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Modeling of Forests Fuels Load from Dasometric Attributes in Temperate Forests of Northern Mexico

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ABSTRACT
The study of fuels is a factor to define the vulnerability of ecosystems to forest fires. The aim of this study was to model the dead fuel load based on mensuration attributes from forest management inventories. A scatter plot analysis from explanatory trends between the variables considered was performed using the stepwise regression method of SAS. The results showed that the depth of litter, total real stocks and intensities of cut, largely explain the dead fuel load as dependent variable. In addition, to discussing the benefits of statistics of the models studied, it has been concluded that the inventory data management programs are an efficient and inexpensive alternative to estimate forest fuel loads.

Key words: Forest fires, allometric relationships, fire risk, fuel wood

INTRODUCTION
Wildland fires constitute a significant cause of land degradation, yet often they are a natural process (Neri-Pérez *et al.*, 2009). For managers, an accurate knowledge of the fuel complex is essential for designing management prescriptions aimed at reducing fire risk (Nuruddin *et al.*, 2006). Fuels are defined according to the physical characteristics of the live and dead biomass that contribute to the spread, intensity and severity of wildland fire (Andrews and Queen, 2001). Dead fuels are all biomass found on the ground; live fuels consist of live grasses, shrubs and trees (Wong and Villers, 2007). Dead fuels in turn are divided according to their weight in light fuels and heavy fuels and are often classified by the amount of time required for them to dry in order to burn (Estrada and Angeles, 2007). They are also classified according to where they are located within a site: ground fuels, surface fuels and aerial fuels (Schwarz, 1999).

The forest fuel is one of the key elements involved in wildfire and is a very important factor in defining the hazard of forest fires (Syaufina and Ainuddin, 2011). The degree of danger depends on the amount and type of combustible material present in corresponding forest areas (Djarwanto and Tachibana, 2010). It is known that the intensity of a fire changes according to fuel material type that is displaced. Therefore, it is essential to design accurate inventories of the fuel loadings in forest. One of the most popular techniques is the planar intersect technique (Brown, 1974). This author mentions that this method can be applied in any type of forest and involves counting intersections of woody pieces with vertical sampling planes. Based on this sample volume is estimated and weight is calculated based on the volume and the application of estimators of specific gravity of the woody materials.

Unfortunately, this technique has as drawback that the data should be taken *in situ* which require considerable time, effort and money. Indeed, the fuel load is dynamic and for those who have information within a certain time such information will be limited for this purpose. Therefore, the forest land for the quantification of dead fuels is scarce (Brown, 1974).

Currently, there are many procedures to estimate fuel loads in Mexican forests, through remote sensing (Flores-Garnica and Omi, 2003). However, such systems require reliable spatially referenced data, their use has been limited.

A method that facilitates quantification of dead fuels are the allometric relationships, using the stepwise regression; it allows us to obtain an equation to predict the value of the dependent variable if the values of the independent variable are known (Abdelkader *et al.*, 2007; Abdullah *et al.*, 2012). This method is a useful tool, easy and fast to calculate dead fuel material from live fuel material. Also can be developed in all those ecosystems from which there is information of forest inventories necessary for its application.

The aim of this study was to estimate the dead fuel material from the live fuel material by allometric relationships, with a hypothesis that there is correlation between dasometric data and forest fuel load.

MATERIALS AND METHODS

Description of the study area: The study area selected is geographically located southwest of the State of Durango, Mexico (Fig. 1). 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 a topography in a system of plateaus associated with streams and altitude from 500 to 2 800 m.a.s.l. The soils were originated by weathering of igneous rocks. The main land uses are agriculture,

