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MODELLING AND MAPPING FIRE RISK FROM HUMAN FACTORS IN MEXICO

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INTRODUCTION

Forest fires are complex events that occur as a result of natural processes and human factors. Human beings alter the fire regime in three ways: changing their distribution and density, seasonality and altering the amount of available fuels (Bowman *et al*, 2011). It is necessary to find the relationship between fires, climatic factors, vegetation and human factors, in order to understand their interactions (Pwe & Larsen, 2001). Among human factors, the density of roads and urban areas are relevant factors in the spatial pattern of fires (eg Vasconcelos *et al*., 2001; Vilar *et al*., 2010; Liu *et al*., 2012; Grawelitz *et al*., 2012), being associated with accessibility for ignitions from an anthropic source (Oliviera *et al*., 2014).

In Mexico, it is estimated that more than 95% of forest fires that occur in the national territory are caused by human activities (CONAFOR, 2018). Most of the studies in Mexico to address these variables have focused on a local or regional scale (Muñoz *et al*., 2005; Roman & Martinez, 2006; Perez Verdin *et al*., 2011, 2014; Rodríguez-Trejo *et al*., 2011; Vilchis-Franés *et al*., 2015, Ibarra-Montoya & Huerta-Martínez, 2016, Monzón-Alvarado, 2018), but there is still no study of human factors on fire occurrence at a national level in Mexico.

Unlike countries such as the United States, Canada, Australia or Brazil, which have national fire hazard and risk prediction systems, in Mexico a fire danger system was recently lacking. A forest fire danger prediction system has been recently developed in Mexico to map near real-time fire occurrence risk and danger (Vega-Nieva *et al*., 2019a, 2019b). Previous studies have resulted in the development of temporal and spatial models for predicting the number and spatial distribution of wildfires from daily fuel dryness indices at 1 km resolution by vegetation types and regions in the country (Vega-Nieva *et al*., 2018, 2019b), but there is still no information on the influence of human factors on these spatial patterns of fire occurrence. This presentation summarizes the study of Monjarás-Vega *et al*. (under review). The objective of the study is to model and map at 1km the spatial occurrence of suppressed fires from Distance to Roads, Urban Areas and the interaction of both factors.

MATERIAL AND METHODS

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Fire database: The CONAFOR (National Forestry Commission) provided the database of the forest fires suppressed in the period from January 2005 to December 2015.
Distance maps of roads and urban areas: The digital database of the considered factors was obtained from INEGI (National Institute of Statistics and Geography - http://www.inegi.org.mx/geo/contenidos/urbana-) for the Distance to Urban Areas -DUA- and from CONABIO (National Commission for the Knowledge and Use of the Biodiversity - http://www.conabio.gob.mx/informacion/gis/-), for the Distance to Roads -DR-. DR and DUA were calculated with1 km of resolution in ArcGIS 10.5® (software by Esri) with *Euclidean distance* up to a maximum of 15 km. The values of DR and DUA were extracted to the records of fires suppressed by CONAFOR in ArcGIS with the *Extract multivalues to points* tool.

Analysis of Percentage of fire by Roads and Urban Areas: The values of percentage of fires observed were calculated for each value of DR (Percentage of Fires by Roads -PFR-) and DUA (Percentage of Fires by Urban Areas -PFUA-), according to the following equations:

$$PFR = N_{DR} / N_T \times 100$$
$$PFUA = N_{DUA} / N_T \times 100$$

Where: N_{DR}: Number of fires observed for each DR value; N_{DUA}: Number of fires observed for each DUA value. N_T: Total number of fires.

The predicted values of PFR and PFUA were normalized from 0 to 100 (PFR_N, $PFUA_N$), where 100 is the maximum predicted value for each variable and mapped in ArcGIS.

From these maps, the Percentage of Fires by Roads and Urban Areas (PFRUA) was calculated as: $PFRUA = N{ij} / N_T \times 100$

Where: N_{ij}: Number of fires observed for each value *i* of PFR_N and *j* $PFUA_N$; N_T; Total number of fires.

