Article

Social factors of land use and vegetation related to forest fires in *Hidalgo* state.

Miguel Ángel Cruz Espíndola[1]

Dante Arturo Rodríguez Trejo[1*]

Antonio Villanueva Morales[1]

Javier Santillán Pérez[1]

[1] División de Ciencias Forestales, Universidad Autónoma Chapingo. México

[*]Autor por correspondencia, email: dantearturo@yahoo.com

Abstract

The study of forest fires requires an integrated analysis of the territory, since fire is not generated by the action of an isolated factor, but is derived from the joint action of a group of factors. In *Hidalgo* State, the alteration of fire regimes is considered the third cause of forest loss and degradation, only after the change of forest land use and clandestine logging. In this work, the meteorological, productive, land use and social factors that best explained the occurrence of forest fires in the municipalities of the state during the period 2000-2011 were identified, based on the analysis of four loss variables and 73 explanatory. By logistic regression a probability model was constructed in which the significant variables were: forest area, Gross Domestic Product *per capita*, road length and disturbed area, all positively related to the probability of fire, except the last, with negative influence. Based on fire probability, an occurrence scale was established and mapped. There were 39 municipalities that were placed in a medium category and 10 in a high category. The variables in the model were closely linked to human activities, which evidenced the importance of considering the human factor in the fire risk assessment. The management of fire requires the understanding of the causes behind the ignitions.

Key words: Fire risk, Fire forest fires, Fire Danger Index, integrated fire management, logistic regression, land use.

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Introduction

The study of forest fires requires, in most cases, an integrated analysis of the territory as a forest fire is not generated by the action of an isolated factor, but is derived from the joint action of a group of them, among which vegetation, climatic types, topography and human activities are particularly significant (Chuvieco and Congalton, 1989).

In many ecological systems, large-scale forest fires have a negative impact on the degradation of soil and vegetation cover and on greenhouse gas emissions, but the effects caused by fire are not necessarily negative. This influences the structural heterogeneity of forests, which is essential for the maintenance of biodiversity (Fulé *et al*., 2002; Cochrane, 2003).

Forest fires have been part of the dynamics of the world's terrestrial ecosystems and an important selective force in the evolution of biota (Whelan, 1995). A view of this phenomenon that is being explored in Mexico is the integral fire management, which considers its community use, the ecological and silvicultural use of fire, as well as the prevention and combat of forest fires (Rodríguez, 2000, 2015).

In Mexico, there are numerous forest fires every year that affect, to varying degrees, different terrestrial ecosystems, without losing sight of the fact that fire also fulfills ecological functions (Rodríguez, 2014). For the state of Hidalgo during the period 2000 to 2011, the average number of conflagrations was 171 on an average surface equal to 1 385.4 ha. The maximum reached 346 fires and 4 082.9 ha respectively, both in 2011, while the minimum was 50 fires and 164.7 ha, both in 2007.

According to recent statistics, 98 % of fires are regularly induced by human activities and only 2 % by other types of natural agents (Conafor, 2012), although some researchers suggest that the proportion of unprovoked casualties is underestimated (Rodríguez and Fulé, 2003). Subject to improve knowledge of the exact causes, Conafor's data highlight the close relationship between fires and the anthropic factors in the country.

Some studies have identified variables related to the causation and incidence of forest fires. For example, Román and Martínez (2006) determined that a greater density of roads and agricultural extensions increases their number in Biosphere Reserves in the state of *Chiapas*; Rodríguez *et al.* (2008) indicate that the area of the disturbed area, the maximum wind speed, the number of agricultural producers receiving support during the spring - summer productive cycle, the number of casualty fighters and the level of literacy are the most related variables to the affected area, the number of fires and other indicators of accidents in Mexico.

Ávila *et al.* (2010) identified the close relationship between the intensity and land use and the change of land use, with the fire occurrence patterns in *Durango*; Carrillo *et al.* (2012) showed that mean annual precipitation, land exposure and the number of lanes of communication were related to the spatial distribution of accidents in Puebla State; Pérez-Verdín *et al*. (2013) linked the influence of population density, access roads, low rainfall and high temperatures to the size of fires in *Durango*.

