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DEVELOPMENT OF A DANGER INDEX OF FOREST FIRES BY USING MULTINOMIAL LOGISTIC REGRESSION AND ITS APPLICATION IN DIFFERENT ZONES OF THE REGION OF CASTILE AND LEON (SPAIN)

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☐ Copia para el tutor/a

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I would like to dedicate this Master Thesis to my family.

Contents

Abstract

The forest fires have supposed events which are capable of destroying big zones of forest areas. With the purpose of developing a good strategy against forest fires, it is necessary to know the most dangerous zones. At this point, a danger index which displays these zones gains importance. The objective of this study is to develop a danger index based on a multinomial logistic regression which can provide a forecast for the size of the future wildfires from the weather conditions and silvicultural features that can be developed in the hypothetic zone affected by the wildfire. A combination between two methods has been proved to develop this new danger index: the implementation of GIS software and a statistical model which is based on a multinomial logistic regression. This new danger index focuses on the forest stands instead of the borders of the different townships. In case of a wildfire, this fact entails a deeper definition of different danger levels due to its analysis of the zones which might be more dangerous than others.

Resumen

Los incendios forestales suponen un importante problema que puede arrasar grandes áreas forestales. No solo existe en este problema el quebranto en la gestión forestal en las áreas forestales afectadas sino además la destrucción de bienes naturales de importancia, materiales y vidas humanas. La administración cuenta con recursos limitados para atajar este problema de tal manera que cause el menor daño posible. En este caso, una adecuada estrategia contra incendios forestales cobra importancia. Con el fin de desarrollar una estrategia bien pensada y emplazar lo mejor posible los medios de extinción la administración competente ha contado desde hace décadas con medios tradicionales. La aplicación de las nuevas tecnologías (GPS, SIG,…) en este campo ha supuesto una mejora muy importante que ha facilitado la lucha contra incendios forestales y la determinación más apropiada de emplazamientos para los medios. La implementación de Sistemas de Información Geográfica (SIG) en la lucha contra incendios mediante la determinación de las zonas más peligrosas ha sido desarrollado desde mediados del siglo pasado. Mediante superposición de capas de SIG de distintos factores se podía determinar aquellas zonas donde el peligro de incendios forestales era mayor. Desarrollando así diversos índices de peligro a partir de cierta información en diferentes países del mundo como Estados Unidos, Canada, Australia, etc. En la región de Castilla y León este sistema ha sido muy desarrollado teniendo su cénit en el Plan INFOCAL.

En el presente estudio se propone desarrollar un índice de peligro que ayude a diseñar una adecuada estrategia contra incendios forestales mediante la implementación de SIG y el ajuste de una regresión logística multinomial a partir de información de los incendios de los últimos años extraídos de los partes de incendio de la Estadística Nacional de Incendios y de información geográfica (SIG) de la Junta de Castilla y León (España). Finalmente se obtendrá un mapa de la región donde se aplique, dividido en zonas, cada zona representará la peligrosidad que existe en ella en caso de incendio forestal. La peligrosidad de cada zona estará definida por el índice de peligro. Una vez reunida toda la información requerida se procede a procesar los datos eliminando aquellas observaciones en las que en alguna variable no hay información o que la misma presenta una clara falta de precisión. De cada variable anotada en los puntos de incendio y de información extraída de las capas SIG, se procede a ajustar la regresión logística multinomial con diversas combinaciones de

variables. Para el ajuste de la regresión logística multinomial se clasifican las observaciones, es decir, los incendios de acuerdo a su superficie afectada en tres diferentes clases: pequeños (superficie menor de una hectárea), medianos (superficie comprendida entre una y veinte hectáreas) e incendios grandes (superficie superior a veinte hectáreas). El ajuste de la regresión logística multinomial se realizó con el programa IBM SPSS Statistics 21. Una vez ajustada la regresión logística multinomial, se procede a calcular la probabilidad de la ocurrencia de un gran incendio, mediano o pequeño de acuerdo a unas condiciones meteorológicas determinadas y las diferentes condiciones del terreno en cada punto determinado ya sea en cuestión de diferente modelo de combustible o clase de uso de suelo. Esta aplicación de la fórmula fue realizada mediante el programa ArcMap (v. 10).

El índice de peligro define tres categorías diferentes: categoría 1, representada en el mapa de color amarillo y que define aquellas áreas que en caso de incendio éste sería menor de una hectárea (pequeño incendio), categoría 2, representada en color naranja, define aquellas áreas que en caso de incendio su superficie sería entre una y veinte hectáreas (incendio mediano), y categoría 3, representada en color rojo, y que en caso de incendio éste sería mayor de veinte hectáreas (gran incendio).

La implementación de este índice en el presente trabajo de investigación se realizó en dos términos municipales elegidos al azar, al igual que las condiciones meteorológicas aplicadas. En estas últimas se buscó tener un escenario favorable con unas condiciones meteorológicas que en caso de incendio, este fuera teóricamente fácil de apagar y otras condiciones meteorológicas más adversas para el otro escenario. En estos escenarios se pudo observar que dentro de un mismo término municipal existen zonas con un diferente nivel de peligro que de acuerdo a las condiciones meteorológicas existentes y el tipo de combustible y uso de suelo pueden dar lugar a un incendio grande, más virulento o a un incendio pequeño y por tanto, menos peligroso. Esto significa que este sistema hace un análisis más en profundidad, distinguiendo dentro de un término municipal diferentes áreas donde se pueden ocasionar incendios de mayor o menor tamaño. En términos municipales bastante extensos o en grupos de términos municipales la diferencia del nivel de peligro en incendios forestales puede ser muy notable. Esto conlleva un análisis más profundo en contraposición a lo implantado en la región de Castilla y León, el Plan INFOCAL, que solo representa la peligrosidad a nivel de los limites administrativos del término municipal.

Los resultados de este estudio, es decir, la definición de zonas más o menos peligrosas de acuerdo a las características de cada zona y las condiciones meteorológicas cabe destacar que son resultado del cálculo de probabilidad de ocurrencia de cada tipo de incendio a partir del desarrollo de la regresión logística multinomial, es decir, a partir de las observaciones tenidas en cuenta. Esto conlleva una serie de limitaciones a mejorar en siguientes estudios relacionados con esta línea y cuya solución puede ser la inclusión de más variables en el ajuste de la regresión logística multinomial. Este índice de peligro logra una mayor fiabilidad debido a que está basado en sucesos que realmente ocurrieron y no en simuladores. Finalmente, este índice de peligro se puede integrar en un sistema de ayuda a la toma de decisiones junto con simuladores y sistemas de información meteorológica lo que otorga a ese sistema una fiabilidad mayor al basarse en sucesos reales ocurridos.

1. INTRODUCTION

The forest fires have supposed events which are capable of destroying big zones of forest areas. In this way, the forest fires can suppose an authentic variation in the planning of forest management. The assumption of the fire risk into the planning of forest management has been a highly debated topic during the last decades (Van Wagner, 1983; Reed & Errico, 1986; Gonzalez-Olabarria *et al*., 2012b).

Many times, the department responsible for the regional ministry includes limited economic resources in the designing of the strategy against wildfires. This supposes a significant difficulty in distribution, for example, of the firefighter teams at some moments. Neither is it possible to allocate a firefighters team in each village nor, even, any of the most conflictive villages. At this point, a well thought out strategy against forest fires gains importance. However, it is not an easy task to get a perfect distribution of all of the forces as well as allocation of funding. The zone where the number of problems is more frequent has to be considered more important and a large portion of the efforts must be concentrated on in that area (Consejería de Fomento y Medio Ambiente, 2006).

The Administration has different traditional tools in order to achieve the best distribution of the resources used. The use of the National Fires Statistic supposes an important database to implement careful strategies against forest fires. The importance of having very good maps of the exact zones and forest inventories which let us know the characteristics of the vegetation in each point. Also, the accuracy of the weather data, most importantly, during the fires season enables us to know the exact weather conditions during the whole day. In the case of a wildfire, we are able to foresee the future behavior of the forest fire. During the last decades the effect of forest fires has been taken into account in different ways: since the application of different formulas in the forest management to take the site parameters into account considering the wildfire like a spatially explicit event (Bettinger, 2010).

The implementation of the new technologies has improved the protection system against forest fires. It has been an effective tool protecting the lives of the people of the firefighters. For example, the case of lost men in the forest while they are fighting against the wildfire. Current studies provide much information about different features of the fires behavior depending on the fuel models, types of vegetation, slope, aspect… As a result it is easy to predict the behavior of future fires taking into account the factors previously mentioned (Chuvieco & Congalton, 1989; Lee *et al*., 2002; Kaloudis *et al*., 2005; Morehouse *et al*., 2006; Bonazountas *et al*. 2007; Kalabokidis *et al*., 2011). Nevertheless, this is more difficult in practice, because in reality all these factors act jointly, even when wildfires are a stochastic phenomenon, the future behavior is a bit random in some cases (Gonzalez-Olabarría *et al*., 2005).

Taking into consideration the evolution of the study of forest fires, numerous studies and research have been developed. Since 1960s with the utilization of satellite images to the latest technologies in GIS, the risk of forest fires has been considered in several ways (Chuvieco & Congalton, 1989). The most frequent way has been the overlapping of different layers which have been developed in different themes: vegetation, fuel models, slope, aspect… Once all these layers were made, the next step was the overlapping of these layers. The overlapping consisted of the application of different values to each pixel of each layer, thus via overlapping the layers, a last layer of danger index was developed. This case has been very common during the last 20 years and different danger indexes have been developed in different countries. In Castile and Leon (Spain) the danger index applied in the Plan INFOCAL was developed this way.

During the last years, the study of the spatial patterns has been considered from the statistical point of view in different studies such as Rorig & Ferguson (1999), Podur *et al.* (2003), González-Olabarria *et al.* (2005; 2012), Genton *et al*. (2006), and Lin & Rinaldi (2008), Serra *et al.* (2012. These research projects aimed to study the phenomenon of the forest fires from the statistical point of view to implement it in different aspects such as the relationship between the causes and the sites where they occurred or characteristics of the fire. In the same way, other research aimed to find out the relationships between silvicultural and topographic features and the occurrence of forest fires (González-Olabarría *et al*., 2005).

For the present research project the following ideas have been taken into account: forest fires are a stochastic phenomenon, the idea of the danger index developed by the government of Castile and Leon with the overlapping of different layers from the Plan INFOCAL and the possibility of studying these events from the statistical point of view in order to develop a danger index based on some relationships between the factors which have had an influence on forest fires. The research consulted only takes into account the silvicultural or topography features. The main goal is to discover the common features of forest fires or the study of the spatial patterns.

A goal of present study from the different cases in different provinces of Castile and Leon (Salamanca and León) is to develop a formula which predicts the size of the wildfire according to different weather conditions and different silvicultural features. The following step requires the implementation of GIS by designing some simulations via ArcMAP from the fuel models map. The final result will be different risk maps of territory considered according to different weather conditions.

A prompt arrival to wildfires by extinction media (firefighter teams, fire vehicle…) is very important in regards to an effective extinction of the wildfire without having to regret big losses related to environmental, agricultural and economic aspects (Cubo Maria *et al*., 2012). The main purpose of this project is to facility the development of strategies against wildfires and the creation of a system whose result is a map which reflects the hazard of each area in the studied zone. This system can be implemented by a decision support system for forest fire protection.

2. LITERATURE REVIEW

2.1. Implementation of GIS in the determination of forest fire risk zones

Much research from 1960s has been developed in relation to this topic. It started with the application of different remote sensing techniques. The first applications of these techniques to map wildfires dates back to the 1960s when several aerial infrared scanners were tested for fire spot detection. With the development of the Landsat program, several projects were led to evaluate the reliability of satellite imagery for mapping wildfires and forest inventories (Chuvieco & Congalton, 1988). The main problem with that imagery was the low quality of the image where the burned areas could be confused with other types of land cover (Benson

& Briggs, 1978; Husson, 1982; Tanaka *et al.,* 1983). Along these lines, the remote sensing techniques could be used for fire hazard mapping. The application of GIS software made it possible to combine some variables with the purpose of determining fire hazard areas or danger index (Deeming *et al.,* 1978; Artsybashev, 1983; Calabri, 1984).

One of the studies in this field was developed by Chuvieco and Congalton (1989). They implemented remote sensing techniques and Geographic Information Systems to map fire hazard. They applied the following variables: vegetation species, classified according to fuel class, stand conditions and site, elevation, slope, aspect and proximity to roads and trails, campsites or housing. Each variable had its own layer of information for the integrated analysis. After defining the variables, the overlapping of all these layers was able to define fire hazards levels within the study area. Once it was made, those areas with highest hazard were compared with the actual areas which had been affected by wildfires. The agreement between the predicted high-hazard areas and the burned area was assumed to be a major test in regards to the reliability of the study approach. Some values, according to each feature, were given to each layer of each variable. Then the overlapping of the layers of information was determined according to a hazard formula which was the following: $H=1+100v+30s+10a+5r+2e$; where “v”, “s”, “a”, “r” and “e” were the coefficients which corresponded to vegetation, slope, aspect, roads and elevation groups respectively. The result was a final fire hazard map. More than 22% percent of pixels with high hazard values in the whole study area were burned by the fire, while only 3,74% of those with low hazard values were actually burned (Chuvieco & Congalton, 1989).

In this line of work, other research studies have been developed by different authors from a variety of countries such as Jaiswal *et al.* (2001). The quality of the information used in these kinds of research projects is very important. Because LiDAR measurements provide more accurate information it was used in the following project: Mapping fire risk in the Model Forest of Urbion (Soria, Spain) based on airborne LiDAR measurements (Gonzalez-Olabarria *et al.,* 2012b). Finally, implementation of GIS is applied to the region of Castile and Leon in the Plan INFOCAL in order to determine different danger areas. This Plan is explained later.

2.2. Prediction models of wildfire behavior

The behavior of the hypothetical wildfires can be predicted by certain models of prediction. These models can simulate the wildfire’s behavior. It is possible to develop prediction models based on natural factors like fuel models, relative humidity, wind and topography (Vélez *et al.,* 2000)

There are two kinds of groups of prediction models regarding wildfire spreading.

- Deterministic. Wildfire’s spreading is based on the interpretation of natural factors. The spreading factors are described by mathematical formulas.
- Statistical. They determine correlations between descriptors of the factors which influence the spreading of wildfires. The data is taken from experimental fires or real events. Nevertheless, it is necessary to have numerous observations to develop a model like this.

Some examples of prediction models of wildfire behavior follow.

2.2.1. North American model

The deterministic models are the most commonly used to predict the fire spreading. BEHAVE (Andrews, 1986) uses the model of Burgan and Rothermel (1984). This model was developed under homogeneous conditions of fuel and wind speed. Posterior studies allowed applying this model in more fuel models (Vélez *et al.,* 2000). This model takes the following factors into account:

- Amount of fuel, volume and shape.
- Fuel compression
- Horizontal and vertical continuity
- Wood density
- Calorific capacity of the fuel
- Existence of volatile chemical substances
- Alive and dead vegetal matter

Initially, the researchers could define 13 different fuel models. The models of Anderson (Anderson, 1982). The researchers could develop more values with laboratory, field trials like for example: spreading speed of the flames, flame length, fire intensity per meter of the frontline and given heat per area unity by the fire frontline (Vélez *et al.,* 2000). These values were helpful to adjust the mathematical function of the fuel models using easy inputs such as: moisture content of the dead and alive fuels, speed wind and direction wind and the terrain slope. The BEHAVE (Andrews, 1986) system consists of the formula displayed in figure 1.

Figure 1. Formula implemented in the BEHAVE system

$$\text{Advance speed } = \frac{heat\ flux\ speed\ in\ the\ frontline}{required\ heat\ for\ the\ ignition}$$

The effect of the slope can become completely reduced when the wind action is very strong. BEHAVE (Andrews, 1986) is the most extended system in the entire world. However it has some important limitations: it must be calibrated frequently for the variability of the fuel models. It does not work in crown fires and it is only reliable in homogeneous fuels. It does not work very well in wildfires over the shrubs (Vélez *et al.,* 2000).

2.2.2. Australian model

It is based on experimental fires, occurred fires and wildfires data. It uses the temperature, humidity, drought, wind and slope. Some prediction equations have been developed for several vegetation types. The extinction probability in accordance with the wind speed, content of moisture in the fuel and biomass has been determined solely for one kind of shrub. From the studies developed in Australia it has been verified that the fire speed changes a lot according to the convective activity (Mc Arthur, 1966; Vélez *et al.*, 2000).

2.2.3. Canadian model

It relates the spreading speed and the intensity with combinations of wind and moisture content of the fuel, taking the slope effect into account. It is based on occurred wildfires and big experimental fires. Its equations are not valid for small fires (Van Wagner, 1974; Vélez *et al.,* 2000).

2.3. Statistical studied models of wildfires

Some research studies have been developed to analyze the spatial patterns of the forest fires. The main objective of these studies was to become aware of the areas where many wildfires could be ignited and the placement of the firefighters in those areas.

One of those projects was developed by Gonzalez-Olabarría *et al.* (2005). They studied the plots of the Second Spanish National Forest Inventory (from now onwards II IFN) which have been burned during the studied period (1991-2002) in Catalonia. They assigned the 0 for the plots which were not burned and 1 for the burned plots. After that they implemented GIS tools to find out which plots were burned and which were not, with the overlapping of the layers with the wildfires' perimeters and the layer with the II IFN plots. The information about the forest fires consisted of the perimeter of forest fires larger than 20 ha of the whole region of Catalonia. This information was complemented with the information from fire reports. After that, the logistic distribution was implemented due to the following reasons: easy to use, mathematically flexible and it has a meaningful interpretation (Hosmer *et al.,* 2000). Once they have decided on the best model for study the case, the following step was to determine a set of independent variables which could explain in a logical and statically significant way the probability of a fire occurring in a determined forest area (Gonzalez-Olabarria *et al.,* 2005). The variables must be easily calculated from forest inventory data or predicted using growth models. They can also be affected through forest management (Gonzalez-Olabarria, *et al.,* 2005). In this study, the sources of risk were assumed to be related to the structural and compositional characteristics of stands as well as site factors. The variables were taken into account according to the stand structure, species composition and site (Gonzalez-Olabarria *et al.,* 2005). The software used was SPSS. The predictors had to be significant at the 0.05 level. The chosen variables were the followings: elevation, basal-area-weighted mean diameter (cm) of trees, total basal area (m^2/ha), proportion of hardwood species of the number of trees per hectare and the standard deviation of the breast height diameters of trees (cm) (Gonzalez-Olabarria *et al.,* 2005). The obtained results were that the probability of a forest stand could be affected by a wildfire increased with: lower altitudes, smaller diameters, larger basal areas, higher proportion of coniferous species and increasing variation in tree diameter (Gonzalez-Olabarria *et al.,* 2005). Finally, the authors of this study adhere to the principle that a wildfire is a stochastic phenomenon. Although they added that the model and the applied parameters were significant and the test results were consistent (Gonzalez-Olabarria *et al.,* 2005).

