

Practical Application of a Daily Prediction Model for the Occurrence of Human-Caused Forest Fires in Catalonia¹

Cristina Vega-García,² Christian Ortiz Ruiz,² Raquel Canet Castellà,³ Inés Sánchez Bosch,² Daniel Queralt Creus²

Abstract:

A study was conducted in 2002 with the aim of defining and analysing, both spatially and temporally, meteorological, topographic, socio-demographic and vegetation conditions which might be linked to the occurrence of forest fires caused by humans in Catalonia in Spain, by integrating them into a GIS.

Based these analyses, various daily prediction models were developed for human caused fires. All of them predicted occurrences in binary values (yes/no) in the 10 km² grid generally employed by various government bodies in Spain with responsibility for fire prevention and suppression. The best of these models, a statistically based logit model, was evaluated in an operative manner during the summer of 2003, once the process for generating a daily prediction map before 8:00 am had been automated.

This paper presents the modelling process, the testing of the models and the advantages and disadvantages of applying the model to the daily prediction of forest fires.

Keywords: fire occurrence prediction, Spain, logit.

Introduction

The aim of this study was to define and analyse, both spatially and temporally, meteorological, topographic, socio-demographic and vegetation conditions which might be linked to the occurrence of forest fires caused by humans in Catalonia in Spain, by integrating them into a GIS.

The analysis variables thus generated, together with the historical fire data, made it possible to construct and evaluate a daily prediction model for human caused fires, which would be operatively tested in the subsequent summer campaign. The system had to be able to predict the daily number of fires in the 10 x 10 km squares routinely employed by several government agencies such as the Forest Fire Department of the Directorate-General of Nature Conservancy (DGNC), The Environment Ministry and the Forest Fire Section of the Directorate-General of Emergencies and Civil Protection (DGECP) of the Catalanian Regional Government.

¹ An abbreviated version of this paper was presented at the second international symposium on fire economics, planning, and policy: a global view, 19–22 April, 2004, Córdoba, Spain.

² Dept. d'Enginyeria Agroforestal, ETS d'Enginyeria Agrària, Universitat de Lleida, Av. Alcalde Rovira Roure, 191 25198 Lleida, Spain email: cvega@eagrof.udl.es.

³ Secció d'Incendis Forestals. Direcció General d'Emergències i Seguretat Civil. Departament d'Interior. Generalitat de Catalunya. Ctra. de la Universitat Autònoma s/n, 08290 Cerdanyola del Vallès, Barcelona, Spain.

The stated goals for the trials of the model included evaluating the technical difficulty of setting the model up, the necessary sources of data, the personnel requirements and the qualifications required for these people, and an assessment of its practical worth in the day-to-day work of the Catalanian Government's Fire Brigades.

Methods

The area chosen for the study was Catalonia, which already possessed fuel model maps (by Vélez Muñoz, 2000) before the project commenced, i.e. in the provinces of Barcelona and Gerona, as well as part of the provinces of Tarragona and Lérida (*fig. 1*).

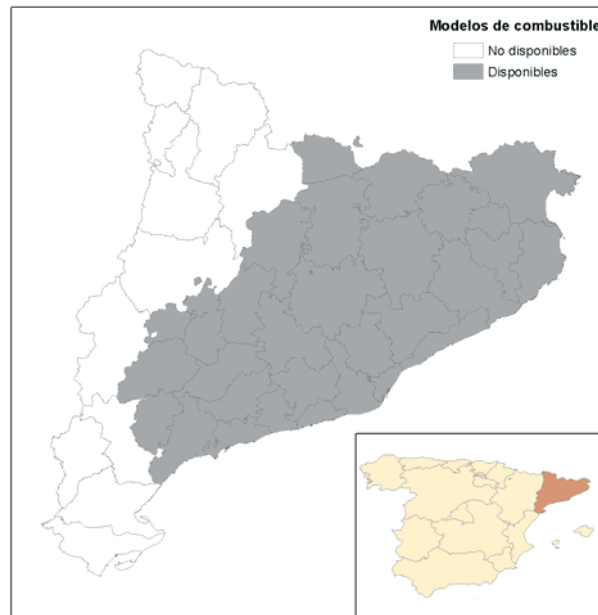


Figure 1 – Local areas in Catalonia with fuel models available for the project.

The layers available for analysis in GIS format were obtained from the Catalonia Cartographic Institute and the Environment Department of the Catalanian Government, and included road networks, railways, power lines, urban centres, housing developments, and protected zones at 1:50,000 scale, and a digital terrain data model at 45 m resolution, all digitalised in 1994. All these cartographic sources were drawn upon to generate new gridded and raster layers for the corresponding 10 km x 10 km prediction squares (348). These newly-created layers made it possible to draw up the geographical analysis variables listed in *table 1*.