There are few studies of this type in the state of *Hidalgo* and the same can be said for most of the states of the Mexican republic. In the State Forestry Program 2011-2016, the state government recognizes the importance of this issue, since there is a growing annual rate of forest loss and degradation (10 000 ha year-1), mainly due to the above-mentioned problem (Semarnath, 2011).

According to the approach of the present work, the objective was to identify the factors that best explain the occurrence of forest fires in the different municipalities of the state of *Hidalgo* during the 2000-2011 period. It was hypothesized that these losses are the result of a social pattern, whose origin must be sought in the environmental, forest and socio-economic conditions of each zone.

Materials and Methods

Study area

The state of Hidalgo is located in the central-eastern region of Mexico. Its coordinates are: north 21°24 ‘- 19°36' north; 97°58 '- 99°53' west. It is 20 846.5 km^2 and stands for 1.1 % of the country's total area. It has 84 municipalities (Inegi, 2012a) (Figure 1).

Figure 1. Location of the study area, municipalities of *Hidalgo* State, Mexico.

Generation of the database

The variables that were associated for calculation of the occurrence of fires were identified from bibliographic reviews and consultations with state experts. A database was developed in the Excel program for the 84 municipalities of *Hidalgo*, with information for the 2000-2011 period (Table 1).

Table 1. Variables used to explain the forest fire incidence in Hidalgo State municipalities.

Group	**Variables**	**Units**
Metheorological		
Temperature	Maximum, minimum and mean (average, maximum and minimum). Maximum, minimum and mean of the fire season, January-June (average, maximum and minimum).	°C
Precipitation	Annual accumulated (average, maximum and minimum). Total annual accumulated Accumulated of the fire season, January-June (average, maximum and minimum). Total accumulated from the fire season.	mm
Cartographic		
Land use	Area: total of the municipality, forest, tropical forest, arid zones, hydrophilus and halophilus vegetation, disturbed areas, wooded (forests plus tropical forests), arid zones + hydrophilus and halophilus vegetation+ disturbed areas + total forested.	ha
Socioeconomic		
Productive	Financially supported producers during	number

	the spring-summer and fall-winter cycles (p-v and o-i)	
	Land supported in the p-v and o-i cycles, sowed land, crop land, agriculture land	ha
	Amount of the financial supports provided in the p-v and o-i cycles, production value.	$
	Lamb, goat and cow cattle.	
	Lamb cattle + goat cattle, lamb cattle + goat cattle + cow cattle	number
	Total population, 6-14 year- old literate, 15 +year- old literate, population with cased water, households with sewer system, households with electricity.	number
	Length of the road net (with pavement and dirt roads).	km
Variables and social indexes	Gross Domestic Product (PIB) per capita.	US$
	Life expectancy	years
	Education index, service index, IDH[1] in services, IDH in standard of living, IDH in gender, IDH.	
Associated to population	Literacy of the 6-14 year- olds, literacy of the 15 + year-olds, cased water, sewer system, electricity	number number[1]

	Length of the roads	
		km no.$^{-1}$
Relative to total forest area	Literacy of the 6-14 year- olds, literacy of the 15 + year-olds, cased water, sewer system, electricity, lamb cattle + goat cattle, lamb cattle + goat cattle + cow cattle.	number ha^{-1} km ha^{-1}
	Length of the roads	km ha^{-1}
Forest fires		
	Number of fires	number
Indicators	Affected area	ha
	Affected area / Number of fires	ha number^{1}
	Number of fires	number ha^{-1}
Relative to total forest area	Affected area	ha ha^{-1}
	(Affected area/ Number of fires)	(ha number^{-1})ha^{-1}

[1]IDH = Human development index

The metheorological information was taken from the data base of the surface climatic stations of the *México* Climate Computing Project (CLICOM) managed by the *Servicio Meteorológico Nacional (National Metheorological Service)* (Cicese, 2015). The temperature and precipitation data were completed with the method proposed by Gómez *et al*. (2008) and the isoyettes and isotherms of Inegi (2015a) were also taken into account.

The statistical variables (production, number of fires and surface area) and the road network were compiled from the *Anuario Estadístico y Geográfico de Hidalgo* (Hidalgo Statistical and Geographic Yearbook) (Inegi, 2015a).