Another research study by Gonzalez-Olabarria *et al.* (2012a) looked at the spatial patterns of the wildfires and the identification of their causes in a determined zone in the region of Catalonia (Spain). The reason behind the study derives from the idea of the study regarding the spatial patterns of the wildfires and their causes for the application of measures with the purpose of reducing the problem in those areas. They applied the kernel methods (non-parametric statistical methods for estimating the spatial distribution of probabilities of point-based data) which were applied to define ignition hotspots based on historical records of fire ignitions in the region of Catalonia (Spain) during the period between 1995-2006 (Gonzalez-Olabarria *et al.,* 2012a). The kernel analysis was based on the Home Range Extension (HRE) package in ArcGIS v.9.0 (ESRI Inc., Redlands, CA) developed by the center for Northern Forest Ecosystem Research (CNFER (Rodgers & Carr, 1998) (Gonzalez-Olabarria *et al.,* 2012a). This system presented the results via generation polygons or isopleths. That isopleths was based on percentage Volume contours (PVCs). That is the volumes under the utilization distribution, and encloses areas with a defined proportion of ignitions in the smallest possible area.

After that, the location of the ignitions in the hotspots was studied and then an analysis of ignition causes within hotspots was made. The final results were that the activity of the arsonists had strong spatial clustering, along with intentionally caused ignitions within the hotspot areas accounting for 60.1 % of the fires, whereas for the whole region of Catalonia (Spain) they only represented 24,3%. This fact is due to the arsonist successfully setting fire to the fields which in turn encourage him to light more fires (Gonzalez-Olabarria *et al.,* 2012a). This study can deduce the possibility of defining an arsonist's potential area of activity by using previous statistics on ignition location. It will provide the responsible department with the necessary surveillance levels for these zones (Gonzalez-Olabarria *et al.,* 2012a).

2.4. Decision support system for forest fire protection

During the last decades some systems have been developed with the purpose of facilitating the decision-making in the fight against forest fires. In the next lines some of these systems will be explained. The following systems have been taken into consideration to develop the danger index of this study.

The pioneer system in the support of decisions about the wildfires management was developed by the "Laboratorio de teledetección de la Universidad de Valladolid" (from now onwards LATUV) created in 1989. Since 1995 LATUV distributes a daily journal during the fire season which measures the wildfires risk. It divides the territory of Spain in grids of 10x10 km^2. Since 1999, this journal was distributed in some regions twice per day. From 2003 onwards a journal was made which forecasted the meteorological variables for the following day. The meteorological prediction was forecasted by physical-mathematical models. This system used images from NOAA satellite (Natural Oceanic Atmospheric Administration) whose resolution was 1km x pixel. This resolution was considered sufficient for the detection and evaluation of the affected areas. The state of the vegetation can be determined through a suitable combination of particular bands in order to determine the danger risk and the risk zones simultaneously. The whole territory of Spain is divided into 10 x 10 km^2 cells. A risk index is indicated in each cell. The evolution of NDVI is taken into account during the last fire seasons and it is compared with the satellite image captured daily by the NOAA-16 satellite. LATUV processed all this information daily and in real-time by order from the department against forest fires of the National Department of Nature Conservation of Ministry of Environment. It should be highlighted that the NOAA satellite has a sensor AVHRR which provides images with five bands of the electromagnetic spectrum.

From 1997, a new interesting tool was developed by a Spanish company called: Meteologica. The technology used is based on mathematical models of prediction which develops technological simulations of the atmospheric evolution for the following days. These models are based on a tridimensional net which covers the atmosphere and the superior layers of mainland and oceans. With the application of physics laws, the mass fluxes and the energy are calculated between adjacent points in a net. The future atmospheric states are predicted with the temporal integration of these fluxes.

The effectiveness in the prevention and extinction of wildfires is improved by using this tool. This fact is due to the visualization of these maps which allows a quick evaluation of the weather conditions each day as well as the visualization of the danger indices in a determined zone. Meteologica also allows the development of wildfire simulations with a very friendly interface. It is not necessary to be very qualified to create these simulations due to its simplicity. It will be easier to predict the zones which are going to be affected and determine the suitable measures to be taken in advance with the purpose of reducing the danger e.g. cutting of the roads, disconnection of the electric networks, evacuation of the population before the wildfire reaches their town and so on.

Finally the latest tool for these kinds of systems was developed in 2011 with the purpose of developing a new tool useful for the prevention planning and emergency management of wildfires. It is called AUTO-HAZARD PRO (AHP) DSS. This tool was developed for the Euro-Mediterranean region and applied in some areas of Spain and Greece (Kalabokidis *et al.,* 2011). This model is much more complete than the previous systems. The system incorporates the following factors: weather data management, geographical data viewer, a priori danger forecasting and fire propagation modeling, automatic fire detection and optimal resource dispatching (Kalabokidis *et al.,* 2011). The results obtained include short-term and dynamic danger indices with the purpose of obtaining more improved and realistic prevention.

The fire DSS's propagation module appears as a friendly interface. It takes meteorological and other fire environmental factors into account and it can predict the fire spreading in a certain period of time. The main advantage of this system is that the new data is fed automatically and due to this fact the initial fire front is constantly updated (Kalabokidis *et al.,* 2011). It predicts the area and the perimeter, fire spread speed and direction, energy release, flame length, and linear intensity. It can also predict threats and damages, helps to plan tactical operations and selects and dispatches resources (Kalabokidis *et al.,* 2011).

The most significant fact from this research study is the way in which the program analyzes the fire propagation. It has a computer model called "Fire Spread Engine" (FSE). It can estimate the fire front expansion on surface forest fuels, using spatial data related to topography, moisture content, wind vector field and fuel type (Kalabokidis *et al.,* 2011).

The FSE uses the following models:

- Rothermel's (Rothermel,1972) theoretical approach
- Calculation algorithms based on those found in the BEHAVE (Andrews, 1986) and FARSITE (Finney, 1998) systems.
- Cellular-automata algorithm is applied for the spatial simulation of the fire spread (Caballero, 2006)

The aforementioned tools support decision-making in the case of wildfire emergencies. The first tools offered managers a very powerful tool to make the best decision to prevent the wildfire and in case of emergency to extinguish it in the most efficient way. The last tool offers a wider range of possibilities for the manager. Nevertheless all the tools are deterministic, that is to say they are based on mathematical-physical models and they are not based on statistical models although they had been verified in the observations.

2.5. International danger-indexes

Meteorological indexes of wildfire danger are numbers which reflect the possibility of the existence of a wildfire and its facility of propagation (according to the vegetation). There are three factors which influence a fire spreading: fuel, heat and oxygen. The fuel changes with time and this variation influences the fire spreading (Vélez *et al.,* 2000).

The state of vegetation depends on intrinsic and extrinsic factors. The first ones are the following: vegetal matter composition itself, vegetal species and the silvicultural state of the stand: dimensions and amount of existent fuel. The extrinsic factors are the following: orography influences the fire spreading and meteorological factors. Meteorological factors modify the inflammability of the vegetal matter because they modify its humidity content and the wind facilitates the fire spreading.

With the exception of the meteorological factors, the rest of the factors are constant in the short-term. Therefore, the factors which must be considered to determine a danger index have to be the meteorological factors (Vélez *et al.,* 2000). All of them consider the meteorological factors although each grants them different importance. Next, the danger indices of different countries will be explained briefly. The factors considered in each were taken into account to determine which factors are the most suitable to be implemented in the development of the multinomial logistic regression taking into consideration the variables pertaining to the fire reports.

2.5.1. Canada- Forest Weather Index (FWI)

Its base is the inflammability of the vegetation according to meteorological factors. In order to develop this index two important lines have been studied.

First, the correlation between the draining of the vegetal fuel and the meteorological factors was studied. Secondly, the fire behavior with real and experimental cases was analyzed. This system consists of six standardized components (Van Wagner, 1974; Vélez *et al.*, 2000):

- Three codes of the vegetation humidity
- Three indexes of the fire behavior which represent spreading speed, fuel load and caloric intensity.
- The data is exclusively meteorological:
  - Temperature
  - Wind speed
  - Precipitations in the last 24 hours.

The components are the following:

- Fine Fuel Moisture Code (FFMC): it indicates the relative vulnerability of the particles ignition which represents an approximate weight of 2, 5 t/ha of dry matter.
- Duff Moisture Code (DMC): it gives a consumption indication of the materials of medium thickness which exists there. The approximate weight is 50t/ha of dry matter.
- Drought Code (DC): numerical index of the humidity content of the material which is in the deepest layer of organic matter. It indicates its seasonal effects of the drought in the forest fuels and the amount of particles and thick pieces which can be burned.

- Initial Spread Index (ISI): it combines the wind effect and the FFC with the wind speed regardless of variations in the amount of fuel.
- Buildup Index: numerical index which provides information about the amount of fuel available for the combustion. It is determined based on the combination of the components DMC and DC.
- Fire Weather Index (FWI): numerical index which displays the caloric intensity of the wildfire. It is obtained by the combination of the ISI and BI indexes. It is used as a general index of the danger level for all of them.

2.5.2. United States of America - National Fire Danger Rating System

This index consists of several indexes whose values range from 0 to 100 and are valid for the planning, execution and supervision of the operations against forest fires. The following indexes are considered:

- Occurrence index: potential initiation of wildfires in a limited zone. It is obtained from the activity level of the ignition causes and it is related with the ignition component as well.
- Burning index (BI): it derives from the spreading components and the releasing of energy. It forecasts the speed of the fire spreading, combustion rate per area unit in a flame line and the width of the determined zone.
- Fire Load Index (FLI): it is related to the potential work load of the firefighters to extinguish all of the fires in a given area and in a determined period of time considering the occurrence and combustion indexes.
- Ignition component: it represents the ease in which the thin fuels are ignited.
- Spread component (SC) is a mathematical model which integrates wind effects and the slope with the properties of fuel layers and the vegetal particles which are incorporated into the respective fuel model.
- Energy release component (ERC): it is defined for each fuel model. In this case the ERC requires the precedents of humidity content of medium and thin particles (10 and 100 hours of delay time).

The last three indexes are valid for the evaluation of the danger level because they integrate the effects of the fuels, state of the atmosphere and topography in a numerical system which can be used by the responsible personnel (Deeming *et al.,* 1978; Vélez *et al.,* 2000).

2.5.3. Australia

The danger index in this country has been adapted to the typical forests in Australia. With the purpose of analyzing specific features in this country, the following characteristics have been examined:

- Fuel humidity and the wind speed effects on the spreading of the fire.
- Daily variation of the humidity content
- Wind variation at different heights
- Relationship between the fuel amount and the spreading speed
- Slope effect
- Process of fire spreading via displacement of the bark and leaves.
- Flame’s height according to the humidity, fuel amount and the wind speed.

The system consists of two indexes: drought and fire danger. Drought index is based on NFDR drought index although it has been adapted for its application in Australia. The fire danger, as from the drought index, forecasts fire probability, its spreading speed and extinction difficulties (Mc Arthur, 1966; Vélez *et al.,* 2000).

The following data has been considered (Mc Arthur, 1966; Vélez *et al.,* 2000):

- Maximum temperature
- Precipitation
- Relative humidity
- Speed wind
- Duration of the drought
- State of the atmosphere
- Fuel amount

2.5.4. France

In this country the fire danger is located in Provence and Corsica. To confront this problem an inter-ministerial agreement has been made which coordinates the actions between the forest and meteorological services. The latter has developed a simple system which allows us to determine “meteorological alerts”, which in turn starts preventative actions (Orieux, 1974; Vélez *et al.,* 2000).

In accordance with other countries the meteorological factors have the most importance. From the wildfire statistics it can be deduced that the factors which play a key role are drought and wind. During the summer time strong air currents called Mistrals enhances the spreading of wildfires. A drought is defined as the lack of water on the soil. This parameter can indicate the daily variation of the drought when it is raining or it is not raining. The water reserve of the soil has to be measured daily because the deficit will be equal to the water saturation (150 mm) minus the water reserve (Orieux, 1974; Vélez *et al.,* 2000). The major factor to be measured is wind speed, although the direction is essential as well. The data considered is water deficit on the soil and wind speed. They are obtained using a hygrometer and a wind gauge (Orieux, 1974; Vélez *et al.*, 2000).

Some facts to be taken into consideration in regards to these indexes are the followings:

- All of them consider meteorological factors to be the most important.
- The state of the vegetation is decisive for the fire spreading and the meteorological factors directly influence the state of the vegetation.
- The common factors to be considered are: precipitation, relative humidity and wind speed although the temperature is considered in some cases as well.
- The traditional devices to be used are: pluviometer, hygrometer, wind gauge, thermometer, weather-vane and vapor gauge.
- The methodology has changed during the last years, from the utilization of tables (more or less complicated) to the utilization of technological media as well as the management of the weather data.

2.5.5. Spain – Danger Index of forest fires

During the 1980s the introduction in Europe of the North American system BEHAVE and the acquired experience with the previous indexes brought from The USA, Canada and Australia lead to the consideration of a new system with the following principles:

An index of probability ignition which estimates the probability of an incandescent wood piece, when it is falling over a dead thin fuel, causing a wildfire. An alert index combines the ignition probability with the wind speed taking into consideration not only normal breezes but also the effects of the land breezes. They cause bigger alerts due to their secant effect. Ignition probability takes the humidity of the dead fuel into account at the same time as the temperature and the percentage of the occupied area. The table which shows ignition probability is displayed in appendix 1.

2.5.1. INFOCAL (Castile and Leon, Spain)

Risk analysis in this plan takes into consideration three different elements: local risk, vulnerability and potential risk.

To calculate the local risk the plan takes into consideration the following resources:

a) Forest inventory of Castile and Leon
b) Fuel map
c) Topographic map
d) Statistics of meteorological variables
e) Statistics of the frequency and causality

The local risk index takes into account the following factors:

- Probability of the presence of some of the typical causes of wildfire
- Features of the forest fuel in the forest
- Meteorological conditions in each moment.
- The danger of the forest fuels is influenced by the following factors:
    - Principle vegetation species
    - Stage of the principle vegetation species in each area
    - Possible interrelationships in the natural ecosystem

The vulnerability is analyzed by taking into account the elements to be protected:

- People
- Living zones, infrastructures and installations
- Economical values
- Ecological values
- Landscape values
- Artistic-historical heritage
- Protection elements against soil erosion

All these factors will be considered in the selection of the variables of the danger index developed in this study.

Once the risk indexes are calculated, they are represented on a map of Castile and Leon. The whole region is divided into zones. Then, it is divided into nine historical provinces.

Depending on risk and vulnerability analysis, the local risk, vulnerability and potential risk maps will be determined for each province.

The provinces are subdivided based on the potential risk map. This subdivision will be useful in determining the resources and firefighters teams which must be deployed in case of emergencies.

The townships of the region are classified in five groups based on their risk of forest fires:

- Towns with very high forest fires risk
- Towns with high forest fires risk
- Towns with moderate forest fires risk
- Towns with low forest fires risk
- Towns with very low forest fires risk

With this data the whole region is divided into zones by provinces, and then, the townships with the highest risk of forest fires are distinguished. The townships with higher forest fire risks will have more protection than the others.

The zoning of this territory must be seriously considered because it only shows the risk in the whole township rather than each zone inside the township. Therefore, there are some areas inside each township which are underestimated or overestimated.

3. OBJECTIVES

The main objective is develop a model based on a multinomial logistic regression which can provide a forecast for the size of the future wildfires from the weather conditions and silvicultural features that can be developed in the hypothetic zone affected by the wildfire. Once the statistical model had been developed, different maps of risk will be designed. These maps will be based on the fuel models maps and they will be developed for some weather conditions and conditions of the hypothetic wildfire. As from these maps, the size of the hypothetic wildfire will be able to be known according to determined weather conditions and silvicultural features.

4. METHODS

4.1. Data

The data referenced has been extracted from the fire reports collected in the national fire statistics. It is managed by AEGIF software. The fire reports are written manually by the rangers. After that, it is recorded into the software by the technicians of the regional government. The extracted information from this software uses an excel file which contains the following information:

- Number of the fire report (classified by provinces in the whole region of Castile and Leon). It is just a number which describes itself the year when the wildfire occurred, the province where it occurred and the correlative number counts the number of fires depending on when it occurred in an ordinal relationship.
- Year of the fire. The year when the wildfire occurred.
- Autonomous community. The name of the community where the wildfire occurred. In this research project the name of the community is Castile and Leon.
- Province. It is the name of the province where the wildfire occurred.
- Region. It is an aggrupation of several townships where the wildfire occurred.

- Township. The name of the town where the wildfire occurred inside its limits.
- Sub district of the township. The name of the landscape where the wildfire occurred.
- Place. A particular zone of the landscape. This information is written when for example the landscape area is too big.
- Map. The coordinates of a map where the township is located. These numbers make reference to the maps which are used by the environmental ministry of the Spanish government.
- Grid. The grid of the map used by the environmental ministry of the Spanish government.
- Coordinate system
- X , Y coordinates
- Detection date. The date when the wildfire was detected.
- Detection time. The time when the wildfire was detected.
- Control date. The date when the wildfire was controlled. This means that the wildfire was controlled inside a determined perimeter and it could not spread more.
- Control time. The time when the wildfire was controlled.
- Extinction date. The date when the wildfire was extinguished.
- Extinction time. The time when the wildfire was extinguished.
- Storm days before the wildfire
- Station. The identification number of the meteorological station. There is no data where the indicated number is zero.
- Days after the last rain. It counts the days passed since the last precipitation.
- Maximum temperature. It is measured in degrees Celsius. It corresponds to the maximum temperature in the zone of the wildfire during a particular day.
- Relative humidity. It is measured in percentage. It is the amount of water vapor that really is in a determined space with respect to the water vapor that could be occupying the whole space.
- Wind speed. It is measured in kilometers per hour. It is the speed of the wind. It is measured via the utilization of an anemometer.
- Wind direction. It is measured in azimuth degrees by a weather-vane.
- Fuel model. It indicates the type of vegetation in a determined area. The vegetation is classified in fifteen different classes of fuel models. The classification is made according to the features of the vegetation, if there are meadows, shrubs, trees, meadows under trees, shrubs under trees and so on. The classification is displayed in table 1.
- Ignition probability. It indicates the probability of a thin fuel can be ignited by the fall of an incandescent object over it. It takes the fuel humidity into account.
- Danger index
- Type of fire, what dries the fire. It indicates the site where the fire is driven: meadows, shrubs on the owners.
    - Woodland forest area
        - State forests
        - Forest whose owners are the State and the regional governments
        - Forests with an agreement between the government and private owners
        - Forests pertaining to the State but not cataloged
        - Private forests
    - No woodland forest area
        - State forests
        - Forest whose owners are the State and regional governments
        - Forests with an agreement between the government and the private owners
        - Forests pertaining to the State but not cataloged

        - Private forests
    - No forest area
    - In this research study the total burned area is the sum of these three types of areas. This is due to the fact that a wildfire can be ignited in a no forest area affecting forest zones or inside the forest areas where there could be no forest areas like crop fields inside enormous forest areas.