Table 1—*Geographic analysis variables.*

Name	Description	Units
Elevation	Average elevation for the square taken from a 50 metre Digital Terrain Model	Metres
Class-O1,O2,O3,O4,O5	Orientation in the square Flat North East South West	Percent of surface area occupied by each class. During the analysis stage, Class 1 (flat) was considered to be the same as south (Class 4)
Class-P1,P2,P3,P4	Surface occupied by one of the following categories of slope 0-5% 5-15% 15-30% >30%	Percent of surface occupied by each category
Roads1	Average distance per square to motorways and principal roads.	Metres
Roads2	Average distance per square to asphalt roads (not taking into account motorways and principal roads)	Metres
Roads3	Average distance per square to unsurfaced roads, these considered to be earth roads and paths	Metres
Rail	Average distance per square to railway lines	Metres
Powli	Average distance per square to power lines	Metres
Housdev	Average distance per square to housing developments	Metres
Urbcent	Average distance per square to urban centres	Metres
P-SNV	Surface occupied by a Protected area of Special Natural Value-	Percent of occupied surface
Mod2,mod3,mod4,mod5,mod6,mod7,mod8,mod9,mod10	Surface occupied by each fuel model	Percent of surface occupied by each model

Eighty-four of the automatic stations operated by the Catalonia Meteorological Service and the Catalonia Agrometeorological Network were used to gather the daily meteorological variables over a five-year period from 1996 to 2000, not too long after the raster layers were digitalised. The daily variables taken into account included the usual meteorological parameters, such as relative humidity, precipitation, temperature, wind, but also some danger ratings such as the DGNC⁴'s probability of ignition index, the Canadian Fire Weather Index (Van Wagner 1987), the Keetch-Byram Drought Index (Keetch and Byram, 1988) and the intensity of potential solar radiation as developed by Volk (1997) in each 10 x 10 km cell. The calculation and spatial interpolation of all these variables was only carried out during

⁴ Según apuntes del Curso Básico de Defensa contra Incendios Forestales organizado por el Colegio de Ingenieros de Montes de España.

each year's summer campaign during the five-year period, which, in Spain, runs from 15th May to 15th September. The variables are set out in *table 2*.

Table 2— *Meteorological analysis variables.*

Name	Description	Units
Intensity	Intensity of potential solar radiation - Volk	mm
P24	Precipitation in 24 hr, daily	10 ⁻¹ mm
Taverage	Average daily temperature	Degrees centigrade
RHaverage	Average daily relative humidity	Percent, 0-100%
WSaverage	Average wind speed each day	m/s
WDaverage	Average wind direction	Degrees
Tmax	Maximum daily temperature	Degrees centigrade
RHmin	Minimum relative humidity each day	Percent, 0-100%
WSmax	Maximum daily wind speed	m/s
PWS	Peak Wind Speed	m/s
SD	Standard deviation of wind	Degrees
RadG	Real solar radiation at the station	mj/m ²
FWI	Fire Weather Index	Open-ended, 0 to +100
KBDI	Keetch-Byram Drought Index	Scale 0-800
PDFM	Fine dead fuel moisture, The DGNC's probability of ignition	Percent, 0-100%

The forest fire database for 1996 to 2000 needed rasterizing and relating to the 10 x 10 km square, which defined the prediction units. From an overall available total of 3,310 forest fires including verified location and causes, 1,600 were caused by humans in the summer campaigns between 1996 and 2000. However, the removal of incomplete observations following the cross-referencing of all the geographic and meteorological databases associated with the prediction cells produced a database with 36,190 daily observations in 348 squares over a five-year period, with 43 fields (variables) associated with each observation, of which 35,896 did not include forest fires and only 294 were witness to fires.

An analysis of the small number of occurrences in the squares indicated that it would not be possible to develop models, as originally intended, to predict the number of occurrences in each prediction cell and day due to a lack of data. There were only 10 cases of 2 fires/day square and 2 cases of 4 fires fires/day square in a database containing 36,190 items of data. This even led to the rejection of appropriate statistical models for rare events such as the Poisson distribution, and made it necessary to consider binary response models, such as the logit model, which others had previously used in forest fire prediction (Martell et al. 1987, Chou et al. 1993, Loftsgaarden and Andrews 1992, Vega-García et al. 1995). The evaluation of logit models in fire prediction (yes / no in a particular cell and day) in our own Mediterranean area was one of the specific goals of this project.

The logit models were developed in accordance with the recommendations of Hosmer and Lemeshow (1989) and Cox and Snell (1989), after generating a database which was smaller and more balanced in respect of the dependent variable by means of the random removal of 294 observations with no forest fire, which were brought together with the 294 observations which did include fires, in a similar way to the study by Vega-García et al. (1995). One of the advantages of the logit model is that it is possible to create equilibrium between the proportions of the dependent variable

(forest fire yes / no) within the observations employed to create models. It then becomes possible to create models which are equally effective in predicting occurrences and non-occurrences, and which can subsequently be applied to the real world (where the non-occurrences are much more common) by means of a simple transformation of the independent variable (Maddala 1988, Prentice 1986). The 598 observations were, at the same time, randomly combined and 117 (20 percent) were separated out in order to validate the models.