Municipal areas and land use were determined by using the *Sistema de Información Geográfica ArcGis* 10.1 (ESRI, 2012) (Geographic Information System) (ESRI, 2012), based on the *Áreas Geoestadísticas Municipales* (Geographic Statistics Areas) (Inegi, 2012b) map, which is the result of the *Inventario Forestal Nacional 2000* (Semarnat, 2001) (National Forest Inventory 2000) (Semarnat, 2001) and the *Cartas de Uso del Suelo y Vegetación de Inegi escala* 1:250 000 (Inegi Soil and Vegetation Use Scale scale maps1: 250 000) (Inegi, 2015B) (Table 2).

The annual area information was estimated from a rate of change that was assumed linear and was obtained from cartographic products of different years. For example, if between one map and another edited five years apart, there was a reduction of 1 000 ha in forest area, the reduction rate was 200 ha year^{-1}.

The data about the social variables were consulted from the electronic page of the *Departamento de Estadística, Matemática y Cómputo de la Universidad Autónoma Chapingo* (Statistics, Mathematics and Computation of Chapingo Autonomous University) (DEMYC, 2015). They were completed with the PNUD reports (2006, 2009, 2012). Since the social indexes were calculated every 5 years (2000, 2005 and 2010), a rate of annual municipal change was determined in a similar way to what was pointed out for the maps.

Table 2. Vegetation and land use maps used to get information of the areas.

Key	Name	Status	Series and year of publication	Year of data collection
	Inventario Forestal Nacional 2000	National	II (2000) (actualizada)	1999 and 2000
E1402	*Cd. de México*	*Edo. de México*	III (2003), IV (2010) and V (2013)	2003, 2007 and 2011, respectively
F1411	*Pachuca de Soto*	*Hidalgo*	III (2003), IV (2010) and V (2013)	2003, 2007 and 2011, respectively

F1408	*Cd. Valles*	*San Luis Potosí*	V (2013)	2011

When working with such a large set of variables, the possibility of multicollinearity increases, in order to reduce its possible effects, the SAS 9.0 statistical package (SAS, 2002) carried out exploratory analyzes and correlation matrices, using the Pearson coefficient among all the variables. The explanatory types that correlated with each other were eliminated.

In addition, since the 22 municipalities did not have fires in record during the study period, and one has not forest area, it was decided to remove them from the analysis. After depuration, the data base was made up by 732 observations and 77 variables: four about the number of fires and the area the affect and response variables and 73 independent variables referring to the sociodemographic and territorial characteristics.

Later, another correlation analysis was made in order to know the relationship between the independent variables and the response ones; as expected, the values of the coefficient were low, in general, even if they were considered the greatest values to select one 10 variables and use them for the logistic regression: mean average temperature of the maximum temperature of the season, number of lambs, number of goats, number of cows, forest area, disturbed areas, life expectancy, length of the roads and Gross Domestic Product *per capita*. All the variables that were previously selected were significant with an $\alpha = 0.05$.

Statistical model

The logistic model has been used in different analyzes to estimate the occurrence of forest fires at regional or local scales, by generating predictive and explanatory models, by knowing the most important variables in the phenomenon (Carvacho, 1998).

For the statistical analysis of forest fire probability, the logistic regression model of Hosmer and Lemeshow (2000) was used:

$$P = \frac{1}{(1 + e^{-(\alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + ... + \beta_n X_n)})}$$

Where:

P = Probability of forest fire occurrence

e = Basis of natural logarithms

α = Ordinate to the origin

β_1 = Constant related to X_1 *as* independent variable and thus until $\beta_n X_n$.

This method requires a binomial dependent variable; therefore, the continuous variable number of forest fires was transformed, assigning the value 0 when a fire did not occur and 1 when there was at least one during the year. The analysis was performed using the logistic procedure (Proc logistic) of the SAS 9.0 program (SAS, 2002) for microcomputers.

To evaluate if the parameters were significant, the estimated parameters were examined, in addition to using the values of the χ^2 test and the Wald statistic. The 10 previously selected variables were "backward" stepwise and alternated one by one, until they were found to have no statistically significant differences ($p \leq 0.05$) in the model. Finally, four variables were selected: two of land use, disturbed area (apertur) and forest area (supbosq); in addition, two social, longcarr and GDP *per capita* (pib_p_c). Few variables were chosen because it was intended to achieve a meaningful model, but that its use was not complex.