The statistical analysis and modeling of the data was processed using the *Proc Mod*el package of the SAS System 9.0 software. Linear and non-linear (power, exponential) models were explored for the prediction of the fires percentage. Further details can be found in Monjarás-Vega, *et al*., (under review).

RESULTS

The parameters obtained for the modeling of PFR, PFUA and PFRUA, as well as the statistics that describe the goodness of fit of the observed data are shown in table 1, where it is shown that the models can accurately describe the occurrence of fires.

Table 1. Adjustment parameters for the models used.

Model	a	b	b2	MSE	R^2	R^2 adj	Bias
$PFR= a*EXP^{(b*DR)}$	87.564	-0.6359	-	0.1885	0.9998	0.9998	0.1
$PFUA = a*EXP^{(b*DUA)}$	119.461	-0.8050	-	1.4392	0.9936	0.9928	0.4
$PFRUA = a*PFUA_N^{b*PFR_N**b2}$	0.060	0.7811	0.00585	1.0395	0.9543	0.9526	-0.01

Where: PFR: Percentage of Fires by Roads; PFUA: Percentage of Fires by Urban Areas; PFRUA: Percentage of Fires by Roads and Urban Areas; DR: Distance to Roads; DUA: Distance to Urban Areas; $PFUA_N$: Normalized Percentage of Fires by Urban Areas; PFR_N: Normalized Percentage of Fires by Roads; a, b, b2: constants; MSE: Mean Square Error; R^2: r-squared; R^2 adj: r-square adjusted; Bias: model bias.

Predicted PFR_N, $PFUA_N$ and $PRFRUA_N$ are shown in Figure 1. The highest risk of fire occurrence (in red and orange in the maps) was predicted in the two first kilometers from the roads and urban areas center. 80% of the fire suppression records in the study period correspond to that area. Further details can be found in Monjarás-Vega *et al.* (under review).

