
| (8) c1=$\beta_1$*QSD | $\beta_1$ | 0.013 | 0.0008 | 0.595 | 0.380 |

In Table 2, the results show standard errors close to zero and reliable $R^2$ values, which indicates that there is a good correlation between the dependent and independent variables. It is important to mention that although some models (2, 3, 4, 5, 6, 7 and 8) have fewer parameters they are equally reliable as the models with more of them. As it can be seen in models 1 and 2, although they differ in number of estimated parameters, the calculated variable is the same and the final results are similar.

Quantity of leaf litter in model 1 shows standard errors close to zero and the fit statistics value is $R^2$= 0.761 indicating that there is a good correlation between leaf litter and the dependent variables. In model 2 the total fuel load also shows standard errors close to zero, with an $R^2$= 0.683. The results indicate that both models yield statistically reliable data even when they differ in the number of estimated parameters.

On the other hand, the models show that the main factors for the concentration of forest fuels are a function of the waste generated during cutting and total actual stocks, as outlined in the work by Rentería and others, 2005.

According to the obtained results, the cutting intensity, total actual stocks and leaf litter depth variables can be reliably used in calculating fuel load, although its classification is difficult in terms of dimensions (light, medium and heavy) and the place where it was found (ground, surface or aerial). For Flores and Omi (2003), their estimation is a useful strategy to identify areas with a higher susceptibility to forest fire occurrence, and is thus very useful to direct prevention, control and attack strategies. This is coincident with Estrada and Angeles (2007), who mentioned that the values obtained during any assessment of forest fuels, can serve as a basis for mapping forest fire risk by combining with other parameters. Additionally, with this method it is not necessary to carry out an inventory of forest fuels that requires time, effort and funding. Fuel data can be updated while updating the forest inventory.

## Conclusion

Dead fuel load can be calculated from living fuels by using statistical techniques supported by mensuration data correlation. In this study, the variables that best explained the models were: cutting intensity, total actual stocks and leaf litter depth. It was determined that this correlation method is a fast, reliable and efficient technique since the dependent variables are taken from existing inventory data. Additionally, it can be a useful tool in modeling fire danger, regimes and fire management strategies.

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