Of course, there are some limitations in these fire reports. These limitations have to be taken into account. However, in this research project the accuracy of the data is considered to be high quality due to the fact that these fire reports are official government documents and the national fire statistics are prepared from them. In addition, more information was extracted from the GIS files (*.shp) of the “Consejería de Fomento y Medio Ambiente de la Junta de Castilla y León”.

The GIS files are composed of the following:

- Township of the region of Castile and Leon (Spain): all the boundaries of each town are displayed in this layer. It allows us to see where, in the township, we are studying and determine the study area.
- Forest map: the tree stands of the whole region of Castile and Leon are displayed on this map. It displays the species which can be found in a determined zone.
- Perimeters of forest fires: this map represents the perimeters of the wildfires during the period 2007-2011. Only wildfires whose sizes were more than 5 hectares are displayed.
- Fuel map: in this map the Castile and Leon region appears divided in different polygons which represent different fuel models. The zones where there are no burning materials (rivers, lakes, rocks…) are represented but with different colors. The different fuel models are classified following the indications of the fuel models of Rothermel (Rothermel, 1972).
- Map of ignition points. This map displays the starting points of each displayed wildfire.

This data was purchased from the regional government of Castile and Leon in accordance with the law: “DECRETO 27/2012, de 19 de julio, por el que se regulan las condiciones de utilización de la cartografía e información geográfica producida por la Administración de la Comunidad de Castilla y León, y se fijan los precios públicos del servicio para su puesta en soporte físico.”

In the fire reports there are some codes which are used to indicate some information occupying the least possible space. These codes are used in different cases which are:

- Fuel models
- Type of fire
- Meteorological danger

The codes of the different fuel models used are displayed in appendices 3 (Anderson, 1982), 4 (classification of the fire reports) and 5 (Rothermel, 1972).

The wildfire is classified in seven different groups depending on the side where the fire is driven. This is useful to know how the forest fire was. The different types of fire (which are displayed in table 1) are important to know how the fire is driven across the vegetation. It is possible that in a zone which will be affected by the wildfire there may be trees but they cannot be affected by the wildfire because the wildfire is only driven by the meadows under the trees. In this case the wildfire is driven on the ground, it is a ground wildfire and the conditions of wildfire of course are very different in comparison to a canopy wildfire. The speed and the virulence of a particular wildfire can be explained according to the following classification.

The wildfires whose size is bigger than the others are the wildfires that were driven by crown and ground. This is due to the reason that a wildfire that is driven by these two ways are very virulence and difficult of to be extinguished. On the other hand there are big wildfires which have been driven by ground solely. This is due to the reason that if the weather conditions are very unfavorable the wildfire can spread very fast and in that cases the deployment of the fire teams have to be very quickly to be capable to extinguish it before the perimeter will be able to spread too much. Also, this can be occurred because other reasons like topography features.

Table 1. Codes of the classification of the types of the forest fires

TYPE OF FIRE	
Type of fire or combination	**Code**
Ground	1
Crown	2
Subground	3
Ground and crown	4
Ground and subground	5
Crown and subground	6
Ground, crown and subground.	7

The codes of meteorological danger are displayed in table 2.

Table 2. Meteorological danger codes

METEOROLÓGICAL DANGER	
Alert index	**Code**
Yellow alert	**1**
Orange alert	**2**
Red alter	**3**
Alarm	**4**

4.2. Data processing

All the meteorological data is noted by the ranger in the fire report, taking into account the data from the closest meteorological station. Sometimes this is not possible, if for some reason, the closest meteorological station is so far that the data is not valid in the fire zone or the closest meteorological station does not have the required data to fill in the whole fire report. In such cases the information is collected from the Provincial Command Center where the data is extracted from all the meteorological stations and it is designed and represented via maps of the province with all the meteorological information. As a result of these maps, the required data can be precisely extracted from any determined point in the province.

The data of the provinces of Salamanca and León have been selected due to the frequency of wildfires and the variety of weather and silvicultural features. The fire reports from each province during the period between 1995 and 2011 are:

- León: 10494 events

- Salamanca: 4061 events

With the purpose of establishing a homogenous data base to develop the statistical analysis those events with lacking data (e.g. the days after the last rain, maximum temperature, relative humidity, wind speed, wind direction, ignition probability, and fuel model) have been removed.

After modifying the data, we are left with the following fire reports:

- León: 710 events
- Salamanca: 1212 events

From all the given data in the fire reports, the data which must be taken into account due to its importance is the following:

- Point of localization (X,Y coordinates)
- Days after the last rain
- Maximum temperature
- Relative humidity
- Ignition probability
- Wind speed
- Wind direction
- Fuel model

The aforementioned variables are mainly used by the international danger indexes, which were indicated in section 2.5 (Mc Arthur, 1966; Deeming *et al.,* 1977; Van Wagner, 1987; Vélez *et al.,* 2000).An excel file will be created from this information. This file was processed using a program called SPSS with the purpose of developing a multinomial logistical regression.

After the first modification and with information from the GIS layer of forest map of the autonomous community of Castile and Leon, a new modification was made. The vegetation species data and classification of the land used were implemented as well. This provided two more variables for statistical analyses.

With the purpose of extracting that information, the implementation of GIS software (ArcMAP v.10) was necessary. The following steps to achieve this data are explained:

3. The layer of forest map was converted into a raster layer with the values of “USO_NIVEL3” and “ESPECIE1”, using a conversion tool called: “Polygon to Raster”.
4. With the layer of the starting points of the wildfires and with the implementation of the spatial analyst tool called: “extract values to points”, the name of the vegetation species and the land used in the wildfire start point were extracted. All these points were checked and each one was inside an established stand.
5. Several events were removed because they started in zones classified as landfills, roads, mines… and in these cases forest lands were not affected or at least not completely. In the same way more events were removed because the type of land used was not specifically classified in any type and the information in these cases did not exist.

After this last shifting, the final data for each province were the following:

- León: 226.
- Salamanca: 340.

It should be pointed that the GIS layers only had information for the period of years between 2007 and 2011. Due to this fact, the reduction in the number of events was so high. In order to develop the multinomial logistic regression, the different categorical variables were redefined with the purpose of simplify them.

4.2.1. Fuel models

The fuel models are classified in fifteen different types in the fire reports. All these classes were redefined in five new ones. The new classification was made according to the fuel load, the virulence in the behavior of the potential fire and the way by which the wildfire is driven across the vegetation. Another classification of fuel models had to be taken into consideration due to the fact that the fuel models which are displayed in the fuel models map are classified according to the classification of Rothermel (Rothermel, 1972). This classification of Rothermel (Rothermel, 1972) is displayed in the appendix 5.

4.2.2. Land use classification

The field called: USO_NIVEL3 appears in the attributes table of the GIS layer of the forest map of Castile and Leon. From the map of starting points of the wildfires, the different classes of uses of the land of each wildfire were discovered using GIS Software (ArcMAP v.10). In each province, each class displayed different codes and therefore all of them had to be redefined and simplified with the purpose of facilitating the development of the multinomial logistic regression. The land use classes for each province appear in the appendices 8 and 9. ArcMap assigned a different number to each class of land use. The displayed land use classes where a wildfire obviously cannot start such as continental waters were removed with the purpose of avoiding inaccurate information and following the same rules in all the considered cases with the implementation of the methodology used.

A new classification of the land use classes was made using those values. In this new classification, those classes where wildfire ignition is impossible were removed. In the same way, those land use classes where the wildfire could affect other types of areas such as mine extraction types, landfills or adjacent zones of the roads where there are no forest zones were removed as well. The reason for these actions is the goal of this research project: to study the spreading of the forest fires and not other types of wildfires which mainly were not affected in forest lands.

4.2.3. Vegetation species

The field called: ESPECIE1 appears in the attributes table of the GIS layer of the forest map of Castile and Leon. This is the main vegetation species in that stand. Different names of vegetation species are displayed in this field. From the map of starting points of the wildfires, the name of the vegetation species of each wildfire was discovered using GIS Software (ArcMAP v.10). In each province each name of vegetation species was displayed with different codes and therefore all of them had to be redefined and simplified with the purpose of facilitating the development of the multinomial logistic regression. The names of the vegetation species for each province appear in the appendices 6 and 7.

The new classification was made separating the woodland vegetation species in pastures and crops, shrubs, hardwood (Fam. Fagaceae), coniferous, riparian vegetation, eucalyptus stands and other tree species which usually form copses (Costa *et al.,* 1997). Each vegetal species in each group is related to its location, the type of stand it usually belongs to and the specific features related to the fire behavior. As was the case in land use class, those areas where the wildfires started in the areas classified with the value 1 were removed due to missing information.

4.3. Statistical analysis

A model to predict wildfire size has been fitted by using a multinomial logistical regression which allows us to obtain the size of the potential wildfire from the weather and silvicultural conditions.

Multinomial logistic regression (Hosmer & Lemeshow, 1989) is used in those models which have a dependent variable (nominal type) with more than two categories. The independent variables can be as continuous as categorical. This technique is implemented in statistical software such as SAS (PROC CATMOD) or SPSS (NOMREG). The use of this technique in the forest sciences has already been proved in previous studies e.g. Harig & Fanch (2002) and Rio *et al.* (2004) (Pando Fernandez & San Martín Fernandez, 2004).

Once the multinomial logistic regression is developed, the coefficients ß are calculated. With those coefficients and the formula displayed in figure 2 the probability of occurrence for each case considered can be obtained. The result with the highest probability of all will be the case predicted.

Figure 2. Formula of the multinomial logistic regression (Pando Fernandez & San Martín Fernandez, 2004).

$$\left.\begin{aligned} p_1 &= \frac{\exp(Z_1)}{1+\exp(Z_1)+\exp(Z_2)} \\ p_2 &= \frac{\exp(Z_2)}{1+\exp(Z_1)+\exp(Z_2)} \end{aligned}\right\}$$

$$p_3 = 1 - p_1 - p_2 = \frac{1}{1+\exp(Z_1)+\exp(Z_2)}$$

$$\begin{aligned} Z_1 = {} & \beta_{01} + \beta_{WS1}\cdot X_{WS} + \beta_{RH1}\cdot X_{RH} + \beta_{LU11}\cdot X_{LU1} + \beta_{LU21}\cdot X_{LU2} + \beta_{LU31}\cdot X_{LU3} + \beta_{LU41}\cdot X_{LU4} \\ & + \beta_{LU51}\cdot X_{LU5} + \beta_{LU61}\cdot X_{LU6} + \beta_{FM11}\cdot X_{FM1} + \beta_{FM21}\cdot X_{FM2} + \beta_{FM31}\cdot X_{FM3} + \beta_{FM41}\cdot X_{FM4} + \beta_{FM51}\cdot X_{FM5} \end{aligned}$$

$$\begin{aligned} Z_2 = {} & \beta_{02} + \beta_{WS2}\cdot X_{WS} + \beta_{RH2}\cdot X_{RH} + \beta_{LU12}\cdot X_{LU1} + \beta_{LU22}\cdot X_{LU2} + \beta_{LU32}\cdot X_{LU3} + \beta_{LU42}\cdot X_{LU4} \\ & + \beta_{LU52}\cdot X_{LU5} + \beta_{LU62}\cdot X_{LU6} + \beta_{FM12}\cdot X_{FM1} + \beta_{FM22}\cdot X_{FM2} + \beta_{FM32}\cdot X_{FM3} + \beta_{FM42}\cdot X_{FM4} + \beta_{FM52}\cdot X_{FM5} \end{aligned}$$

Where:

- P_1 represents the probability of the occurrence of a small forest fire (less than one hectare)
- P_2 represents the probability of the occurrence of a medium forest fire (between one and twenty hectares)
- P_3 represents the probability of the occurrence of a large forest fire (more than twenty hectares)
- β_{01} and β_{02} represent the intercept
- β_{WS1} and β_{WS2} represent the coefficients of the factor of wind speed, 1 for small forest fire and 2 for medium forest fires.
- β_{RH1} and β_{RH2} represent the coefficients of the factor of relative humidity, 1 for small forest fire and 2 for medium forest fires.
- β_{LU11} and β_{LU12} represent the coefficients of the class 1 of the land use, 1 for small forest fires and 2 for medium forest fires.
- β_{LU21} and β_{Lu22} represent the coefficients of the class 2 of the land use, 1 for small forest fires and 2 for medium forest fires.

- β_{LU31} and β_{LU32} represent the coefficients of the class 3 of the land use, 1 for small forest fires and 2 for medium forest fires.
- β_{LU41} and β_{LU42} represent the coefficients of the class 4 of the land use, 1 for small forest fires and 2 for medium forest fires.
- β_{LU51} and β_{LU52} represent the coefficients of the class 5 of the land use, 1 for small forest fires and 2 for medium forest fires.
- β_{LU61} and β_{LU62} represent the coefficients of the class 6 of the land use, 1 for small forest fires and 2 for medium forest fires.
- β_{FM11} and β_{FM12} represent the coefficients of the fuel model 1, 1 for small forest fires and 2 for medium forest fires.
- β_{FM21} and β_{FM22} represent the coefficients of the fuel model 2, 1 for small forest fires and 2 for medium forest fires.
- β_{FM31} and β_{FM32} represent the coefficients of the fuel model 3, 1 for small forest fires and 2 for medium forest fires.
- β_{FM41} and β_{FM42} represent the coefficients of the fuel model 4, 1 for small forest fires and 2 for medium forest fires.
- β_{FM51} and β_{FM52} represent the coefficients of the fuel model 5, 1 for small forest fires and 2 for medium forest fires.
- X_{RH} represents the value of relative humidity to be implemented in formula.
- X_{WS} represents the value of wind speed to be implemented in formula.
- X_{FM1}, X_{FM2}, X_{FM3}, X_{FM4} and X_{FM5} represent the value of the class of fuel model. The value is implemented such as it is explained after.
- X_{LU1}, X_{LU2}, X_{LU3}, X_{LU4}, X_{LU5} and X_{LU6} represent the value of the class of land uses. The value is implemented such as it is explained after.

The information taken into account is organized in different groups of variables as is displayed:

- Continue variables:
  - Maximum temperature (ºC).
  - Relative humidity (%).
  - Wind speed (km/h).
  - Ignition probability (%).
  - .
- Categorical variables:
  - Fuel model (five classes).
  - Land use class (taking into consideration FCC) (six classes).
  - Vegetal species class (seven classes).

The total burned area is classified in three size classes: small, medium and large wildfire. The number of each class is 1, 2 and 3 respectively as is displayed in the Table 3.

Table 3. Classification of the forest fires sizes

<table>
<tr><td colspan="2" rowspan="2">Area</td><td>1</td><td>2</td><td>3</td><td rowspan="2">Total</td></tr>
<tr><td>≤1 (Ha)</td><td>(1-20] (Ha)</td><td>>20 (Ha)</td></tr>
<tr><td rowspan="3">Number of events</td><td>León</td><td>99</td><td>98</td><td>29</td><td>226</td></tr>
<tr><td>Salamanca</td><td>226</td><td>103</td><td>11</td><td>340</td></tr>
<tr><td>Total</td><td>325</td><td>201</td><td>40</td><td>566</td></tr>
</table>

The highest number of events is concentrated in the first class. This is because the firefighter teams actions which extinguish the wildfires when they are still little wildfires, generally less than 5 hectares in most of these cases. The multinomial logistic regression was fitted with SPSS software. First, the multinomial logistic regression was fitted with the data of the provinces of León and Salamanca with the purpose of obtaining one greater dataset and implementing all the considered factors with more data. The two datasets were joined to establish one dataset. As a result, a greater amount of data could be used.

The unification of this data is justified because both of the considered provinces have similar numbers of airborne fire brigades; a fact which is not common in other provinces of the region. These brigades along with the action of other firefighter teams are able to extinguish the wildfires earlier. The two provinces whose data have been gathered in one dataset belong to the provinces included in the Plan 42 (Consejería de Fomento y Medio Ambiente 2006). This plan mainly covers three provinces: León, Zamora and Salamanca. All of these provinces display some similarities in the field of forest fires e.g. similar causes of the occurrence of wildfires as a result of the behavior of the population, deployment of firefighter teams…. The provinces present these similarities and they are large enough to take into consideration data of different types of land use, vegetation and fuel models. All the considered variables which are indicated from above were applied to the multinomial logistic regression. Nevertheless, the analysis of the results obtained in the multinomial logistic regression showed which factors had more significance in the regression.

4.4. Simulation of scenarios

In order to display some maps which show how big the wildfire will be should it occur in the zone; the following conditions have been selected for the weather conditions. The selected conditions have to be related to the factors which have demonstrated that they actually influence the spreading of forest fires.

Two different scenarios are simulated:

Scenario 1:

- Relative humidity: 65%
- Wind speed: 5 km/h

Scenario 2

- Relative humidity: 35%
- Wind speed: 40 km/h

Scenario 1 presents favorable weather conditions and scenario 2 presents unfavorable weather conditions. The simulated maps which were designed according to these conditions were applied in the townships of Barjas (León) and Mieza (Salamanca). The selection of these townships was random. Designing the maps in one township instead of bigger areas is due to this research's study aims, to highlight the difference inside the same township and indicate that this danger index is developed at landscape level and not at township level. The fuel models map and forest map were prepared for the implementation of the formula and to show the hazard level in each zone. First, the layers of the forest map and the fuel map were intersected via implementation of GIS software ArcMAP (v. 10) with the tool called: "intersect". From this action a new layer was created in each township. This new layer takes both of the attribute tables of each layer and combines them into one attributes table. All the considered factors taken into account in the multinomial logistic regression can be found in this attributes table.

The different values of the fields: "USO_NIVEL3" (this is land use class), "ESPECIE1" (this is the vegetation species names) and "MODELO1_" (fuel models) in the attribute tables were modified and the new classifications were previously explained. With this purpose, new fields were created in the attributes tables of the two townships. One field for the land use class, the other field for vegetal species class and an additional field for a new class for fuel models. The new values of each field were calculated with the application "Field calculator". Then, the obtained formula was implemented with the values of each created new field and the data extracted from the fire reports.