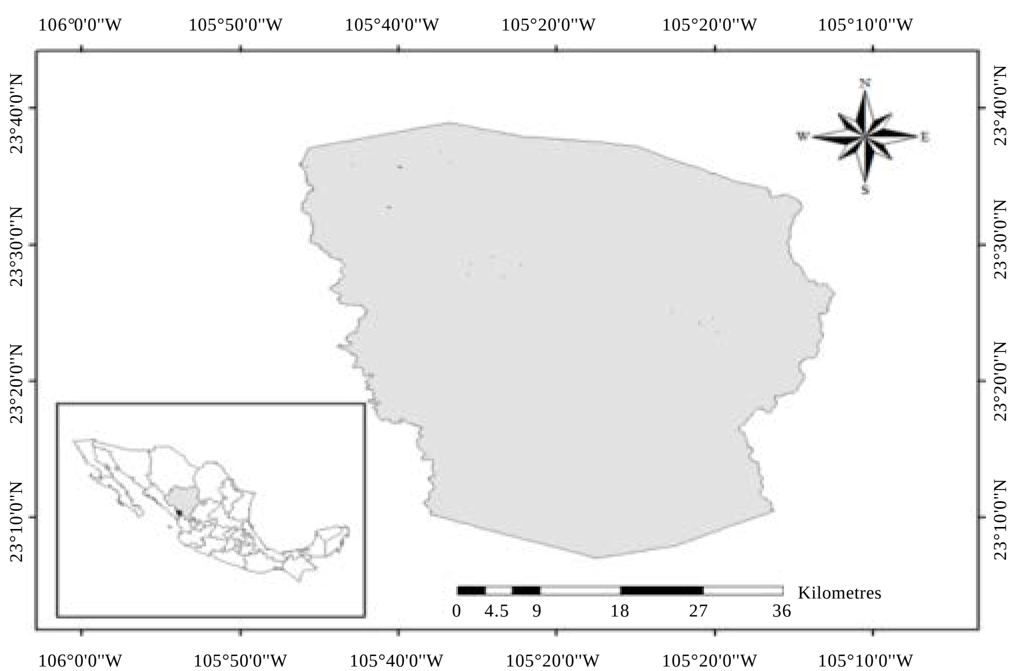

Fig. 1: Location of the Ejido Pueblo Nuevo, Durango

Table 1: Models used for estimating fuel load

No.	Model		
1	H	=	$\beta_1 \times P + \beta_2 \times A + \beta_3 \times R + \beta_4 \times DQ + \beta_5 \times ICP + \beta_6 \times ICM$
2	T	=	$\beta_1 \times H + \beta_2 \times DQ$
3	LP	=	$\beta_1 \times H + \beta_2 \times ICQ$
4	PES	=	$\beta_1 \times DP$
5	LP	=	$\beta_1 \times OC + \beta_2 \times DQ$
6	C3	=	$\beta_1 \times OC + \beta_2 \times DQ$
7	C2	=	$\beta_1 \times OC + \beta_2 \times DQ$
8	C1	=	$\beta_1 \times DQ$

Where, β_1, β_2, β_3, β_4, β_5, β_6: Regression parameters, H: Litter load (Mg ha^{-1}), P: Slope (%), A: Average height of *Pinus* (m), R: Average removal (m^3), DQ: Quadratic diameter of *Quercus* (cm), ICP: Intensity of pine cutting (%), ICM: Intensity of average cutting of *Pinus* (%), T: Total load (mg ha^{-1}), LP: Sum of the light, medium and heavy woody fuels (mg ha^{-1}), ICQ: Intensity of cut of *Quercus* (%), PES: Load of Heavy woody fuels (mg ha^{-1}), DP: Pine quadratic diameter (cm), OC: Total number of other conifers (No. of individuals), C1, C2, C3: Loads of woody fuel categories with 1, 10 and 100 h of TL (time lag), respectively (Mg ha^{-1})

livestock and forestry. Most ecosystems are common property, although there are some lands privately owned. Climates are: C (w2), temperate, sub-humid, summer rains from 5-10.2% a year (A)C(w2), semi-warm, temperate sub-humid, summer rains from 5-10.2% a year, Cb'(w2), temperate, semi-cold, with long cool summers, sub-humid, summer rains from 5-10.2% annually; Aw1, warm, sub-humid, summer rains from 5-10.2% annually; C(w2), temperate, subhumid, summer rains from 5-10.2% annually (Pompa-García, 2012).