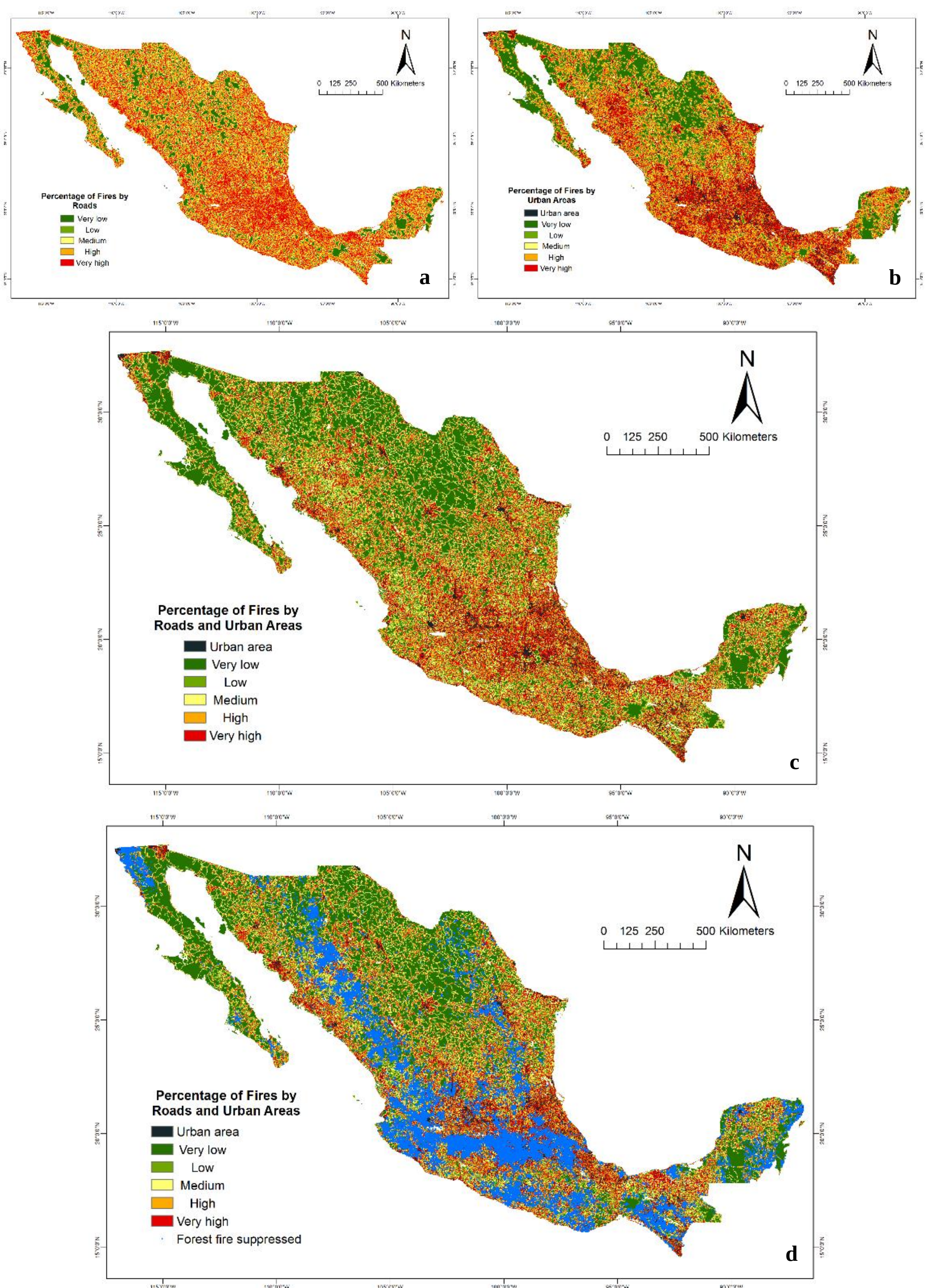

Figure 1. a) Map of the Normalized Percentage of Fire by Roads -PFR_N-. b) Map of the Normalized Percentage of Fire by Urban Areas -$PFUA_N$- c) Map of the Normalized Percentage of Fire by Roads and Urban Areas -$PFRUA_N$- d) Map of $PFRUA_N$ with forest fire suppressed by CONAFOR since 2005 to 2015 (Very high: 50%; High: 30%; Medium: 15%; Low: 4%; Very low: <1%).

These first results confirm what was found in other international studies (Ager, *et al*., 2010, Abdi, *et al*., 2018, Costa, *et al*., 2017) and at national studies at the regional level (Muñoz *et al*., 2005; Román & Martínez , 2006, Rodríguez-Trejo *et al*., 2011; Pérez-Verdín *et al*., 2011, 2014), where the proximity to roads and the proximity to urban areas has influenced occurrence of fires. These variables have been integrated into some of the risk indexes used in other studies at a regional or local level (Chuvieco *et al*., 2010; Costa *et al*., (2017).

The final result (Figure 1c) was integrated into the Forest Fire Hazard Prediction System of Mexico (http://forestales.ujed.mx/incendios; -Section: *Situación actual – Temáticos- Mapa de Riesgo de Ocurrencia de Incendio por Factores Humanos),* which is used for strategic planning in the allocation of resources for fire suppression and for the prioritization of fire management actions, such as the location of firebreaks and the management of fuel loads for the prevention of forest fires. This human-based fire risk map is combined with the daily weather-based fire ignition density index (Vega-Nieva et al., 2018, 2019b) to produce daily maps of fire danger (Vega-Nieva et al., 2019b).

Further factors are influencing fire occurrence. For example, agricultural activities are known to largely influence fire activity in the country (e.g. Román-Cuesta and Martìnez, 2006; Rodríguez-Trejo et al., 2011) and elsewhere (Haas, *et al*., 2013; Romero-Calcerrada, *et al*., 2010). Fire occurrence is also limited by climatic conditions and fuel availability (Littell *et al.,* 2009), as analyzed in the country by the recent study of Briones-Herrera *et al.*, (2019), which focused on the effect of aboveground biomass on fire occurrence. Consequently, this preliminary map should be expanded with the inclusion of such additional factors for improved fire occurrence risk predictions.

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