The calculation of the probabilities of occurrence of small, medium and large forest fires is possible with the implementation of the formula displayed in figure 3. For the implementation of that formula, the values of the wind speed (km/h) and the relative humidity (%) in X_{WS} and X_{RH} respectively have to be implemented. After that and depending on which class of land use and fuel model it is, it has to be replaced by number 1, its respective factor. For example, if it is fuel model 3 then the factor X_{FM3} must be replaced by number 1 and the other factors of fuel models have to be replaced by 0. The land use is operated in the same way. After the implementation of the formula which is displayed in figure 3, the probabilities of occurrence of small, medium and large wildfires were obtained. The wildfire size will correspond to the highest probability calculated using this formula. The different values of each size class will be assigned depending on the size class obtained from the highest probability of occurrence. These values will be classified accordingly; 1 for small wildfires, 2 for medium wildfires and 3 for large wildfires.

Finally, this last column will be implemented in the attribute table of the GIS layer of each township via implementation of the tool "join". The symbols on each map will be changed to demonstrate the occurrence of each size of wildfire in each polygon inside the displayed map. This map is the final map which shows the hazard of each area.

5. RESULTS AND DISCUSSION

5.1. Statistical model developed

The results of the regression were displayed in tables 4, 5 and 6. The mean agreement between the predicted and observed values of all the classes was 60, 1 %.

Table 4. Model Fitting Information

Modelo	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 log verosimilitud	Chi-Square	df	Sig.
Intercept Only	964,961			
Final	892,340	72,621	22	,000

Table 5. Pseudo R-Square

Cox y Snell	,120
Nagelkerke	,146
McFadden	,073

Table 6. Likelihood Ratio Tests

Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	892.340[a]	0,000	0	
Wind speed	901,683	9,343	2	,009
Relative humidity	898,996	6,656	2	,036
Land uses	928,007	35,667	10	,000
Fuel model	910,005	17,665	8	,024

The coefficients (B) to develop the formula for the multinomial logistic regression are displayed in the table 7.

Table 7. Parameter Estimates

Size class		B	Std. Error	Wald	df	Sig.	Exp(B)	95% Confidence Interval for Exp(B)	
								Lower Bound	Upper Bound
1.00	Intercept	1,551	1,135	1,868	1	,172			
	Windspeed	-,060	,024	6,392	1	,011	,942	,900	,987
	Relative humidity	-,008	,013	,331	1	,565	,992	,967	1,018
	[landuseclass=1]	1,500	,509	8,682	1	,003	4,481	1,652	12,153
	[landuseclass=2]	,750	,705	1,132	1	,287	2,116	,532	8,419
	[landuseclass=3]	,479	,715	,448	1	,504	1,614	,397	6,557
	[landuseclass=4]	1,776	,798	4,957	1	,026	5,907	1,237	28,209

	[landuseclass=5]	,195	,471	,172	1	,679	1,216	,483	3,062
	[landuseclass=6]	0			0				
	[fuelmodel=1]	2,932	1,327	4,883	1	,027	18,771	1,393	252,899
	[fuelmodel=2]	,541	,899	,362	1	,547	1,717	,295	9,995
	[fuelmodel=3]	,188	,922	,042	1	,838	1,207	,198	7,347
	[fuelmodel=4]	18,794	,938	401,264	1	,000	145307693,613	23102572,914	913938283,030
	[fuelmodel=5]	0			0				
2.00	Intercept	1,191	1,212	,965	1	,326			
	Windspeed	-,027	,024	1,242	1	,265	,974	,929	1,020
	Relativehumidity	-,024	,014	3,024	1	,082	,976	,951	1,003
	[landuseclass=1]	,936	,530	3,124	1	,077	2,550	,903	7,199
	[landuseclass=2]	,635	,728	,761	1	,383	1,888	,453	7,869
	[landuseclass=3]	-,091	,780	,014	1	,907	,913	,198	4,211
	[landuseclass=4]	2,315	,802	8,343	1	,004	10,127	2,105	48,727
	[landuseclass=5]	,446	,486	,840	1	,359	1,561	,602	4,050
	[landuseclass=6]	0			0				
	[fuelmodel=1]	3,159	1,384	5,208	1	,022	23,540	1,562	354,798
	[fuelmodel=2]	,849	,979	,751	1	,386	2,337	,343	15,928
	[fuelmodel=3]	,630	1,001	,396	1	,529	1,878	,264	13,360
	[fuelmodel=4]	18,561	0,000		1		115088486,526	115088486,526	115088486,526
	[fuelmodel=5]	0			0				

The obtained results of the multinomial logistic regression are displayed in the table 8 and with those coefficients the formula of the multinomial logistic regression is developed as displayed in figure 3.

Figure 3. Formula for the calculation of the probabilities of the multinomial logistic regression (Pando Fernandez & San Martín Fernandez, 2004).

$$\left.\begin{aligned} p_1 &= \frac{\exp(Z_1)}{1+\exp(Z_1)+\exp(Z_2)} \\ p_2 &= \frac{\exp(Z_2)}{1+\exp(Z_1)+\exp(Z_2)} \end{aligned}\right\}$$

$$p_3 = 1 - p_1 - p_2 = \frac{1}{1+\exp(Z_1)+\exp(Z_2)}$$

Where:

$$Z_1 = 1.551 - 0.060 \cdot X_{WS} - 0.008 \cdot X_{RH} + 1.500 \cdot X_{LU1} + 0.750 \cdot X_{LU2} + 0.479 \cdot X_{LU3} + 1.776 \cdot X_{LU4} + 0.195 \cdot X_{LU5} + 0 \cdot X_{LU6} + 2.939 \cdot X_{FM1} + 0.541 \cdot X_{FM2} + 0.188 \cdot X_{FM3} + 18.794 \cdot X_{FM4} + 0 \cdot X_{FM5}$$

$$Z_2 = 1.191 - 0.027 \cdot X_{WS} - 0.024 \cdot X_{RH} + 0.936 \cdot X_{LU1} + 0.635 \cdot X_{LU2} - 0.091 \cdot X_{LU3} + 2.315 \cdot X_{LU4} + 0.446 \cdot X_{LU5} + 0 \cdot X_{LU6} + 3.159 \cdot X_{FM1} + 0.849 \cdot X_{FM2} + 0.630 \cdot X_{FM3} + 18.561 \cdot X_{FM4} + 0 \cdot X_{FM5}$$

5.2. Analyses of the variables considered in the multinomial logistic regression

5.2.1. Meteorological variables

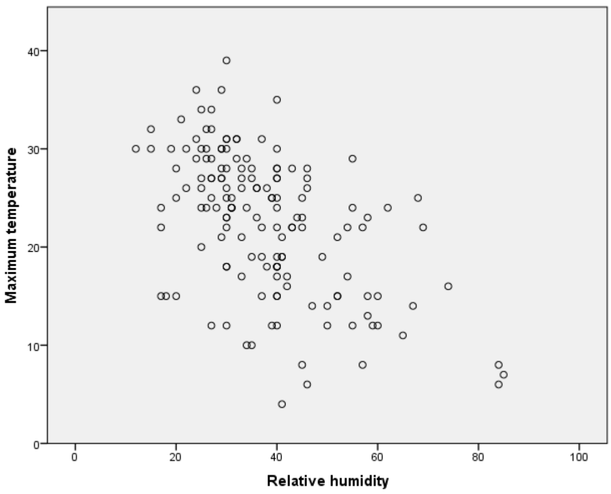
It should be pointed out that the considered variables in this analysis were extracted from the fire reports and the GIS layers. Many of them did not have much importance according to the results of the multinomial logistic regression. The most influential factors in the results were: relative humidity, wind speed, land used and fuel models. Other factors which had to be considered were removed due to their low level of significance. Their "p" values were high (more than 0.05). The data considered is displayed in appendix 10.

5.2.1.1. Temperature

It is the measure of the effect of solar radiation. It plays a key role in the vegetation because it regulates its draining and the internal temperature of the vegetation tissues and therefore the requirements of necessary caloric energy for the ignition. It has influence on the relative humidity of the air and therefore on the humidity of the dead fuels. Also, the temperature changes during the day being the lowest at dawn and the highest after midday (Vélez *et al.,* 2000).

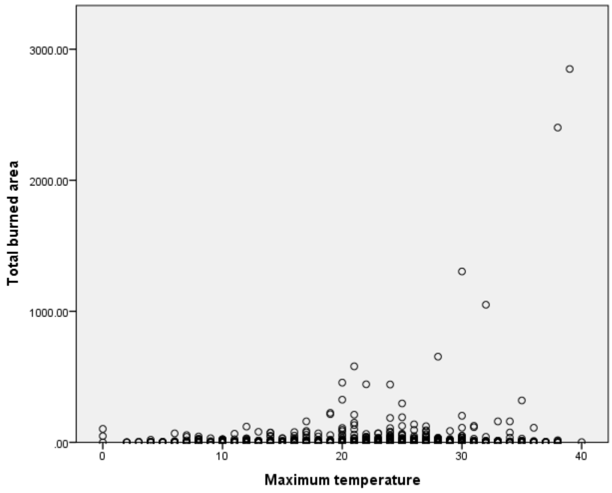
The temperature has influence on the movements of the air. It creates thermic differences between the air stands producing density variations and winds (Vélez *et al.,* 2000). The temperature has an important influence on the wildfire spreading as well. The temperature dries the environment and decreases the relative humidity. Heat is also one of the sides of the fire triangle. This means that the higher temperatures increase the virulence of the wildfire (Vélez *et al.,* 2000). In figure 4 we can see the influence that the maximum temperature has on the relative humidity. A high maximum temperature involves a low relative humidity.

Figure 4. Relationship between maximum temperature and relative humidity



It can be seen in figure 5 that the size of the wildfires is bigger when the maximum temperature (during the day when the wildfire occurred) is higher. At the same time, the number of events which occurred is higher from twenty degrees onwards.

Figure 5. Relationship between the total burned area and the maximum temperature



Nevertheless, the data extracted from the fire report about this factor had a low level of significance. Therefore it is not included as a determinant factor in the multinomial logistic regression. It may be because of the low accuracy in the data collected and the maximum temperature is not determinant data. It would be better if another kind of data related to this factor could be collected e.g. temperature at the ignition time.

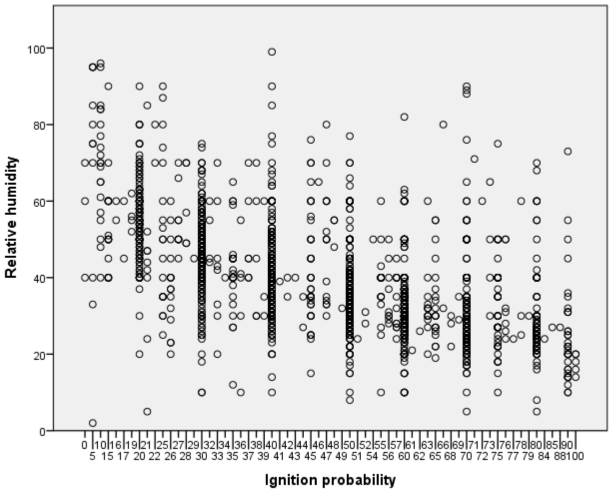
5.2.1.2. Relative humidity

The water vapor is one of the most important parameters for the ignition and the fire behavior. This concept means the proportion of water vapor in the air mass in respect to the maximum that it might contain with that temperature. For values under 30% the conditions are very favorable for the ignition and the fire spreading (Vélez *et al.,* 2000). The relative humidity affects the fire behavior in two ways. First, it has influence on the amount of oxygen available in the combustion process. More relative humidity means less available oxygen. Second, it affects the moisture of the vegetation (Vélez *et al.,* 2000). As we can see in figure 4, the relative humidity has a close relationship with the temperature. It can be verified that this factor has a high significance level in regards to the development of the multinomial logistic regression.

5.2.1.3. Ignition probability

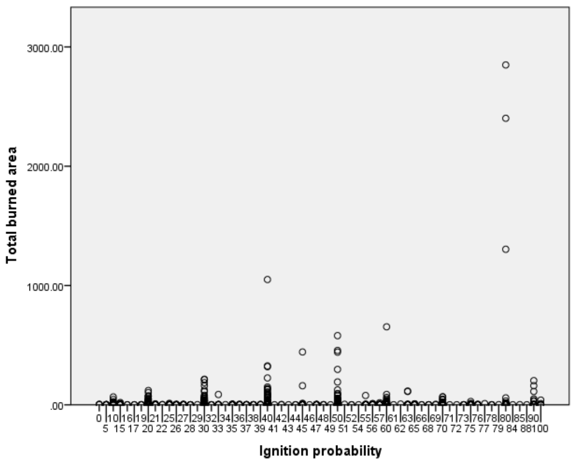
As it is displayed in figure 6 the ignition probability takes into consideration the relative humidity. The relative humidity values decrease as the ignition probability increases. There are some exceptions in figure as mistakes could be commited when the fire report was written. The zones with low relative humidity are drier and therefore they burn easier. Also, when a wildfire occurs and the ignition probability is higher, the size of the wildfire will be bigger. In figure 6 statistics demonstrated that from 40% onwards wildfires reach bigger sizes. This is due to the fact that the thin fuel is drier than in other conditions. In this case, when a large wildfire occurs, several incandescents wood pieces can be expelled from the trees or big shrubs because of the heat. These incandescent wood pieces can travel by air up to the thin fuels and set them on fire. This produces secondary fires which make the wildfire bigger and they increase the perimeter of the wildfire whereas the frontline of the wildfire becomes longer. As a consequence, the wildfire spreads faster and becomes more dangerous.

Figure 6. Relationship between relative humidity and ignition probability



As can noted in figure 7, the biggest wildfires were those with the highest values of igntion probability. The alert index which takes into consideration this factor is displayed in appendix 2. Nevertheless, the development of the multinomial logistic regression as from the data used demonstrated that this factor had a low level of significance. Therefore it is not included in the multinomial logistic regression, though in reality it acquires importance in the alert index in the Spanish system.

Figure 7. Relationship between the total burned area and the ignition probability indicated during the occurrence of the wildfire



5.2.1.4. Wind speed

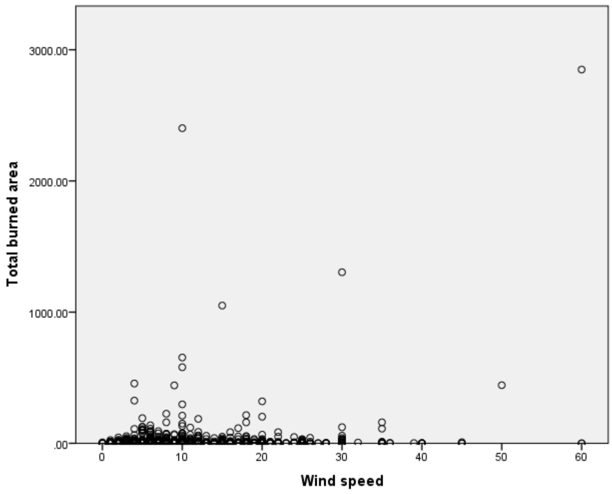
The most interesting features of this factor are the direction and the speed (Vélez *et al.,* 2000). Large forest fires can create their own meteorological conditions in respect to the air movements. The wind is a critical element which is responsible for the fire breaking the defenses and magnifying the flames' height, in turn affecting to the security of the firefighters (Vélez *et al.,* 2000). The most important effects of the wind in the forest fires are the following (Vélez *et al.,* 2000):

- Draining of the forest fuel. It accelerates the transpiration of the plants because of the decrease in the relative humidity of the air.
- Increment of the intensity because it adds more oxygen to the reaction.

- Inclination of the flame affecting the vegetation with more intensity because it influences more perpendicularly the adjacent vegetation.
- Increment of the efficacy (uphill) in the energy transmission (convection) at the same time as it increments the fire spreading.
- Increment of the scope of incandescent materials which can be thrown by the convection plume and they can cause secondary wildfires.

The wind speed has importance in the spreading of the wildfires. Also, the wind direction due to the wind blows toward the zones already burned or the green zones. In the first case the wildfire will decrease its virulence and it will be easier to extinguish it, but in the second case the spreading of the wildfire will be faster and dangerous. The latter can suppose that many resources are destined to its extinction. In addition, the damages in that zones will surely be catastrophics (Vélez *et al.,* 2000). Wind direction is discarted as a factor to take into consideration in the development of the multinomial logistic regression due to the fact that the fire reports do not reflect if wind blows in the same direction of the spreading of the wildfire or against it. As can noted in figure 8 the size of the wildfire increases as long as the wind speed is faster. The usual values in this region are contained between 5 and 20 km/h. The largest wildfires are those that occurred with high wind speeds and the wildfires with lowest wind speeds up to 5 kilometers per hour were not too big.

Figure 8. Relationship between the total burned area and the wind speed occurred for each wildfire



It was verified that this factor has high significance level in regards to the development of the multinomial logistic regression. Therefore, it is included in the formula of the multinomial logistic regression.

5.2.1.5. Days after the last rain. Precipitation

It is the easiest way to change the moisture content in the soil and vegetation. It influences relative humidity and humidity of dead wood. Also, it influences the living wood some days after the rain because water is assimilated by the plants. This parameter plays an important role in the formulation of the accumulative risk indexes (Vélez *et al.,* 2000). The days after the last rain had a low significance level in the development of the multinomial logistic regression. Therefore, it was dismissed as a factor to take into consideration.

5.2.2. Silvicultural variables

5.2.2.1. Fuel model

5.2.2.1.1. New classification of the fuel models

The vegetation with similar conditions is grouped in different classes according to the fuel load and its distribution among the size classes of fuel particle (Anderson, 1982) (Rothermel, 1972). Under these conditions the vegetation is classified in 13 different classes. They are displayed in appendices 3 (Anderson, 1982) and 5 (Rothermel, 1972). Nevertheless, another simplifier classification is written in the fire reports. It only classifies the fuel models depending on which fuel burned during the forest fire. Each fuel model has its own code as well as the classification according to Anderson (Anderson, 1982) or Rothermel (Rothermel, 1972), and there 15 different fuel models. This can be seen in appendix 4. Due to the different classifications both in the fire reports and in the fuel model map, it was necessary to determine a new classification. The new classes of the fuel models were included in the development of multinomial logistic regression. The new classification is displayed in Table 8.

Table 8. New classification of fuel models

New classes of fuel model	Fuel models classification of the fire reports	Fuel models classification of the fuel model map
1	1	1
2	2 and 5	4, 5 and 6
3	3, 6, 8, 9 and 11	8 and 9
4	4, 7, 10, 12, and 13	4 and 7
5	14 and 15	10, 11, 12 and 13

In the first class the wildfire is driven by the meadows, with a low flame height. The virulence in this case can be stronger if the meteorological conditions are very unfavorable. In this last case the height of the flames can reach one or two meters and the spreading speed can be very fast. In the second class, the wildfire is driven by the shrubs. The calorific potential is higher than the first class and here there is more fuel load than the previous class. The flame height is usually higher than the first class though it depends on the height of the shrubs. The fuel load is higher than the first class. In the third class, the wildfire is driven by the crown of the trees in the woodland areas. Moreover, the wildfire is driven by the shrubs and the ground, but these wildfires are classified in this class because all of them are driven by the tree crowns as well. The calorific potential is quite higher than the previous classes as well as the fuel load. The flame height is the highest because its extension is higher than the trees height. In the fourth class the wildfire is driven by the ground, shrubs and tree crowns. In this last case one more factor appears, the wood residues. These residues provided high amounts of fuel load to the stands and therefore, the calorific potential is the highest in this case. The flame height is similar to the third class; nevertheless, the virulence in this case is at the most dangerous level.