Methodology: The variables utilized in this study were forest litter (mg ha^{-1}) light, medium and heavy woody fuels (mg ha^{-1}), slope (percent), average height of *Pinus* (m), average removal (m^3), oak-pine quadratic diameter (cm), intensities of pine-oak cuts (%), pine and hardwoods, real stocks of each species (number of individuals); total Mean Annual Increment (MAI) and productivity level of the stands all obtained from the forest management inventory of the Ejido Pueblo Nuevo Durango. In order to visually identify correlations between variables, a scatter plot analysis was performed of dead fuel material versus live fuel material variables. Having been identified the explanatory variables with greatest dependence, they were processed by the stepwise method of linear regression using SAS program to fit the linear relationships between dead fuel with live fuel. The models used for estimating the dead load of the fuel were as follows (Table 1).

The criterion for evaluating the goodness of fit of the models was based on numerical analysis involving the comparison of three statistics frequently used in forest modeling (Pompa-Garcia *et al*., 2012): (1) the bias (E) which evaluates the deviation of the model with respect to the observed values; the Root Mean Square Error (RMSE) which examines the accuracy of the estimates; the fitted coefficient of determination R^2_{adj} which represents the part of the variance explained by the model, taking into account the number of parameters in it. Their expressions are: Bias:

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

Root mean square error:

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

Fitted coefficient of determination:

$$R^2_{adj} = 1-(n-1)-\sum_{i=1}^{n}(y_1-\hat{y}_1)^2/(n-p)-\sum_{i=1}^{n}(y_1-\bar{y}_1)^2$$

where, y_1, $\hat{y}_1$ and $\bar{y}$ are the value observed, estimated and mean of the dependent variable; n is the total number of observations used to fit the model; p is the number of parameter of the model.

RESULTS AND DISCUSSION

According to the fit statistics obtained by the stepwise method of linear regression, the independent variables that explain mainly the influence of dead fuel load are: intensity of cutting of pine and oak, the total real stock of pine, oak and other hardwoods and depth of litter (Table 2).

In Table 2, the results shows standard errors close to zero and reliable R^2. Thus, indicates that there is great percentage of the variation in the response variable can that be explained by the explanatory variable. It is important to note that although some models (2, 3, 4, 5, 6, 7 and 8) measured lower number of parameters, their results are equally reliable to models with a higher number. As shown in models 1 and 2 that although they differ in number of estimated parameters the variable calculated is the same and its results are similar.

In model 1, quantity of litter, there are near-zero standard errors and fit statistics show an R^2 of 0.761 indicating that there is good correlation between litter and the dependent variables. In model 2 total fuel load, in the same way it throws us standard errors close to zero, with an R^2 of 0.683. The results show that both models yield statistically reliable data even when they differ in the number of estimated parameters.

Table 2: Models estimated of dead fuels from live fuels

				Fit statistics	
Model	Parameter	Estimation	Bias	RMSE	$R^2_{adj.}$
(1) $H = \beta_1 \times P + \beta_2 \times A + \beta_3 \times R + \beta_4 \times DQ + \beta_5 \times ICP + \beta_6 \times ICM$	β_1	-0.084	0.018	4.363	0.761
	β_2	0.377	0.071		
	β_3	31.250	5.375		
	β_4	0.162	0.027		
	β_5	-0.066	0.015		
	β_6	-2.149	0.393		
(2) $T = \beta_1 \times H + \beta_2 \times DQ$	β_1	1.053	0.173	15.635	0.683
	β_2	0.413	0.044		
(3) $LP = \beta_1 \times H + \beta_2 \times ICQ$	β_1	1.120	0.128	17.100	0.371
	β_2	0.104	0.027		
(4) $PES = \beta_1 \times DP$	β_1	0.308	0.026	14.818	0.269
(5) $LP = \beta_1 \times OC + \beta_2 \times DQ$	β_1	0.106	0.018	5.729	0.554
	β_2	0.149	0.009		
(6) $C3 = \beta_1 \times OC + \beta_2 \times DQ$	β_1	0.052	0.009	2.847	0.520
	β_2	0.068	0.004		
(7) $C2 = \beta_1 \times OC + \beta_2 \times DQ$	β_1	0.052	0.009	2.847	0.520
	β_2	0.068	0.004		
(8) $C1 = \beta_1 \times DQ$	β_1	0.013	0.0008	0.595	0.380

RMSE: Root mean square error

On the other hand, the models show that the main factors of the concentration of forest fuels are a function of the waste generated during the treatments of cuts and by the total actual stock, as outlined by Rentería *et al.* (2005).