The apertur, supbosq and pib_p_c variables were categorized from a cut-off point, 10 000 for the three variables (Table 3). The value chosen for the cut corresponds to its proximity to the averages of the explanatory variables: area with forest (11

481 ha), disturbed area (13 531 ha) and GDP *per capita* (US $ 7 795). The variable longcarr remained continuous.

Table 3. Categories made up from the study variables.

Variable	Type	Minimum Value	Maximum Value
apertur	Categorical	0	1
supbosq	Categorical	0	1
pib_p_c	Categorical	0	1
longcarr	Continuous	4.5	689.56

Construction of the fire occurrence model for *Hidalgo* State

A scale of fire occurrence was made (Table 4), in regard to the obtained values for the probability of forest fire occurrence (P); and they were included in a map.

Table 4. The categories of occurrence that were used.

Probability of occurrence	Degree of occurrence	Related tone in the map
0	Null	
0.01 – 0.19	Minimal	
0.2 – 0.39	Low	
0.4 – 0.59	Middle	
0.6 – 0.8	High	

Results and Discussion

Logistic model

The best model included four variables: forest area (supbosq), GDP *per capita* (pib_p_c), length of the roads (longcarr), with positive influence and disturbed areas surface (apertur), with negative influence; Table 5 shows the estimated coefficients and variables in the model.

Table 5. Variables included in the model and regression coefficients and confidence intervals.

Variables	**fd**	**Estimator**	**Standard Error**	**Wald**	***p***	**Confidence Intervals**
Intercept	1	-0.6190	0.1762	12.3374	0.0004	----
supbosque	1	1.1825	0.3219	13.4938	0.0002	1.736 – 6.132
pib_p_c	1	0.7485	0.1906	15.4184	0.0001	1.455 – 3.071
longcarr	1	0.00299	0.00106	7.9179	0.0049	1.001 – 1.005
apertur	1	-1.5231	0.2680	32.2981	0.0001	0.129 – 0.369

g.l. = Degrees of freedom; p = Probability

$$P = \frac{1}{(1 + \mathrm{e}^{-(-0.6190 + 1.1825(\sup bosq) + 0.7485(pib\_p\_c) + 0.00299(longcarr) - 1.5231(apertur))})}$$

Where:

P = Probability of forest fire occurrence

e = Euler number (2.7182)

supbosq = Forest area (ha)

pib_p_c = GDP *per capita* ($ person^{-1})

longcarr = Length of the roads (km)

apertur = Disturbed areas surface (ha)

Most of the signs of the coefficients for each variable are logical, according to the previous knowledge that exists about the causes of forest fires in Mexico. For the disturbed area, the relation is not what was expected, whose coefficient is negative. Rodríguez *et al*. (2008) recorded a positive relation between the disturbed areas and the affected area, at a national scale.

The significant variables in this study, in part, confirm what other studies have documented for some federative entities, for example: Román and Martínez (2006), Carrillo *et al.* (2012) and Pérez-Verdín *et al.* (2013) state that the density of roads is one of the anthropic factors related to the incidence, distribution and size of the fire in *Chiapas*, *Puebla* and *Durango* States, respectively.

At the global level, there are also coincidences with the results of the present study: Guo *et al.* (2015), through logistic regression analysis, indicate that the heterogeneity of the distribution of forest fires is caused by altitude, nearness to train tracks, forest type and temperature in the Daxing'an Mountains, China. Chas *et al.* (2012) studied the spatial pattern of fires in the region of Galicia, Spain. They observed that high demographic pressure, communal property, large number of roads and access roads to the forest increase the likelihood of a conflagration; while with the establishment of forest plantations the risk decreases.

Cardille *et al.* (2001) applied generalized linear regression to abiotic, biotic, and human variables to determine which best explain the fire activity in the midwest region of the United States of America. Their results evidenced that the combination of the three groups of variables was related to the spatial distribution of fire, but they emphasized that the areas with greater population density, of roads and with the shortest distance to non-forest areas were more prone to conflagrations.