Finally, in the fifth class, the fuel load is so high that it has to be taken into account in another fuel model class. In this last case, the wildfire will be very violent and dangerous. The flame height is similar to the previous class, but the wildfire will have more calorific power than the others.

5.2.2.1.2. Analyses of the fuel model respect to the burned area

According to this classification a wildfire will behave differently if it affects one kind of fuel model or another. The speed and the virulence of the wildfire will be conditioned depending on the type of the vegetation affected by the wildfire although of course wind speed and relative humidity have an influence as well. The amounts of fuel to burn as well as the features of the vegetation, such as the existence of trees or shrubs, will play a key role in the fire's behavior. For example: the height of the flame is not the same if the meadows are burning or a burning tree which is 3 meters tall. In the first case the flame's height would be at most 1 meter and in the other case it would be at least 3 meters. It is important to take into consideration the amount of fuel. For example, the wood residues which are left in the middle of the forest become dry residues which are very dangerous because they are capable of burning under limited but favorable conditions. In this case the firefighters or the extinction director will be face with too much fuel load making it almost impossible to extinguish unless many liters of water are wasted in this zone. On the other hand, they must wait until the residues have completely burned, as a result, wasting too much time and too many resources that could be used in other more significant sites of the wildfire.

By analyzing the fuel models in regards to the total area burned, it can be seen that the size of the wildfires is larger when the fuel models have more fuel load. The next figure demonstrates which type of fuel model is affected by each wildfire. Of course, the type of fuel model affected by the wildfire is random. The higher the amount of fuel, the more violent a wildfire becomes. In the figure 9, it can be seen that the larger sized wildfires occurred in the fuel models with more fuel load. These fuel models are: 2, 5, 11, 14 and 15.

Figure 9. Relationship between the total burned area of each forest fire and the affected fuel model

From the data used, it was verified that this factor has a high significance level in regards to the development of the multinomial logistic regression. Therefore, it is included in the formula of the multinomial logistic regression.

5.2.2.2. Land use

As each class of land use was classified with different values in regards to each province, it was necessary to determine a new classification. The new classes were included in the development of the multinomial logistic regression with the purpose of simplifying its inclusion and facilitating its development. The new classification has six different classes. The different values for each class from the old classifications were redefined with the same values for both. The new classification for the different land uses is displayed in Table 9.

Table 9. New classification of the land uses

Types of land use	León	Salamanca
Meadows	4 – 3 – 12 – 15	3 -2 -9 – 14
Shrubs	11 – 18	6 – 20
Woodland (FCC 5-20%)	6	12
Woodland (FCC 20-50)	8	4
Forests (FCC 50-70%)	5	5
Forests (FCC >=70%)	2	7

From the data used, it was verified that this factor has a high significance level in regards to the development of the multinomial logistic regression. In addition, this factor reflects the different FCC in the forest stands which represents the thickness of the stand and its influence on the virulence of the wildfire. Therefore, it is included in the formula of the multinomial logistic regression.

5.2.2.3. Vegetation species

The different types of vegetal species are classified in different ways for each province. Due to this fact, two factors will be taken into consideration in order to determine a new classification which groups the different vegetal species in homogeneous classes: plants with the same silvicultural characteristics and their location in the same forest stands. This new classification is displayed in table 10. However, it was verified that this factor has a low level of significance in regards to the development of the multinomial logistic regression. Therefore, it was not included in the formula of the multinomial logistic regression.

Table 10. New classification of the vegetal species in the provinces of León and Salamanca

New classification	**Old classification**			
	Salamanca		**León**	
Values	**Values**	**Name**	**Values**	**Name**
Class 1 Pastures	13	Pastures	22	Pastures
	20	Crops	41	Crops
Class 2 Shrubs	17	Shrubs	19	*Juniperus communis*
	28	*Juniperus communis*	32	*Myrtus communis*

	34	*Prunus spinosa*	35	*Ilex aquifolium*
	21	*Arbutus unedo*	38	*Juniperus sabina*
			40	*Juniperus phoenicea*
			43	Shrubs
			45	*Arbutus unedo*
			52	*Prunus spinosa*
			60	*Cornus sanguinea*
Class 3 Hardwood	2	*Quercus ilex*	2	*Quercus pyrenaica*
	3	*Quercus pyrenaica*	7	*Quercus ilex*
	6	*Castanea sativa*	12	*Fagus sylvatica*
	16	*Quercus suber*	13	*Corylus avellana*
	22	*Quercus faginea*	14	*Quercus petraea*
			16	*Quercus faginea*
			24	*Quercus robur*
			27	*Castanea sativa*
			54	*Quercus suber*
Class 4 Coniferous	4	*Pinus sylvestris*	4	*Pinus pinea*
	5	*Pinus pinaster*	9	*Pinus nigra*
	14	*Pinus pinea*	11	*Pinus pinaster*
	15	*Pinus nigra*	17	*Pinus uncinata*
	18	*Pinus radiata*	20	*Pinus sylvestris*
	27	*Juniperus oxycedrus*	25	*Picea abies*
	30	*Cupressus arizonica*	30	*Taxus baccata*
			31	*Pseudotsuga menziesii*
			36	*Juniperus thurifera*
			44	*Pinus radiata*

			47	Coniferous mix
			48	*Cedrus atlantica*
			57	*Pinus* sp
			58	*Cupressus sempervirens*
			39	Other coniferous
Class 5 Gallery forest	7	*Betula pubescens*	3	*Populus x canadensis*
	8	*Alnus glutinosa*	5	*Populus nigra*
	9	*Salix* sp	6	*Salix* sp
	10	*Populus nigra*	8	*Salix caprea*
	11	*Fraxinus angustifolia*	10	*Populus alba*
	12	*Populus x canadensis*	18	*Betula pubescens*
	25	*Populus alba*	23	*Betula* sp
	29	*Ulmus minor*	28	*Alnus glutinosa*
	35	*Salix atrocinerea*	33	*Fraxinus excelsior*
			37	*Fraxinus angustifolia*
			46	*Salix atrocinerea*
			50	*Salix alba*
			51	*Salix elaeagnos*
			59	*Ulmus minor*
Class 6 Eucaliptus	19	*Eucalyptus camaldulensis*	49	*Eucalyptus* mix
	31	*Eucalyptus globulus*	55	*Eucalyptus globulus*
Class 7 Other vegetal species (Copse)	23	*Olea europaea*	15	*Tilia* sp
	24	*Celtis australis*	21	*Malus sylvestris*
	26	*Crataegus monogyna*	26	*Sorbus aucuparia*
	32	*Acer campestre*	29	*Sorbus* sp

	33	*Sorbus aucuparia*	34	*Crataegus monogyna*
			42	*Juglans regia*
			53	*Prunus avium*
			56	*Juglans nigra*
			61	*Acer pseudoplatanus*
			62	*Prunus* sp

5.2.3. Final considerations in regard to the variables considered

After the development of the multinomial logistic regression, it could be verified that the factors taken into consideration such as maximum temperature or ignition probability had low importance in the wildfire's spreading because of the data used. On the other hand, the most important factors are the wind speed and the relative humidity. This aspect can be deduced from the multinomial logistic regression. This is caused because these factors have many influences on the behavior of the fire. The wind affects the fire's behavior in some important aspects such as providing more oxygen to the reaction as well as magnifying the flame's height. As consequence the fire has the possibility of breaking the defenses. Also, a high speed of the wind can throw incandescent wood pieces farther and create secondary fires. However, a low relative humidity implies a greater availability of oxygen in the air and allows the moisture in the vegetation to change easier. This causes the wildfire to become more violent. The relative humidity is influenced by the temperature. But in the cases studied those factors gain relevance due to their presence in most big forest fires. The development of the multinomial logistic regression assumes a higher level of significance.

Regarding the silvicultural features, it can be verified that when favorable weather conditions occur, regardless of the different land uses or fuel models, any forest fire will possess too few probabilities to allow it to become a big wildfire. However, the occurrence of small wildfires will have the highest probabilities. This fact is displayed in figures 10 and 12 of the next section where the following favorable weather conditions are taken into account: the wind blows with a speed of 5 km/h and the relative humidity is 65%. When difficult weather conditions occur, different danger zones are produced. This fact is displayed in figures 11 and 13 of the next section, where the following weather conditions were implemented: wind speed was 40 km/h and relative humidity was 35%

As it can be observed in the implementation of the danger index in the next section, the zones with crops or pastures and therefore model 1 are forecasted to become small wildfires. However, it should be pointed out that there was a high probability of it becoming a medium forest fire. In the zones with shrubs and fuel model 2, the forecast was for medium forest fires as well as the forest with a low value of FCC (<50%) and fuel model 3. Forests whose FCC value was between 50 and 70% and the fuel model was 4 in the studied zones, displayed the highest probabilities of becoming the largest wildfires. Those forests whose FCC value was more than 70% and fuel model 4 and 3 were predicted to become medium wildfires. The most dangerous zones for hazardous weather conditions were the models 3 and 4 and the forests whose FCC value was between 50 and 70% and between 5 and 20%.

5.3. Implementation of the danger index and analyses of different scenarios

As from the formula and its implementation in the ArcMAP, the maps displayed in figures 10, 11, 12 and 13 were obtained by the implementation of different conditions of wind speed and relative humidity. In these maps we can see the different zones where different risk levels exist. Each one represents the future size that a potential wildfire would have if a forest fire started in a point within that polygon. The legend of the simulations is:

- The wildfires which are ignited within the zones which are represented in red (category 3) will have the biggest size under the weather and silvicultural conditions indicated. Generally their size will be more than 20 hectares.
- The wildfires which are ignited within the orange zones (category 2) will have wildfires whose size will be between 1 and 20 hectares under the weather and silvicultural conditions indicated.
- Finally, the wildfires which are ignited within yellow zones (category 1) will be wildfires whose size will be less than one hectare under the weather and silvicultural conditions indicated.

As a result, the danger index is developed. The danger index is classified in three different categories:

- Category 1. Low danger in yellow.
- Category 2. Moderate danger in orange.
- Category 3. High danger in red.

Figure 10. Scenario 1. Mieza (Salamanca)

Weather conditions

- Relative humidity: 65%
- Wind speed: 5 km/h

Categories

- Category 1. Low danger.
- Category 2. Moderate danger.
- Category 3. High danger.

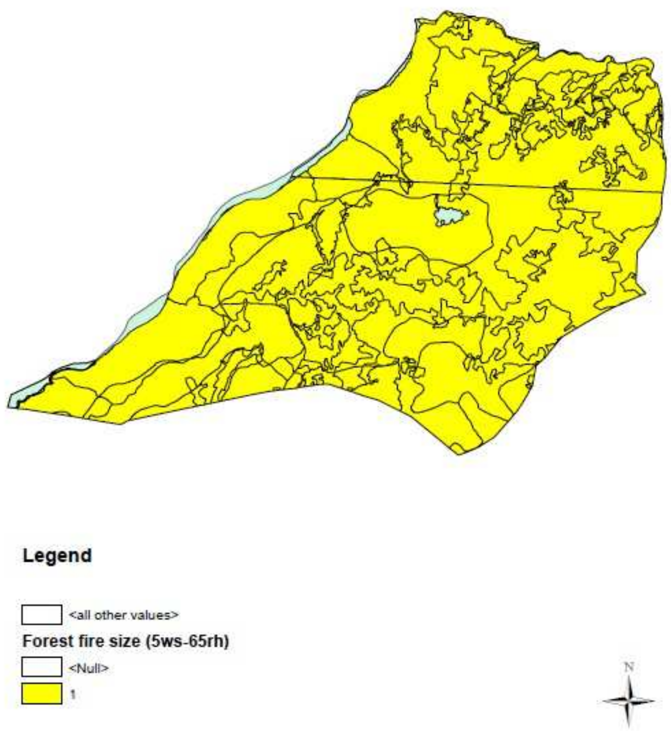


Figure 11. Scenario 2. Mieza (Salamanca)

Weather conditions

- Relative humidity: 35%
- Wind speed: 40 km/h

Categories

- Category 1. Low danger.
- Category 2. Moderate danger.
- Category 3. High danger.

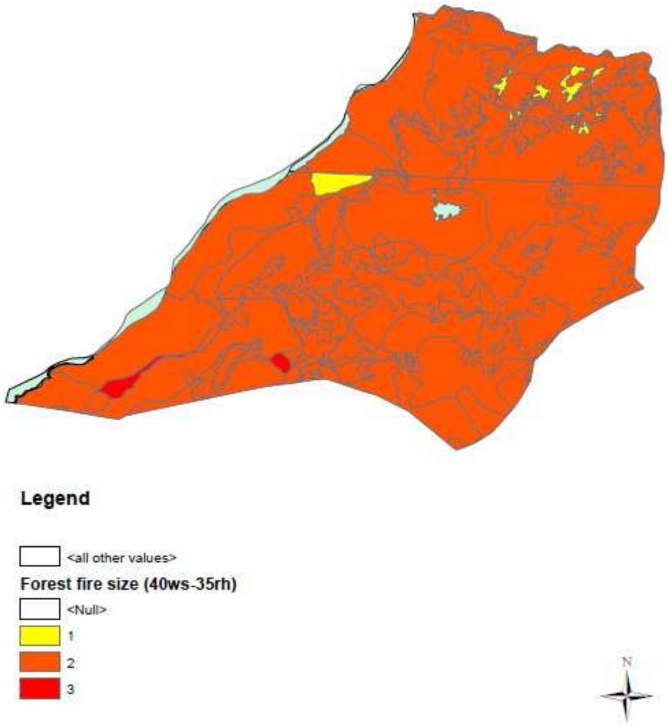


Figure 12. Scenario 1. Barjas (León)

Weather conditions

- Relative humidity: 65%
- Wind speed: 5 km/h

Categories

- Category 1. Low danger.
- Category 2. Moderate danger.
- Category 3. High danger.

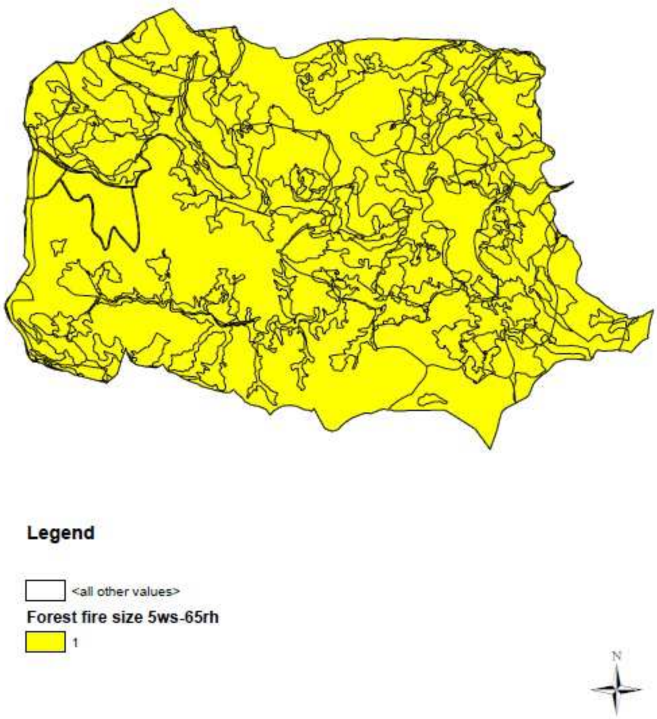


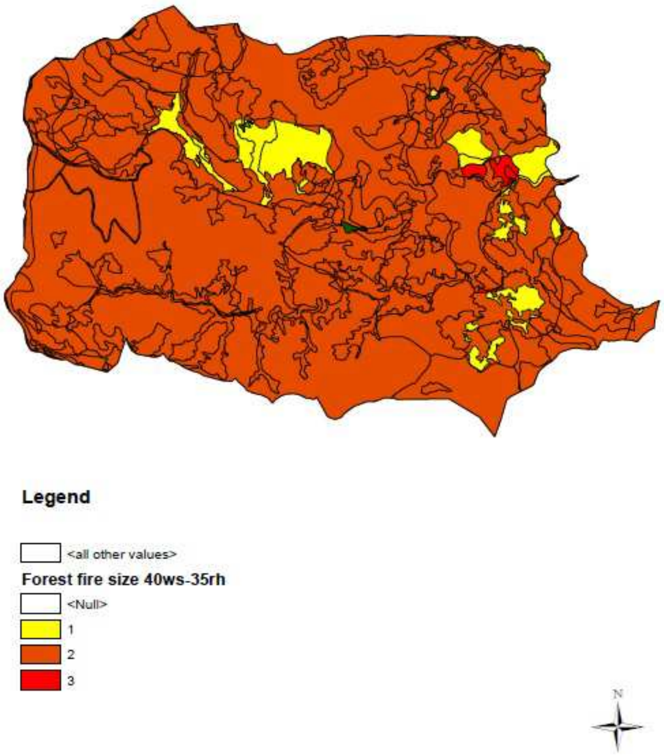
Figure 13. Scenario 2. Barjas (León)

Weather conditions

- Relative humidity: 35%
- Wind speed: 40 km/h

Categories

- Category 1. Low danger.
- Category 2. Moderate danger.
- Category 3. High danger.



5.4. New statistical model for the determination of the hazard zones

The implementation of GIS software in the field of forest fires is a technique which has been implemented during the last decades. The first studies developed by Deeming *et al.* (1978), Calabri (1984) and Artsybashev (1983) and Chuvieco & Congalton (1989) demonstrated that this technique produced very good results, above all, in the design of risk maps via implementation of different variables which were considered important in different studies according to the distinct features of each zone. Later, the following studies in this realm e.g. Jaiswal *et al.* (2001) and Gonzalez-Olabarria *et al.* (2012b) showed that those techniques were efficient in the determination of the zones with high and low risk. This allows us to define good policies in the defense against forest fires. And it also allows planning and strategies against forest fires via an allocation taking into consideration the position of the firefighter teams in those zones with high forest fire risks.

The implementation of this technique in Spain and in the region of Castile and Leon is very advanced. That implementation reaches its peak in the region of Castile and Leon in the Plan INFOCAL. The local risk index takes the frequency, causality and hazard index related to forest fuel indexes into account. After that, the potential risk index takes the local risk index and the vulnerability index into account. Once the risk indexes are determined, they are displayed on a map of the whole region. The whole autonomous community is divided first in its provinces. After that, the indexes are displayed for each township and each township is classified into five different groups based on their fire risk. This research study proposes a new point of view, which is to design the risk maps according to the different forest zones, rather than depending solely on the borders of the township.