According to the results obtained, the variables intensity of cut, total real stocks and litter depth can be reliably used in calculating fuel load, despite its classification is difficult in terms of dimensions (light, medium and heavy) and where they are located (ground, surface and aerial). However, can make an estimate of the fuel load used in different strategies for distributing fuel models. Flores-Garnica and Omi (2003) consider changes in the distribution of fuel loads, required to identify the areas most prone to occurrence of forest fires, thus to direct strategies for prevention, control and combat of these forest fires as set out by Estrada and Angeles (2007), who mention that the values obtained in any evaluation of forest fuels can serve as a basis for mapping of forest fire risk by combining other parameters. Also by this method is not necessary to conduct an inventory of forest fuels that requires time, effort and funding. The fuel data can be updated while updating the forest inventory (Heshmatol Vaezin *et al.*, 2008).

CONCLUSION

The dead fuel load can be calculated from live fuels by statistically supported techniques of correlation from mensuration data. In this study the variables that best explained the models were: intensity of cut, total real stocks and litter depth. It was determined that this method of correlation is a fast, viable and efficient tool as the dependent variables are taken from existing inventory data. It also can be a tool in the modeling of fire danger, regimes and management strategies of forest fires.

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REFERENCES

Abdelkader, I., A. Ferchichi and M. Chaieb, 2007. Aboveground biomass production of *Cenchrus ciliaris* in Tunisian arid zone. J. Boil. Sci., 7: 985-988.

Abdullah, N., H.J. Zainodin and A. Ahmed, 2012. Sustainable urban forest using multiple regression models. Res. J. Forest., 6: 1-15.

Andrews, P.L. and L.P. Queen, 2001. Fire modeling and information system technology. Int. J. Wildland Fire, 10: 343-352.

Brown, J.K., 1974. Handbook for inventorying downed woody material. USDA For. Ser. Tech. Rep. INT-16. Intermt. For. Range Exp. Stn., Ogden, Utah, pp: 24.

Djarwanto and S. Tachibana, 2010. Decomposition of lignin and holocellulose on *Acacia mangium* leaves and twigs by six fungal isolates from nature. Pak. J. Biol. Sci., 13: 604-610.

Estrada, I. and E.R. Angeles, 2007. Evaluacion de combustibles forestales en el Parque Nacional El Chico, Hidalgo. [Evaluation of forest fuels in the national park the Chico Hidalgo]. Seville Spain Wildfire, pp: 1-19.

Flores-Garnica, J.G. and P.N. Omi, 2003. Mapping forest fuels for spatial fire behavior simulations using geomatic strategies. Agrociencia, 37: 65-72.

Heshmatol Vaezin, S.M., P. Attarod and V. Bayramzadeh, 2008. Tree volume increment models of broadleaf species in the uneven-aged mixed caspian forests. Asian J. Plant Sci., 7: 700-709.

Neri-Pérez, P.A., D.A. Rodriguez-Trejo and A. Contreras-Aguado, 2009. Flammability of forest fuels in the tropical forest of Calakmul, Campeche. Univ. Sci. Trop. Humedo, 25: 121-132.

Nuruddin, A.A., H.M. Leng and F. Basaruddin, 2006. Peat moisture and water level relationship in a tropical peat swamp forest. J. Applied Sci., 6: 2517-2519.

Pompa-García, M., J. Vega-Munoz, R. Soto-Gutierrez, G. Trincado and F. Cruz-Cobos, 2012. Estimates of the bark thickness in bole profiles of Oak in Northern Mexico. Res. J. For., 6: 32-40.

Rentería, J.B., E.J. Trevino, J.J. Navar, O.A. Aguirre and I. Cantu, 2005. Woody fuel assessment in Ejido Pueblo Nuevo, Durango. J. Chapingo, 11: 51-56.

Schwarz, A.G., 1999. Fuels-general aspects. Forest Fire Management FOR 340, University of Alberta, Canada.

Syaufina, L. and A.N. Ainuddin, 2011. Impacts of fire on Southeast Asia tropical forests biodiversity: A review. Asian J. Plant Sci., 10: 238-244.

Wong, J.C. and M.L. Villers, 2007. Fuels assessment and its availability in forest fire: A study in the Malinche National Park. Geogr. Res., 62: 87-103.