The forest area variable was positively related to the occurrence of forest fires, partly due to the presence of forest fuels that exist in woods, which increases the fire hazard. Among the works that have reported similar trends, is that of Guo *et al.* (2015).

The center and south of *Hidalgo* has the highest concentration of population and economic development above the rest of the state, coincidentally, in that area the highest number of fires is recorded. The development of the region implies the promotion of programs of productive activities that are better remunerated and generate enough income for families to have access to higher levels of consumption that also lead to more dynamic economies.

In this regard, the region has a high degree of human development on average (associated with high GDP *per capita*) (PNUD, 2014). It is possible that the direct relationship between fire probability and GDP *per capita* can be explained because this variable may also involve a wider range of activities, including the use of fire in or near the forest, as part of agricultural practices.

Apparently, the GDP *per capita* variable had not been recorded as significant in a fire probability model; Although they have contributed in this sense variables such as the human development index by gender, which at national level Rodríguez *et al.* (2008) indicate an inverse relation with respect to the area affected by fires and the total forest area. It emphasizes that more economic development can increase the fires, but a greater human development has an opposite effect.

Forest fires are mainly recorded during the months of March to May, possibly because of the lack of precaution during the use of fire in agricultural activities, which coincide with the dry season, as well as the negligence of walkers and hikers during their visits to the woods. Under these circumstances, the length of roads and highways becomes highly relevant, as it can be linked both to the increase in the accessibility of different areas to start a fire by accident or negligence, as well as to the burning of vegetation that is carried out on the roads.

The same thing happens in pinewoods located on roadsides, where from vehicles are thrown butts (Rodríguez, 2014). An example of this happens in the road of the tourist corridor of *Pachuca* and the one of *Pachuca* to *Real del Monte*, where it is common to see areas burned in its edges.

In *Hidalgo*, Conafor and the State Government provide support in different areas to rehabilitate areas with fire disturbances and other factors (Semarnat, 2016). Such is the case today, during the years covered by this research, policies were developed to recover the forest area for the prevention and awareness of the importance of conserving forest ecosystems.

Thus, during 2003-2010, the Mexican government allocated $ 5 289 000 000.00 under the Environmental Services scheme in an area of 2 767 000 ha (Iglesias *et al.,* 2010). The amount for payment of environmental services in the state of *Hidalgo* in the 2005-2011 period itwas $ 46,656,674 (Conafor, 2017a, 2017b), for an approved area of 22 180 ha (Semarnat, 2011); in 2003 and 2004 no such benefit was granted.

These actions partially explain the negative influence of the area of disturbed areas variable in the occurrence of forest fires, since there are other options such as community forest management, whereby many rural communities care for reforested areas and actively participate to reduce the probability of being burned by a fire, and the one that is being explored in Mexico, is the integral fire management (Rodríguez, 2000, 2015).

Degree of forest fire occurrence

In Figure 2 are shown the degrees of forest fire occurrence for the municipalities of *Hidalgo*, in regard to the area per class and to the forest area of the state.