There were three different ways to determine of the different risk zones:

- Via overlapping of different layers giving each polygon of each layer a determined value. This value had to be determined according to predetermined criteria for each factor in each layer.
- Via deterministic models. They are based on the physical interpretation of the spreading of wildfires. The spreading factors are described by mathematical formulas such as the American model BEHAVE (Andrews, 1986). This model continues to be frequently.
- Via statistic models. They determine correlations between descriptors of the factors which influence the spreading of wildfires. The data is taken from experimental fires or real events. The implementation of statistical methods in the field of forest fires together with the implementation of GIS software provides a new point of view in the determination of fire risk. The first experiences in the implementation of statistical models in the field of forest fires in Spain were carried out in studies by Gonzalez-Olabarria *et al.* (2005, 2012a).

The first study, González-Olabarria *et al.* (2005) was done with the purpose of studying the spatial patterns for the occurrence of wildfires, i.e., in which kind of zones the wildfires had occurred. The most important limitation of this study was that the wildfires are a stochastic phenomenon. These events are ignited mainly where the arsonist starts them in different zones and never in the same zones. Although in some cases the zones can be the same. As it is demonstrated in some studies such as González-Olabarría *et al.* (2012a), Genton *et al.* (2006), Rorig & Ferguson (1999), Podur *et al.* (2003). Nevertheless this fact mainly occurs when the wildfires are ignited by an arsonist. When the first ignitions are successful it causes a state of euphoria in the mind of the arsonist. As a result, the arsonist sets fire to the adjacent zones causing more starting points of wildfires (Genton *et al.,* 2006). On the other hand, the spreading of the wildfires is conditioned by some factors and with the development of a multinomial logistic regression, the potential size of the forest fire may be foreseen. The factors considered have to be easily extracted in order to facilitate the implementation of this technique. The effectiveness factor in regards to the arrival and the extinction concerning the firefighters is assumed in the development of multinomial logistic regression itself, because the observations themselves used in this development take into account the effectiveness factor.

The agreement between the predicted and observed events was low because the variables considered in the statistical analysis were relatively few. This research study can assume a starting point in the development of a statistical model, based on a multinomial logistic regression. It can then be integrated into the planning against forest fires with its implementation in wildfire risk maps which display the fire risk or in a Decision Support System (DSS) such as the study developed by Kalabokidis *et al.* (2011).Taking into consideration all the different systems which form a DSS, this statistical model could be included in the DSS. This integration may provide more reliable predictions of the deterministic models in an easier way than simulators such as FARSITE (Finney, 1998). In the same way the predictions may be more reliable due to they will be based on the observations which already occurred whereas the simulations are only predictions.

The development of this system will entail an improvement in the data collection of the considered factors in the fire repots of the National Wildfires Statistic. This fact will improve this database in the future respect to the accuracy in the data collection. The system developed in this research study can support the strategies and the planning in the fight against wildfires. Its integration in a DSS with more considered variables make it more reliable. The used data in the formula of the multinomial logistic regression with the purpose of the calculation of the probabilities of the occurrence of each wildfire size can be implement on real time (on the same way that the DSS does it) from the meteorological information used in the Command Provincial Center or in the Command Autonomous Center where the decisions of the wildfires extinction are made as well as the strategies for the fight against forest fires are developed.

5.5. Limitations of this study

The main limitation is the considered data during this period. The accuracy with which the data is taken in the fire reports has serious limitations. This can be observed clearly in the number of considered events. From the provinces with the highest number of occurrences of wildfires in the whole region and considering the data from the period between 1995 and 2011 only 1922 of the original 14555 events could be taken into account considering all of the necessary information. This fact is understandable from the point of view of the implementation of new technologies in this field. Some years ago the collection of data was very difficult because the devices used today simply did not exist then. Nevertheless, after the implementation of the GIS layers to introduce more variables in the analysis, the period to be studied had to be reduced specifically to the years between 2007 and 2011 because these layers were only available during these years. This fact assumed a serious limitation in the statistical analysis where the number of events was reduced considerably. It was necessary because it was verified that it was not reliably possible to calculate the probability of occurrence of a large wildfire based solely on the information from the fire reports (mainly weather factors and the fuel models). Then, more variables had to be taken into account. In accordance with this fact, the implementation of the GIS layers was made and two more variables were taken into account: land use class and vegetal species class.

With the purpose of having all of the information in all the events considered and due to the unknown values in the forest map layer, a second reduction was produced in the dataset. This leads to only 566 events being considered in the implementation of the development of the multinomial logistic regression with very few large wildfires. The existence of numerous small wildfires and limited big fires had an influence on the results of the regression and reduced the agreement between the observed and forecasted fires. The number of predicted events for big wildfires is proportionally low in respect to the small and medium classes.

Another limitation in this study is the low accuracy regarding the collection of data in some factors. There are more secondary limitations in the data used such as the obsolescence of the fuel model map from 2006. Between the year when the map was designed and the last year considered in this study; the fuel model, in a given area, can undergo some changes in its vegetal composition due to the development of the vegetation or due to changes in the land uses. In addition, there might be an apparent generalization of the zones where the definition of the fuel model is clearer and the adjacent areas where the definition of the zones for each fuel model in the design of the map is not so clear. This fact was verified in some cases when the fuel model map was overlapped with the forest map. In the same polygons, there were some strange coincidences. For example, the fuel model 1 and a land use of forest with more than 50% FCC. In this example it would be another fuel model.

These limitations may have an important influence on the results of study as well as the development of the multinomial logistic regression. In future studies related to this topic the data used will have to be acquired with more accuracy and verify the reliability of the data. For this research study, this fact was assumed as acceptable initially because the data used is official data obtained from the official organisms of the regional government of the region of Castile and Leon. However, throughout the process of this research study these limitations were discovered.

After the study demonstrated the agreement between observed and forecasted values, the need to consider more variables in this study can be deduced. This research study focused on the weather and silvicultural features. Nevertheless, the variables used were considered as the most important because they are taken into account in the fire reports and appear principally in the forest map. For other studies, the variables can encompass other factors like the topography and more variables related with the meteorology and silvicultural state of the forests. However, the goal of this topic is to use variables which are from information extracted easily from different sources. In this case, the majority of the information was extracted from the fire reports. In the fire reports, the factors considered are noted systematically and the data which is suitably accurate can be valid for this type of research study and the development of the multinomial logistic regression. For following studies if new variables are added the goal will be to add new variables which are easily extracted from the sources with the purpose of implementing them in the formula of the multinomial logistic regression.

One last limitation is the existence of wildfires whose size is less than one hectare in some places, even if the weather conditions are good, probably the wildfire size will probably be greater than 1 hectare, not exceeding more than 5 hectares. However, these results are a consequence of the observations. From these observations, we are logically led to believe that the wildfire will not be more than 5 hectares and not less than one hectare. The model based on this data determines that in those zones the wildfire will not be more than 1 hectare and in many situations, as it is demonstrated in the observations, this is true.

6. CONCLUSION

A new point of view for the determination of the fire danger risk is analyzed in this study. A combination between two methods has been proved to develop a new danger index: the implementation of GIS software and a statistical model which is based on a multinomial logistic regression. This new danger index focuses on the forest stands instead of the borders of the different townships. In case of a wildfire, this fact entails a deeper definition of different danger levels due to its analysis of the zones which might be more dangerous than others.

This fire danger risk defines three different categories:

- Category 1: Low danger in yellow. It represents small wildfires whose size is generally less than one hectare.
- Category 2: Moderate danger in orange. It represents medium wildfires whose size is between 1 and 20 hectares.
- Category 3: High danger in red. It represents large wildfires whose size is generally more than 20 hectares.

This system was proved in two different townships: Mieza (Salamanca) and Barjas (León). It can be seen that different zones exist in a same township where the wildfire could be greater or not depending on different land uses, fuel models in each area, relative humidity and wind speed which occurred in that moment. This danger index is dynamic because it takes into consideration the weather conditions which are changing frequently. This model was developed with the factors considered in the fire reports and the information extracted from the GIS layers of forest map, fuel map and starting points of wildfires of the region of Castile and Leon. After the development of the multinomial logistic regression, it was determined that the variables with the most influence in the determination of the forecasted events were: relative humidity, wind speed, land use and fuel model. Favorable weather conditions (wind speed: 5 km/h and relative humidity: 65%) implemented for scenario 1 in both of the townships verified that, in case of a wildfire, the potential size of wildfires would be less than one hectare in all the zones for those townships. Nevertheless, with the implementation of hazardous weather conditions (wind speed: 40 km/h and relative humidity: 35%) different zones with different categories appear in each township. The most dangerous zones (wildfires larger than 20 hectares) were model 8 forests according to the fuel models described by Rothermel (Rothermel, R.C., 1972) and an FCC of more than 50%. It should be pointed out that the stands recognized with the model 4 and an FCC of more than 50% had a high probability of becoming a large wildfire. In the case of a wildfire, the areas with shrubs were usually foreseen as medium size and the areas with crops and pastures were forecasted as small.

A low level of accuracy regarding data collection and the absence of some data in many events implied that the predicted events may be less trustworthy. The high number of small wildfires and a low number of variables considered led to a low agreement between observed and predicted values. Due to this reason, it would be recommendable to implement more variables from other sources in future studies regarding the results obtained. New variables have to be preferably easy to obtain in order to simplify the method and facilitate its application. This danger index is based on occurred observations and it can be implemented in a DSS using formula and meteorological data programming in real-time. Their presentations can be displayed on maps in real-time in the different provincial command centers with the purpose of extinguishing wildfires and the planning of strategies against forest fires in more detail. This is due to the fact that it focuses on the different forest areas and not on the whole township. Differences in the determination of hazard inside township borders may be very big in some large townships where an extensive variety of vegetation exists. This integration will provide the DSS with more reliability in the predictions made by the simulators and in the traditional danger indexes. These danger indexes may determine zones with different danger risks. The low agreement between the predicted and observed values is due to the data used and factors taken into consideration. If more variables were implemented, the agreement could be higher. However, the results obtained allow us to determine different zones inside the townships which have different danger risks.

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Universidad de Valladolid
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ESCUELA TÉCNICA SUPERIOR
DE INGENIERÍAS AGRARIAS

Máster universitario en Ingeniería de Montes

DEVELOPMENT OF A DANGER INDEX OF FOREST FIRES BY USING MULTINOMIAL LOGISTIC REGRESSION AND ITS APPLICATION IN DIFFERENT ZONES OF THE REGION OF CASTILLA Y LEON (SPAIN)

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☐ Copia para el tutor

CONTENTS

Appendix 1. Table of the ignition probability (Vélez *et al.,* 2000)

Shady (%)	**Temperature dry termometer (ºC)**	**Moisture of the thin dead fuel (%)**															
		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
0-10	40+	100	100	90	80	70	60	50	40	40	30	30	30	20	20	20	10
	35-40	100	90	80	70	60	60	50	40	40	30	30	20	20	20	10	10
	30-35	100	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10
	25-30	100	90	80	70	60	50	40	40	30	30	20	20	20	20	10	10
	20-25	100	80	70	60	60	50	40	30	30	30	20	20	20	10	10	10
	15-20	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10	10
	10-15	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	5-10	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	0-5	90	70	60	60	50	40	40	30	30	20	20	20	10	10	10	10
10-50	40+	100	100	80	70	60	60	50	40	40	30	30	20	20	20	20	10
	35-40	100	90	80	70	60	50	50	40	40	30	30	20	20	20	10	10
	30-35	100	90	80	70	60	50	40	40	30	30	30	20	20	20	10	10
	25-30	100	90	80	70	50	50	40	30	30	30	20	20	20	10	10	10
	20-25	100	80	70	60	50	50	40	30	30	30	20	20	20	10	10	10
	15-20	90	80	70	60	50	50	40	30	30	20	20	20	20	10	10	10
	10-15	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	5-10	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	0-5	80	70	60	50	50	40	30	30	20	20	20	10	10	10	10	10
60-90	40+	100	90	80	70	60	50	50	40	40	30	30	20	20	20	10	10
	35-40	100	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10
	30-35	100	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10
	25-30	100	80	70	60	60	50	40	40	30	30	20	20	20	10	10	10
	20-25	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10	10
	15-20	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	10-15	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	5-10	90	70	60	50	50	40	30	30	30	20	20	20	10	10	10	10
	0-5	80	70	60	50	50	40	30	30	20	20	20	10	10	10	10	10
100	40+	100	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10
	35-40	100	90	80	70	60	50	40	40	30	30	20	20	20	20	10	10
	30-35	100	80	70	60	60	50	40	40	30	30	20	20	20	10	10	10
	25-30	90	80	80	60	50	50	40	30	30	30	20	20	20	10	10	10
	20-25	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	15-20	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	10-15	90	70	60	60	50	40	40	30	30	20	20	20	10	10	10	10
	5-10	80	70	60	50	50	40	30	30	20	20	20	10	10	10	10	10
	0-5	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10	10

Appendix 2. Types of alert

Table 1. Danger index implemented in Spain and interior zones (Vélez *et al.,* 2000)

Interior zones				
Ignition probability	**Normal winds**			
	Wind speed (km/h)			
	0 - 9	10 -19	20 - 39	≥ 40
10-20	Yellow alert	Yellow alert	Yellow alert	Yellow alert
20 - 50	Yellow alert	Orange alert	Orange alert	Orange alert
50 - 70	Red alert	Red alert	Red alert	Red alert
≥ 70	Red alert	Red alert	Red alert	Alarm

Table 2. Danger index implemented in coastal zones of Spain (Vélez *et al.,* 2000)

Coastal zones				
Ignition probability	**Land breezes**			
	Wind speed (km/h)			
	0 - 9	10-19	20 - 39	≥ 40
10-20	Yellow alert	Orange alert	Orange alert	Alarm
20 - 50	Orange alert	Red alert	Red alert	Alarm
50 - 70	Red alert	Red alert	Red alert	Alarm
≥ 70	Red alert	Alarm	Alarm	Alarm

The different states of alert and alarm represent the following indications:

Yellow alert:

- Low or moderate danger
- No special precautions

Orange alert:

- Moderate danger
- The firefighter teams are ready to be deployed.

Red alert

- High danger
- The preventative surveillance will be intensified
- The entrance to the forest zones will be limited
- The firefighter teams will be completely ready
- The population will be informed by media communication to adopt preventative measures.

Alarm

- Extreme danger
- Very high probability of many big fires.
- The secondary fires can appear because of incandescent wood pieces.
- Fire use is forbidden in adjacent zones of the forests (e.g. barbecues and so on).
- The forest roads will be cut off.
- The entrance to the forest zones will be very limited
- All the firefighter teams will be completely ready
- The population will be informed by media communication to adopt preventative measures.

Appendix 3. Fuel models (Anderson, 1982)

Fuel model	**Typical fuel complex**	**Fuel loading (tons/acre)**				**Fuel bed depth (feet)**	**Moisture of extinction dead fuels (percent)**
		1 hour	**10 hours**	**100 hours**	**Live**		
	Grass and grass-dominated						
1	short grass (1 foot)	0.74	0.00	0.00	0.00	1.0	12
2	Timber (grass and understory)	2.00	1.00	.50	.50	1.0	15
3	Tall grass (2.5 feet)	3.01	.00	.00	.00	2.5	25
	Chaparral and shrub fields						
4	Chaparral (6 feet)	5.01	4.01	2.00	5.01	6.0	20
5	Brush (2 feet)	1.00	.50	.00	2.00	2.0	20
6	Dormant brush, hardwood slash	1.50	2.50	2.00	.00	2.5	25
7	Southern rough	1.13	1.87	1.50	.37	2.5	40
	Timber litter						
8	Closed timber litter	1.50	1.00	2.50	0.00	0.2	30
9	Hardwood litter	2.92	41	.15	.00	0.2	25
10	Timber (litter and understory)	3.01	2.00	5.01	2.00	1.0	25
	Slash						
11	Light logging slash	1.50	4.51	5.51	0.00	1.0	15
12	Medium logging slash	4.01	14.03	16.53	.00	2.3	20
13	Heavy logging slash	7.01	23.04	28.05	.00	3.0	25

Appendix 4. Fuel models. Classification of the fire reports

FUEL MODELS	
Fuel model or combination	**Code**
Meadows	1
Shrubs	2
Forests	3
Wood residues	4
Meadows and shrubs	5
Meadows and forests	6
Meadows and wood residues	7
Shrubs and forests	8
Shrubs and wood residues	9
Forest and wood residues	10
Meadows, shrubs and forests	11
Meadows, shrubs and wood residues	12
Meadows, forests and wood residues	13
Shrubs, forests and wood residues	14
Meadows, shrubs, forests and wood residues	15

Appendix 5. Fuel models (Rothermel, 1972)

Grass fuel type

Consider using one of these fuel models from the new set...	... if you used one of these models from the original set.		
	1 Short Grass	2 Timber Grass and Understory	3 Tall Grass
GR1	For very sparse or heavily grazed grass; for lower spread rate and flame length		
GR2	For slightly lower spread rate and comparable flame length	For comparable spread rate and slightly lower flame length	
GR3			For lower spread rate and slightly lower flame length
GR4	For slightly lower spread rate and much higher flame length	For higher spread rate and slightly higher flame length	
GR5			For lower spread rate and slightly lower flame length
GR6			For slightly lower spread rate and comparable flame length
GR7	For comparable spread rate and significantly higher flame length	For much higher spread rate and flame length	For comparable spread rate and slightly higher flame length
GR8			For comparable spread rate and higher flame length
GR9			For higher spread rate and much higher flame length
GS1		For slightly lower spread rate and lower flame length	
GS2		For slightly lower spread rate and flame length	

Note: All grass fuel models from the new set are dynamic fuel models, which means that herbaceous load is transferred between live and dead categories according to live herbaceous moisture content. Original models 1 and 3 have only a dead component. Original fuel model 2 has a live herbaceous component but is static. Exact fire behavior comparisons between original and new grass models can only be made when live herbaceous moisture content is 30 percent or less. These comparisons were made with a live herbaceous moisture content of 60 percent (two-thirds cured).

Shrub fuel type

Consider using one of these fuel models from the new set...	... if you used one of these models from the original set.			
	4 Chaparral	5 Brush	6 Dormant Brush	7 Southern Rough
SH1		For lower spread rate and flame length	For lower spread rate and flame length	
SH2		For lower spread rate and slightly lower flame length	For lower spread rate and flame length	
SH3				For lower spread rate and flame length
SH4			For slightly lower spread rate and comparable flame length	For comparable spread rate and flame length
SH5	For slightly lower spread rate and flame length	For much higher spread rate and flame length		
SH6			For slightly lower spreadrate and higher flame length	For slightly lower spread rate and higher flame length
SH7	For slightly lower spread rate and flame length	For slightly higher spread rate and much higher flame length		
SH8				For slightly lower spread rate and higher flame length
SH9				For slightly higher spread rate and much higher flame length
TU5		For lower spread rate and slightly higher flame length		
GS2		For comparable spread rate and slightly lower flame length; with grass component		

Timber fuel type

Consider using one of these fuel models from the new set...	... if you used one of these models from the original set. 8 Compact Timber Litter	9 Hardwood Litter	10 Timber (Understory)
TL1	For lower spread rate and slightly lower flame length		
TL2		For lower spread rate and flame length	
TL3	For comparable spread rate and flame length		
TL4	For slightly higher spread rate and flame length		
TL5	For much higher spread rate and higher flame length		
TL6		For slightly lower spread rate and comparable flame length	
TL7	For slightly higher spread rate and higher flame length		
TL8		For slightly lower spread rate and slightly higher flame length	
TL9		For comparable spread rate and higher flame length	
TU1	For higher spread rate and flame length		For lower spread rate and flame length
TU2			For slightly higher spread rate and slightly lower flame length; high extinction moisture
TU3			For much higher spread rate and slightly higher flame length; high extinction moisture
TU4			For slightly higher spread rate and comparable flame length
TU5			For comparable spread rate and slightly higher flame length

Slash fuel type

Consider using one of these fuel models from the new set...	... if you used one of these models from the original set. 11 Light Logging Slash	12 Medium Logging Slash	13 Heavy Logging Slash
TL5	For slightly lower spread rate and flame length		
SB1	For comparable spread rate and flame length	For lower spread rate and flame length	
SB2	For much higher spread rate and higher flame length	For comparable spread rate and slightly lower flame length	For comparable spread rate and slightly lower flame length
SB3		For much higher spread rate and comparable flame length	For higher spread rate and comparable flame length
SB4			For significantly higher spread rate and slightly higher flame length

Appendix 6. Table of vegetation species values for the district of León

Value	Vegetal species
1	
2	*Quercus pyrenaica*
3	*Populus x canadensis*
4	*Pinus pinea*
5	*Populus nigra*
6	Salix sp
7	*Quercus ilex*
8	*Salix caprea*
9	*Pinus nigra*
10	*Populus alba*
11	*Pinus pinaster*
12	*Fagus sylvatica*
13	*Corylus avellana*
14	*Quercus petraea*
15	Tilia sp
16	*Quercus faginea*
17	*Pinus uncinata*
18	*Betula pubescens*
19	*Juniperus communis*
20	*Pinus sylvestris*
21	*Malus sylvestris*
22	Pastures
23	Betula sp
24	*Quercus robur*
25	*Picea abies*
26	*Sorbus aucuparia*
27	*Castanea sativa*
28	*Alnus glutinosa*
29	Sorbus sp
30	*Taxus baccata*
31	*Pseudotsuga menziesii*
32	*Myrtus communis*
33	*Fraxinus excelsior*
34	*Crataegus monogyna*
35	*Ilex aquifolium*
36	*Juniperus thurifera*
37	*Fraxinus angustifolia*

Value	Vegetal species
38	*Juniperus sabina*
39	Other coniferous
40	*Juniperus phoenicea*
41	Crops
42	*Juglans regia*
43	Shrubs
44	*Pinus radiata*
45	*Arbutus unedo*
46	*Salix atrocinerea*
47	Coniferous mix
48	*Cedrus atlantica*
49	*Eucalyptus mezcla*
50	*Salix alba*
51	*Salix elaeagnos*
52	*Prunus spinosa*
53	*Prunus avium*
54	*Quercus suber*
55	*Eucalyptus globulus*
56	*Juglans nigra*
57	Pinus sp
58	*Cupressus sempervirens*
59	*Ulmus minor*
60	*Cornus sanguinea*
61	*Acer pseudoplatanus*
62	Prunus sp

Appendix 7. Table of vegetation species values for the district of Salamanca

Value	Vegetal species
1	
2	*Quercus ilex*
3	*Quercus pyrenaica*
4	*Pinus sylvestris*
5	*Pinus pinaster*
6	*Castanea sativa*
7	*Betula pubescens*
8	*Alnus glutinosa*
9	*Salix* sp
10	*Populus nigra*
11	*Fraxinus angustifolia*
12	*Populus x canadensis*
13	Pastures
14	*Pinus pinea*
15	*Pinus nigra*
16	*Quercus suber*
17	Shrubs
18	*Pinus radiata*
19	*Eucalyptus camaldulensis*
20	Crops
21	*Arbutus unedo*
22	*Quercus faginea*
23	*Olea europaea*
24	*Celtis australis*
25	*Populus alba*
26	*Crataegus monogyna*
27	*Juniperus oxycedrus*
28	*Juniperus communis*
29	*Ulmus minor*
30	*Cupressus arizonica*
31	*Eucalyptus globulus*
32	*Acer campestre*
33	*Sorbus aucuparia*
34	*Prunus spinosa*
35	*Salix atrocinerea*

Appendix 8. Table of land uses values for the district of León

Value	Land use
1	3.3.5. Other deserts
2	3.1.4. Forest (FCC>=70%)
3	2.3. Meadow
4	2.0. Crops
5	3.1.3. Forest (FCC: 50-70%)
6	3.1.1. Forest (FCC: 5-20%)
7	1.1. Urban zones
8	3.1.2. Forest (FCC: 20-50%)
9	1.2. Roads
10	5.1. Inland waters
11	3.2.2. Shrubs
12	3.2.3. Pastures
13	1.3. Mineral extraction, dump and construction sites
14	4.1. Inland Wetlands
15	4.1.1. Meadows (Carrizales)
16	3.3.1. Rocky areas (hard rock compact)
17	3.3.2. Stones zones, gullies and ravines
18	3.2.1. Shrubs
19	3.3.4. Glaciers and perpetual snow

Appendix 9. Table of land uses values for the district of Salamanca

Value	Land use
1	4.1. Inland wetlands
2	2.0. Crops
3	3.2.3. Pastures
4	3.1.2. Forest (FCC: 20-50%)
5	3.1.3. Forest (FCC: 50-70%)
6	3.2.2. shrubs
7	3.1.4. Forest (FCC>=70%)
8	5.1. Inland waters
9	4.1.1. Meadows (Carrizales)
10	3.3.5. Other deserts
11	3.3.1. Rocky areas (hard rock compact)
12	3.1.1. Forest (FCC: 5-20%)
13	1.1. Urban zones
14	2.3. Meadows
15	1.3. Mineral extraction, dump and construction sites
16	3.3.2. Stony zones, gullies and ravines
17	1.2. Roads
19	1.4. Urban Green zones
20	3.2.1. Shrubs land
21	3.3.4. Glaciers and perpetual snow

Appendix 10. Data used in the multinomial logistic regression

Number of fire report	Days after the last rain	Maximum temperature	Relative humidity	Wind speed	Wind direction	Fuel model	Ignition probability	Total burned area	Value of land use	Value of vegetal species	Land use classes	Vegetal species class	Fuel Model classes
2007370001	11	14	50	5	150	8	30	0,05	7	3	6	3	3
2007370002	2	8	40	15	300	5	55	0,6	2	20	1	1	2
2007370003	3	8	35	15	300	5	50	0,9	3	17	1	2	2
2007370005	2	15	50	10	45	1	25	0,05	3	6	1	3	1
2007370008	3	15	35	26	225	5	50	0,2	3	5	1	4	2
2007370010	9	18	30	7	300	5	45	0,05	2	3	1	3	2
2007370017	21	8	60	5	225	4	32	0,07	2	3	1	3	4
2007370018	16	14	45	15	180	8	50	0,33	12	3	3	3	3
2007370022	1	18	52	8	45	4	21	0,06	4	5	4	4	4
2007370024	4	23	30	4	180	14	56	10,7	4	3	4	3	5
2007370230	14	29	40	10	360	2	50	0,05	2	5	1	4	2
2007370234	16	28	50	1	180	1	40	0,05	2	2	1	3	1
2007370278	15	18	40	10	180	9	35	0,2	6	19	2	6	3
2007370286	32	18	30	10	200	1	50	0,1	2	2	1	3	1
2007370291	25	13	30	2	250	9	40	0,58	14	6	1	3	3
2007370296	34	18	30	15	45	5	40	0,2	2	3	1	3	2
2007370299	34	15	30	15	45	2	40	0,6	3	3	1	3	2
2007370301	34	12	25	15	10	5	45	1,75	4	3	4	3	2
2007370302	34	8	40	15	45	5	30	0,05	2	2	1	3	2
2007370303	34	8	50	15	45	5	20	0,05	2	18	1	4	2

Number of fire report	Days after the last rain	Maximum temperature	Relative humidity	Wind speed	Wind direction	Fuel model	Ignition probability	Total burned area	Value of land use	Value of vegetal species	Land use classes	Vegetal species class	Fuel Model classes
2007370304	30	12	50	20	75	3	20	1	2	13	1	1	3
2007370305	54	10	43	25	225	8	30	0,84	4	2	4	3	3
2008370001	9	15	43	5	45	5	33	1	4	2	4	3	2
2008370006	30	16	60	15	90	8	30	8	5	11	5	5	3
2008370008	6	10	30	5	360	2	47	0,05	2	3	1	3	2
2008370009	20	18	50	1	90	5	50	0,05	2	13	1	1	2
2008370010	15	18	50	10	180	11	50	4,3	2	3	1	3	3
2008370012	11	17	50	15	90	12	40	2,9	6	3	2	3	4
2008370014	11	13	45	1	180	1	30	0,5	6	2	2	3	1
2008370019	14	18	50	15	90	1	30	4,3	3	3	1	3	1
2008370021	2	16	49	5	270	5	28	0,3	2	17	1	2	2
2008370023	6	11	45	14	360	1	29	1,5	3	3	1	3	1
2008370024	8	10	37	36	45	1	40	3,47	7	16	6	3	1
2008370027	10	15	40	30	270	2	40	0,76	2	5	1	4	2
2008370028	10	15	40	30	270	6	40	0,06	2	3	1	3	3
2008370029	8	18	45	30	360	8	40	0,6	14	5	1	4	3
2008370030	9	14	34	10	45	5	40	15	4	3	4	3	2
2008370038	6	12	10	5	360	5	36	0,86	2	6	1	3	2
2008370040	4	20	25	12	180	5	45	4,85	4	3	4	3	2
2008370043	3	15	70	1	360	1	28	0,06	3	2	1	3	1
2008370051	6	12	26	5	360	2	60	0,07	2	9	1	5	2
2008370054	6	24	26	8	180	2	62	6,31	6	3	2	3	2
2008370063	2	18	60	15	360	1	47	0,15	6	6	2	3	1

Number of fire report	Days after the last rain	Maximum temperature	Relative humidity	Wind speed	Wind direction	Fuel model	Ignition probability	Total burned area	Value of land use	Value of vegetal species	Land use classes	Vegetal species class	Fuel Model classes
2008370064	9	19	30	20	180	11	39	2	4	3	4	3	3
2008370065	10	18	34	14	180	2	50	0,5	7	3	6	3	2
2008370068	4	23	45	18	225	3	40	0,14	4	12	4	5	3
2008370069	3	25	40	10	360	1	63	0,06	7	3	6	3	1
2008370079	13	24	30	24	270	5	70	47,9	2	3	1	3	2
2008370088	21	30	35	15	180	1	90	1,32	2	3	1	3	1
2008370095	20	28	33	18	360	1	63	0,3	2	9	1	5	1
2008370097	30	30	35	10	360	1	69	4,4	2	22	1	3	1
2008370103	9	33	55	7	180	8	90	0,16	4	3	4	3	3
2008370104	7	18	24	5	180	2	84	0,07	2	5	1	4	2
2008370121	20	25	60	5	180	14	78	0,08	2	4	1	4	5
2008370138	30	38	15	5	180	5	75	0,25	4	13	4	1	2
2008370139	18	25	60	10	180	1	70	0,05	2	2	1	3	1
2008370141	19	24	30	6	270	1	70	0,65	2	3	1	3	1
2008370142	43	35	40	15	225	11	70	13	2	3	1	3	3
2008370148	40	30	20	25	270	11	63	1	2	3	1	3	3
2008370150	21	28	50	8	225	8	70	0,15	6	18	2	4	3
2008370155	40	31	50	10	270	2	70	0,1	2	3	1	3	2
2008370163	26	19	32	8	360	11	49	0,19	3	3	1	3	3
2008370168	30	22	50	5	360	5	55	0,32	2	6	1	3	2
2008370171	45	15	35	5	180	2	25	0,33	2	2	1	3	2
2008370184	39	27	30	5	180	5	50	0,2	2	3	1	3	2
2008370186	39	24	30	5	180	5	50	0,2	2	3	1	3	2

Number of fire report	Days after the last rain	Maximum temperature	Relative humidity	Wind speed	Wind direction	Fuel model	Ignition probability	Total burned area	Value of land use	Value of vegetal species	Land use classes	Vegetal species class	Fuel Model classes
2008370196	12	22	40	5	35	5	60	0,05	3	3	1	3	2
2008370202	0	20	50	5	90	1	60	0,05	2	2	1	3	1
2008370206	1	29	32	12	135	6	60	87,12	2	2	1	3	3
2008370207	14	25	35	25	180	15	57	17,6	2	3	1	3	5
2008370211	14	12	40	2	180	8	40	0,22	6	5	2	4	3
2008370229	5	20	50	15	180	1	80	0,06	6	3	2	3	1
2008370242	8	18	28	15	225	5	52	0,1	3	4	1	4	2
2008370248	4	15	35	5	360	5	50	0,05	12	3	3	3	2
2008370250	5	25	35	18	225	5	50	3,34	2	17	1	2	2
2008370265	20	18	60	15	45	1	45	0,76	2	2	1	3	1
2008370271	12	18	45	5	225	5	57	0,05	3	3	1	3	2
2008370279	15	15	40	5	180	1	30	0,05	6	3	2	3	1
2008370281	1	17	70	5	360	1	50	13,7	14	3	1	3	1
2008370291	3	22	60	10	225	6	45	9,28	6	3	2	3	3
2009370005	4	14	50	10	90	1	40	1,15	2	17	1	2	1
2009370012	10	20	70	6	315	5	15	19	2	3	1	3	2
2009370016	18	13	50	10	360	11	50	12	7	4	6	4	3
2009370020	20	15	37	2	360	1	45	0,3	3	3	1	3	1
2009370021	19	14	50	8	360	11	45	1,25	4	5	4	4	3
2009370025	19	16	47	8	225	2	21	3,04	4	16	4	3	2
2009370029	19	16	40	10	225	11	55	78	6	11	2	5	3
2009370033	22	12	40	3	225	5	30	0,05	4	3	4	3	2
2009370034	4	11	40	10	225	2	30	2,1	6	3	2	3	2

Number of fire report	Days after the last rain	Maximum temperature	Relative humidity	Wind speed	Wind direction	Fuel model	Ignition probability	Total burned area	Value of land use	Value of vegetal species	Land use classes	Vegetal species class	Fuel Model classes
2009370036	4	17	48	12	290	5	10	0,13	2	3	1	3	2
2009370037	6	18	40	5	315	11	50	15,11	4	3	4	3	3
2009370038	2	10	42	5	45	2	50	0,05	2	3	1	3	2
2009370040	8	21	33	10	135	5	50	0,36	2	2	1	3	2
2009370042	9	19	32	4	270	8	50	5,15	2	3	1	3	3
2009370045	6	23	28	5	360	8	56	2,5	2	3	1	3	3
2009370046	7	10	29	10	135	2	56	1,4	3	11	1	5	2
2009370047	10	16	28	2	360	5	60	1,25	3	13	1	1	2
2009370048	11	20	29	5	360	5	60	4,9	7	3	6	3	2
2009370049	10	15	27	5	270	11	57	6,78	2	3	1	3	3
2009370050	12	21	29	5	315	11	60	0,65	2	3	1	3	3
2009370051	15	16	40	2	180	1	55	0,27	2	2	1	3	1
2009370053	8	16	33	5	180	5	50	2,2	6	3	2	3	2
2009370054	12	12	35	6	180	2	50	0,07	6	3	2	3	2
2009370055	15	19	35	5	90	1	50	0,05	12	3	3	3	1
2009370056	14	20	31	5	360	5	50	0,65	6	3	2	3	2
2009370057	16	18	40	2	360	11	50	2,8	4	3	4	3	3
2009370059	13	20	33	10	270	2	45	0,34	4	3	4	3	2
2009370062	15	18	33	10	90	2	50	0,06	2	3	1	3	2
2009370063	14	10	30	5	360	2	50	0,5	2	3	1	3	2
2009370066	16	18	50	10	90	5	50	1	4	20	4	1	2
2009370071	15	20	50	15	45	15	76	0,9	2	13	1	1	5
2009370073	15	20	50	7	180	5	75	0,38	2	3	1	3	2

Number of fire report	Days after the last rain	Maximum temperature	Relative humidity	Wind speed	Wind direction	Fuel model	Ignition probability	Total burned area	Value of land use	Value of vegetal species	Land use classes	Vegetal species class	Fuel Model classes
2009370077	17	15	45	10	135	10	50	0,22	2	3	1	3	4
2009370078	15	22	30	5	360	1	70	0,43	2	3	1	3	1
2009370083	14	20	23	15	90	2	70	0,05	6	3	2	3	2
2009370086	11	18	23	5	90	5	70	0,5	6	3	2	3	2
2009370090	17	20	23	8	225	2	70	0,05	2	13	1	1	2
2009370091	11	10	23	5	270	5	70	2,76	2	3	1	3	2
2009370096	17	14	24	10	225	11	70	0,8	2	13	1	1	3
2009370101	24	18	37	20	90	1	26	0,06	5	3	5	3	1
2009370104	18	10	45	5	360	5	50	0,5	4	13	4	1	2
2009370105	20	15	24	5	45	8	57	1,68	2	3	1	3	3
2009370108	25	30	50	6	360	9	75	0,05	5	3	5	3	3
2009370110	44	14	29	16	360	1	26	0,05	4	20	4	1	1
2009370111	19	12	40	10	360	15	26	0,38	5	3	5	3	5
2009370115	22	25	22	12	225	5	75	2,34	5	3	5	3	2
2009370116	42	20	24	10	225	5	21	1	4	3	4	3	2
2009370118	24	13	30	15	45	5	25	12,48	7	3	6	3	2
2009370120	20	10	35	20	360	2	45	0,65	12	6	3	3	2
2009370121	22	14	50	45	360	5	15	0,08	3	16	1	3	2
2009370122	25	8	60	10	90	2	15	0,19	6	6	2	3	2
2009370126	25	12	30	15	360	6	38	0,42	3	3	1	3	3
2009370129	4	13	33	10	45	8	35	0,4	3	3	1	3	3
2009370133	31	17	38	6	360	2	40	0,5	2	3	1	3	2
2009370134	28	12	37	4	5	9	40	0,51	5	6	5	3	3