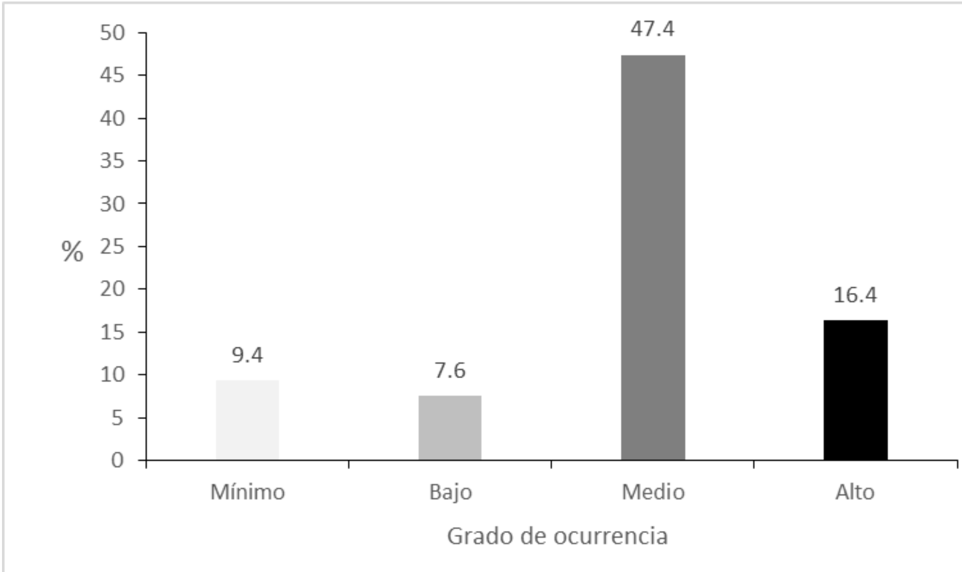

Figure 2. Degree of forest fire occurrence for the municipalities of *Hidalgo*.

Figure 3 shows a map that expresses, on a probabilistic scale between 0 and 1, the estimated possibility of a fire occurring in a municipality, based on the historical variables of the model. The municipalities that appear in white are those that were not considered in the analysis because they did not have records of fires in the period of study or lack forest area, as it is the case of *Tizayuca.*

It is noteworthy that 39 municipalities are classified in a medium category and 10 in the high category; these areas are of interest in fire management strategies. It is observed that the municipalities with the highest probability of fires are located in the southeast of the state, in the regions of *Apan, Tulancingo* and *Pachuca*, mainly, but also in the municipalities *Actopan, Tula de Allende, Zacualtipán de Ángeles* and *Zimapán.*

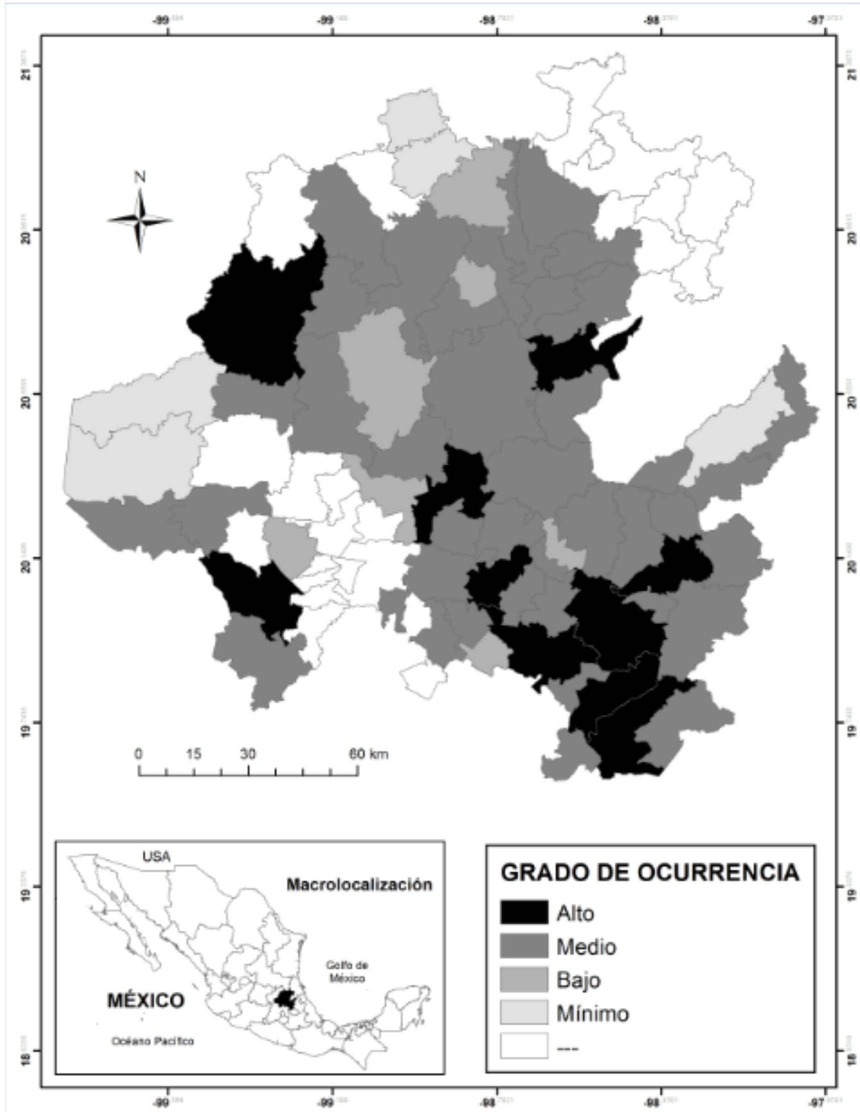

Figure 3. Probability of forest fire occurrence for the municipalities of *Hidalgo*.

The logistic model was plotted to better appreciate the effect of its explanatory variables (Figure 4). In the first case the value of the variable pib_p_c was set at 0 (low GDP), in the second example, the same variable had the value 1 (high GDP). The legend of the graph refers to a degree of occurrence of fire according to the color of the municipalities.

The values corresponding to forest area and disturbed area, 0 or 1 (low or high), respectively, are indicated in brackets. The probability of fires has a positive influence of the forest area, GDP per capita, length of roads variables; and negative effect of the disturbed area. It is suggested that each variable has an additive effect to the others to explain the phenomenon.

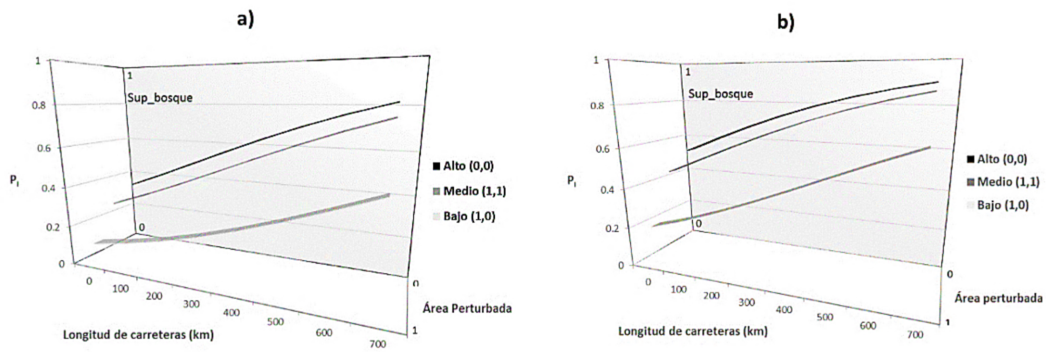

Figure 4. Probability of occurrence of fires. a) pib_p_c bajo and b) pib_p_c alto.

Conclusions

The most relevant variables to explain the probability of occurrence of fires and based on the value of their associated constants in the logistic model are the area of disturbed areas (negative influence), forest area (positive influence), Gross Domestic Product (positive influence) and the length of the roads (positive influence).

The results confirm the importance of the length of roads, since it shows a significant relation with the fires. The logistic regression model proved that the socioeconomic variable GDP *per capita* has a significant weight in the probability of occurrence of fires, so it is important to consider the human factor in the fire risk assessment in *Hidalgo*. The forest area positively influenced the probability of fires, but the area with disturbed areas has a negative effect.

The results are only valid for the municipalities of *Hidalgo*, as probably some of the model variables are not related to the occurrence in other regions of the country. It is considered that this work should be extended by generating other geographically weighted regression models for each of the study units in order to identify the variables whose coefficients vary significantly across the space. Likewise, the validation of the proposed model remains pending.

Forest fire patterns can contribute to the planning of fire management strategies, such as fire prevention, control and control, thereby ensuring that resources are directed to the areas most likely or at risk, or where fire must be reintroduced for conservation, restoration or silvicultural purposes. But it is necessary to emphasize that the answer must be not only to prevent and fight against unwanted fires, but also to stimulate community fire management, to make its ecological-silvicultural application, to use it to reduce the danger of unwanted conflagrations, to favor diversity, among many other goals; that is, an integral fire management.

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Conflict of interests

The authors declare no conflict of interests.

Contribution by author

Miguel Ángel Cruz Espíndola: contribution of the basic ideas for the development of the work, execution of field and laboratory work, statistical analysis; Dante Arturo Rodríguez Trejo: proposition of the subject, contribution of basic ideas for the development of the work, direction of the work, support in the statistical analysis, review of the manuscript; Antonio Villanueva Morales: support in statistical analysis and review; Javier Santillán Pérez: review of the manuscript.