Number of fire report	Days after the last rain	Maximum temperature	Relative humidity	Wind speed	Wind direction	Fuel model	Ignition probability	Total burned area	Value of land use	Value of vegetal species	Land use classes	Vegetal species class	Fuel Model classes
2009370136	32	19	42	2	360	2	40	0,1	7	3	6	3	2
2009370137	5	14	36	5	180	1	40	0,48	2	3	1	3	1
2009370139	40	17	40	10	270	5	50	0,2	5	3	5	3	2
2009370140	27	13	36	8	180	2	50	0,73	2	3	1	3	2
2009370145	50	20	50	15	315	8	40	16,8	4	6	4	3	3
2009370150	30	15	38	5	360	9	40	0,05	7	3	6	3	3
2009370151	2	14	50	18	270	2	40	1,83	3	22	1	3	2
2009370152	4	15	30	10	180	11	40	2,01	2	3	1	3	3
2009370154	4	24	30	12	180	2	75	2,27	6	3	2	3	2
2009370156	2	20	20	20	360	11	60	2	5	3	5	3	3
2009370162	27	14	50	15	180	2	30	0,05	3	3	1	3	2
2009370170	2	22	40	6	135	1	35	0,05	2	10	1	5	1
2009370178	5	25	27	20	225	8	70	65,76	5	4	5	4	3
2009370179	15	20	30	10	180	1	75	0,05	2	3	1	3	1
2009370183	20	25	25	15	180	1	75	0,05	12	8	3	5	1
2009370189	4	31	22	0	315	1	75	0,07	2	12	1	5	1
2009370190	5	28	22	9	45	1	80	2	6	2	2	3	1
2009370191	5	25	22	5	270	1	80	1,5	3	2	1	3	1
2009370192	20	32	25	10	315	5	70	8,6	4	2	4	3	2
2009370193	20	24	30	10	315	1	33	0,05	3	3	1	3	1
2009370198	3	22	35	10	135	1	39	4,54	4	2	4	3	1
2009370199	7	27	27	4	360	1	35	2,5	4	3	4	3	1
2009370201	10	35	30	15	180	1	75	28,3	2	3	1	3	1

Number of fire report	Days after the last rain	Maximum temperature	Relative humidity	Wind speed	Wind direction	Fuel model	Ignition probability	Total burned area	Value of land use	Value of vegetal species	Land use classes	Vegetal species class	Fuel Model classes
2009370204	2	16	70	10	90	1	5	0,05	6	3	2	3	1
2009370206	1	30	34	6	270	1	70	0,05	2	3	1	3	1
2009370207	3	23	45	5	90	3	17	0,06	4	4	4	4	3
2009370209	7	22	60	10	45	6	33	0,5	7	12	6	5	3
2009370211	11	25	27	8	180	7	88	0,9	2	11	1	5	2
2009370217	2	30	60	6	360	1	60	0,1	2	6	1	3	1
2009370219	5	30	60	15	270	1	20	0,32	3	2	1	3	1
2009370221	4	32	32	20	270	11	63	1,1	4	3	4	3	3
2009370225	15	28	50	10	315	1	50	0,61	2	13	1	1	1
2009370228	16	25	40	5	45	5	21	0,07	2	13	1	1	2
2009370232	20	28	60	14	360	1	26	0,05	9	10	1	5	1
2009370233	20	34	37	18	360	1	75	2,22	2	2	1	3	1
2009370237	22	28	27	2	360	11	65	3,29	2	2	1	3	3
2009370238	44	34	30	20	225	2	35	3,95	3	28	1	2	2
2009370240	25	18	50	1	360	1	27	1,39	7	3	6	3	1
2009370241	20	34	29	5	180	5	69	0,1	7	6	6	3	2
2009370244	28	26	75	5	225	1	5	0,05	3	13	1	1	1
2009370249	9	28	25	25	360	1	80	0,05	3	5	1	4	1
2009370252	23	18	23	6	180	11	26	0,41	3	3	1	3	3
2009370253	23	18	23	6	180	11	26	0,1	3	5	1	4	3
2009370256	33	30	50	35	180	7	70	1	2	6	1	3	2
2009370257	20	32	28	9	180	2	70	0,15	3	22	1	3	2
2009370267	2	33	45	10	180	5	50	0,12	2	2	1	3	2

Number of fire report	Days after the last rain	Maximum temperature	Relative humidity	Wind speed	Wind direction	Fuel model	Ignition probability	Total burned area	Value of land use	Value of vegetal species	Land use classes	Vegetal species class	Fuel Model classes
2009370268	6	21	70	1	90	2	10	0,06	3	2	1	3	2
2009370271	40	30	51	5	225	5	30	0,31	2	3	1	3	2
2009370273	3	33	21	15	315	1	90	0,05	4	2	4	3	1
2009370274	7	32	30	3	90	3	30	0,05	2	3	1	3	3
2009370276	1	28	26	17	180	2	90	0,05	4	6	4	3	2
2009370282	5	33	27	5	270	1	70	0,05	6	3	2	3	1
2009370285	41	18	35	7	360	3	35	0,05	2	3	1	3	3
2009370286	25	18	55	10	90	1	27	1	2	2	1	3	1
2009370287	6	15	70	10	270	2	27	0,05	2	4	1	4	2
2009370289	0	20	90	10	225	6	25	0,05	7	3	6	3	3
2009370291	5	25	40	10	90	4	57	0,05	2	3	1	3	4
2009370292	4	30	10	5	180	8	55	5	2	2	1	3	3
2009370301	5	32	34	6	270	11	40	4,7	2	3	1	3	3
2009370302	7	36	29	6	225	11	63	111,2	2	3	1	3	3
2009370305	2	32	15	15	180	11	60	4	2	3	1	3	3
2009370307	10	35	24	20	225	7	75	0,1	2	3	1	3	2
2009370308	17	30	22	10	270	5	50	16,5	2	3	1	3	2
2009370311	3	33	18	8	270	5	75	11,72	2	3	1	3	2
2009370312	5	30	15	5	5	1	45	1,85	2	5	1	4	1
2009370315	15	35	25	24	270	1	55	3,65	4	3	4	3	1
2009370330	19	27	27	10	270	1	75	1,35	2	2	1	3	1
2009370332	19	30	30	12	315	2	70	0,07	2	3	1	3	2
2009370340	26	25	60	15	360	1	15	0,72	2	3	1	3	1

Number of fire report	Days after the last rain	Maximum temperature	Relative humidity	Wind speed	Wind direction	Fuel model	Ignition probability	Total burned area	Value of land use	Value of vegetal species	Land use classes	Vegetal species class	Fuel Model classes
2009370343	27	23	30	15	360	1	40	2,25	2	5	1	4	1
2009370344	21	20	45	12	360	8	20	4,36	9	2	1	3	3
2009370348	30	32	35	8	315	1	45	0,11	2	5	1	4	1
2009370349	25	28	40	7	360	15	75	1,14	7	3	6	3	5
2009370351	25	28	40	7	360	11	75	0,05	12	2	3	3	3
2009370354	25	34	40	4	270	5	75	0,3	7	5	6	4	2
2009370355	0	26	40	6	360	14	75	0,11	5	5	5	4	5
2009370356	0	34	35	4	270	2	75	0,48	6	3	2	3	2
2009370358	0	25	40	5	360	11	75	0,06	2	3	1	3	3
2009370359	0	35	35	4	270	8	75	0,29	2	3	1	3	3
2009370361	32	32	27	5	45	4	35	0,1	2	5	1	4	4
2009370362	1	28	40	5	270	15	15	0,05	5	5	5	4	5
2009370369	1	30	60	5	360	2	15	0,05	7	5	6	4	2
2009370372	2	15	40	30	90	5	5	2,02	2	3	1	3	2
2009370373	2	22	45	50	45	14	45	443	3	3	1	3	5
2009370375	2	15	60	10	135	5	16	0,25	4	20	4	1	2
2009370378	6	8	95	12	315	1	5	0,05	7	2	6	3	1
2009370379	8	12	95	1	315	1	5	0,3	4	3	4	3	1
2009370382	35	26	37	15	360	1	50	0,5	3	16	1	3	1
2009370385	46	23	34	7	360	1	65	0,27	3	3	1	3	1
2009370394	10	22	45	5	180	4	40	0,05	5	13	5	1	4
2009370396	1	20	40	5	270	1	50	0,05	6	3	2	3	1
2009370411	10	21	24	4	45	1	70	0,05	2	3	1	3	1

Number of fire report	Days after the last rain	Maximum temperature	Relative humidity	Wind speed	Wind direction	Fuel model	Ignition probability	Total burned area	Value of land use	Value of vegetal species	Land use classes	Vegetal species class	Fuel Model classes
2009370421	20	14	56	10	225	5	19	0,25	7	3	6	3	2
2009370427	2	12	60	10	225	1	30	0,25	2	3	1	3	1
2009370428	12	12	55	8	225	5	19	1,14	2	3	1	3	2
2009370430	20	7	60	17	90	2	30	5,53	5	3	5	3	2
2010370001	0	5	66	30	90	5	27	4,56	4	3	4	3	2
2010370004	15	15	60	10	360	5	40	0,55	2	3	1	3	2
2010370005	9	12	60	15	180	14	40	0,05	3	3	1	3	5
2010370009	7	18	50	2	225	7	45	0,2	7	3	6	3	2
2010370011	10	10	59	15	180	5	35	0,05	2	3	1	3	2
2010370012	11	16	74	15	180	2	25	0,9	2	11	1	5	2
2010370013	11	15	75	5	180	5	20	0,05	6	3	2	3	2
2010370014	2	18	52	7	270	8	47	0,39	2	6	1	3	3
2010370016	10	15	60	2	45	5	40	0,4	2	3	1	3	2
2010370020	2	32	40	5	90	1	43	0,1	2	6	1	3	1
2010370027	15	22	33	3	90	3	60	5,17	6	3	2	3	3
2010370036	9	22	31	6	135	11	70	0,1	6	6	2	3	3
2010370045	2	22	50	8	360	1	47	0,25	2	3	1	3	1
2010370047	2	17	30	10	45	5	60	0,08	5	2	5	3	2
2010370051	8	25	29	10	360	1	80	1,27	2	12	1	5	1
2010370053	60	33	5	5	360	1	70	13,55	2	3	1	3	1
2010370054	19	35	18	12	360	11	60	0,2	2	5	1	4	3
2010370062	4	28	45	7	180	1	90	1,5	4	3	4	3	1
2010370066	7	19	32	7	180	1	60	0,06	6	19	2	6	1

Number of fire report	Days after the last rain	Maximum temperature	Relative humidity	Wind speed	Wind direction	Fuel model	Ignition probability	Total burned area	Value of land use	Value of vegetal species	Land use classes	Vegetal species class	Fuel Model classes
2010370070	2	34	30	10	90	1	80	0,1	2	2	1	3	1
2010370071	20	38	32	1	180	1	80	12,39	2	2	1	3	1
2010370076	7	38	28	5	290	5	80	0,13	2	8	1	5	2
2010370085	10	29	34	12	360	1	70	0,1	5	2	5	3	1
2010370086	15	30	34	19	270	11	70	2,6	6	5	2	4	3
2010370098	27	22	34	5	180	5	50	0,23	6	2	2	3	2
2010370104	30	37	5	4	180	1	80	0,53	2	12	1	5	1
2010370105	29	27	24	4	360	5	80	2,18	2	2	1	3	2
2010370106	20	30	22	10	360	11	90	50	6	22	2	3	3
2010370125	37	32	29	19	45	1	60	0,16	2	2	1	3	1
2010370139	25	21	10	10	315	1	70	0,25	14	6	1	3	1
2010370141	3	38	20	25	360	1	60	0,1	2	3	1	3	1
2010370148	4	25	35	4	360	1	60	0,45	2	11	1	5	1
2010370159	9	31	30	5	360	1	60	0,07	2	3	1	3	1
2010370161	52	32	45	1	180	8	40	0,06	5	3	5	3	3
2010370177	10	28	40	15	135	7	70	0,05	6	3	2	3	2
2010370189	64	29	26	5	315	5	70	0,33	2	2	1	3	2
2010370191	65	25	25	10	45	1	90	0,13	2	3	1	3	1
2010370195	1	18	49	10	180	1	40	0,05	2	5	1	4	1
2010370198	1	20	44	3	270	3	40	0,05	2	2	1	3	3
2010370202	4	26	30	4	360	1	60	0,05	4	2	4	3	1
2010370218	15	34	22	8	180	1	50	1,8	2	2	1	3	1
2010370226	12	13	34	18	45	5	40	3,11	3	2	1	3	2

Number of fire report	Days after the last rain	Maximum temperature	Relative humidity	Wind speed	Wind direction	Fuel model	Ignition probability	Total burned area	Value of land use	Value of vegetal species	Land use classes	Vegetal species class	Fuel Model classes
2010370228	13	18	34	6	90	8	50	0,05	7	3	6	3	3
2010370229	14	20	14	10	225	1	40	0,15	2	6	1	3	1
2010370240	7	19	41	9	360	5	50	1,78	7	3	6	3	2
2010370242	16	15	37	10	360	1	40	2,69	7	3	6	3	1
2010370243	16	16	40	15	360	11	50	4,6	4	2	4	3	3
2010370261	15	6	40	5	360	1	20	0,07	2	3	1	3	1
2011370001	20	0	48	5	90	2	20	102,63	7	3	6	3	2
2011370002	20	0	46	6	90	2	20	47,9	7	3	6	3	2
2011370007	10	14	60	1	45	7	30	1,08	12	6	3	3	2
2011370013	3	6	50	3	45	7	30	0,07	7	3	6	3	2
2011370015	20	4	41	12	45	6	20	0,95	7	14	6	4	3
2011370018	3	16	45	20	270	6	30	0,11	6	3	2	3	3
2011370019	0	18	37	8	315	1	40	0,48	7	3	6	3	1
2011370026	8	18	34	9	360	5	30	1,52	2	5	1	4	2
2011370031	3	10	80	13	45	1	20	0,05	6	6	2	3	1
2011370033	4	21	33	10	360	1	60	0,07	14	3	1	3	1
2011370034	4	26	33	5	360	4	60	0,76	14	3	1	3	4
2011370036	9	16	41	26	360	8	50	12,15	14	3	1	3	3
2011370037	8	24	28	20	45	14	60	27,5	7	19	6	6	5
2011370051	2	26	23	20	45	1	90	0,08	3	2	1	3	1
2011370054	1	15	20	5	270	11	60	0,05	3	2	1	3	3
2011370063	10	26	40	8	180	1	60	0,05	2	2	1	3	1
2011370068	10	29	27	10	270	1	80	5,1	2	3	1	3	1

Number of fire report	Days after the last rain	Maximum temperature	Relative humidity	Wind speed	Wind direction	Fuel model	Ignition probability	Total burned area	Value of land use	Value of vegetal species	Land use classes	Vegetal species class	Fuel Model classes
2011370080	22	29	34	25	45	1	60	0,68	12	5	3	4	1
2011370084	34	33	21	20	225	1	60	12,55	3	2	1	3	1
2011370090	28	30	26	20	45	6	60	18,31	2	2	1	3	3
2011370094	30	22	57	10	270	1	30	2,76	7	3	6	3	1
2011370097	34	31	23	15	270	1	70	4,2	6	3	2	3	1
2011370100	40	26	30	12	360	1	60	4,45	5	2	5	3	1
2011370112	43	30	27	10	360	2	80	0,17	5	3	5	3	2
2011370121	10	11	10	15	90	5	30	5,4	2	3	1	3	2
2011370123	40	21	55	2	225	1	70	1,8	2	6	1	3	1
2011370131	25	23	20	1	225	1	80	0,8	7	2	6	3	1
2011370133	17	29	25	6	315	1	60	6,9	4	2	4	3	1
2011370138	1	25	46	8	180	1	40	0,05	2	20	1	1	1
2011370142	2	26	35	3	360	1	60	0,05	3	2	1	3	1
2011370160	12	23	48	13	315	5	50	1,68	3	3	1	3	2
2011370161	12	34	30	10	270	1	40	3,31	2	3	1	3	1
2011370162	1	20	99	5	270	5	40	0,05	2	2	1	3	2
2011370167	3	25	33	1	180	5	70	0,05	12	2	3	3	2
2011370175	8	22	35	7	225	1	50	0,1	2	8	1	5	1
2011370177	8	33	30	10	225	2	60	0,15	2	2	1	3	2
2011370180	1	28	37	13	225	3	40	0,05	2	3	1	3	3
2011370181	2	24	44	15	315	1	20	1,3	2	3	1	3	1
2011370186	2	28	27	20	180	8	50	0,22	6	3	2	3	3
2011370192	5	28	33	30	135	12	50	5,3	2	3	1	3	4

Number of fire report	Days after the last rain	Maximum temperature	Relative humidity	Wind speed	Wind direction	Fuel model	Ignition probability	Total burned area	Value of land use	Value of vegetal species	Land use classes	Vegetal species class	Fuel Model classes
2011370197	1	20	51	9	180	1	40	0,05	2	2	1	3	1
2011370200	11	13	68	5	360	1	20	0,25	2	22	1	3	1
2011370205	57	32	22	7	315	1	80	0,05	5	2	5	3	1
2011370209	11	28	35	6	360	6	60	0,1	2	3	1	3	3
2011370216	10	20	24	10	225	5	70	0,25	2	2	1	3	2
2011370228	20	20	24	8	45	8	70	0,16	2	3	1	3	3
2011370233	20	23	30	10	225	1	40	0,05	2	2	1	3	1
2011370241	56	10	60	2	180	1	60	0,25	2	2	1	3	1
2011370244	70	30	19	2	45	1	70	4,5	2	9	1	5	1
2011370264	35	15	5	35	90	5	21	8	3	3	1	3	2
2011370267	63	22	34	12	45	1	50	4,5	9	6	1	3	1
2011370274	40	17	26	4	360	1	60	2,05	4	2	4	3	1
2011370282	60	12	17	1	90	1	80	1,3	2	2	1	3	1
2011370283	56	30	19	10	45	1	60	5,8	2	2	1	3	1
2011370290	45	24	16	5	180	1	80	0,06	9	9	1	5	1
2011370293	48	15	17	3	180	5	70	0,92	9	3	1	3	2
2011370294	20	25	8	10	315	1	50	0,2	2	21	1	2	1
2011370295	20	10	31	15	315	1	50	2,5	7	2	6	3	1
2011370299	20	22	33	5	225	1	40	0,77	12	12	3	5	1
2011370309	7	20	50	5	180	2	20	0,92	2	2	1	3	2
2011370313	30	15	54	5	90	2	20	0,6	2	3	1	3	2