Different logarithmic regression models were calculated using automatic procedures (stepwise, backward elimination, forward selection) and the SAS v8.2 program (SAS Institute Inc. 1999), although steps were also taken to evaluate models employing subsets of non-correlated variables in order to avoid causing multicollinearity problems in the models. The analyses placed particular emphasis on evaluating the contribution of the various danger indices to the prediction, as a means of comparing the performance of the indices. An attempt was also made to find models which were relatively simple, both with respect to the number of variables and the ease of calculation of variables, i.e. models which were easy to set up for practical use.

Rather than selecting the best model on the basis of one sole criterion, an analysis was conducted of all the possible criteria of goodness of fit, predictive capacity, coefficients and residuals.

The model selected for testing in real situations during the summer of 2003 was validated with the 117 data which had not been used in building the model, and which had previously been segregated from the reduced database. However, the data in the full database of 36,190 was also evaluated in proportionately real-life conditions.

In order to implement the model in operative conditions, the daily calculations were automated by AML, the programming language created by ArcInfo (ESRI 2002). This was responsible for performing the necessary tasks of interpolation and map algebra, as well as generating a JPG file available on an Intranet before 8:00 am each morning between 1st August and 15th September 2003. Qualified personnel were asked to evaluate the daily occurrence probability map and to give their subjective opinion each day throughout this period, stating whether or not they felt the predictions were correct. At the end of the period in question, all the statistical data on forest fires occurring during that time were assembled and used to conduct a statistical test of the predictive ability of the model by means of a classification table similar to that used in validating the model.

Results

The statistical analyses of the 43 variables naturally produced high correlations between the risk indices and the variables with which they were calculated, but this was also the case between various geographic variables.

The average and maximum values for the meteorological variables were highly correlated, as was to be expected (>85 percent). This was also true for relative humidity and temperature, albeit negatively (around -60 percent). The RadG variable was positively correlated to the FDFM index (45 percent), to Intensity (30 percent) and to Tmax (35 percent), and negatively correlated with P24 (-40 percent), RHmin (-44 percent) and RHaverage (-41 percent).

The Canadian FWI index presented only a slight linear relation with the other variables, a positive figure of around 20 percent with FDFM, KBDI, Tmax, and a negative correlation with RHmin, also at around 20 percent. It should be borne in mind that the calculation requirements for this variable, added to the relative lack of continuity in the meteorological data from automatic weather stations produced a large number of zeros in the database.

The KBDI index showed positive correlations with Taverage and Tmax (59 percent y 57 percent) and negative correlations with RHaverage and RHmin (-30 percent and -29 percent). The correlations with other indices were low, at 20 and 23 percent respectively for the FWI and FDFM. These data were consistent with its original development as a risk index based on the state of the duff on the ground, rather than the fine dead fuels in the DGNC's index (FDFM). The KBDI is defined as a number which represents the net effect of evapotranspiration and precipitation in producing cumulative moisture deficiency in the deep duff or upper soil layers.

The DGNC's FDFM showed a high negative association with RHmin (-91 percent) and RHaverage (-81 percent), and a positive correlation with temperature (Tmax, 60 percent, Taverage, 37 percent), which appear to indicate that this index responds better, or more swiftly, to the most extreme daily conditions, as would be expected from the response of fine dead fuel. If one takes the degree of exposure of the fuels and cloud cover into account, positive correlations are the found with the intensity of potential solar radiation (24 percent) and RadG (45 percent).

Turning to the geographical variables, the slope categories clearly showed the effects of elevation, the lower categories being negatively correlated to elevation (-46 percent) and the upper categories positively correlated (68 percent).

Housing developments, power lines, railways and roads, which are usually concentrated in specific areas of terrain such as valley floors, also showed positive correlations amongst themselves. The percentage of protected areas of Special Natural Value showed positive correlations with elevation (39 percent), steep slopes (77 percent) and proximity to centres of population (47 percent), which reflects the true situation in this area. The correlations for fuel models suggested a relative degree of independence with respect to the other variables and amongst themselves. The only correlations worthy of note are those between model 2 for grazing and elevation (62 percent), steep slopes (54 percent) and Protected Areas of Special Natural Value (35 percent), and those for model 8 for forests with steep slopes (58 percent), Protected Areas of Special Natural Value (56 percent) and elevation (56 percent). Both models were correlated amongst themselves at 53 percent. The majority of the fuel models showed slightly negative correlations with gentle slopes and slightly positive correlations with the steep slopes, which reflects the fact that the vegetation in the study area has been relegated to the worst sites by other, more productive uses of the land.

The use of automated and manual procedures to build models led to several which offered a good predictive capacity.

The best logit model selected by automatic procedures included the following variables: Elevation, percentage of surface area with slope between 0 and 5%, percentage of surface facing east, radiation intensity, RadG, FWI and KBDI. Although the overall percentage which it predicted correctly was 74.7 percent, the model was not considered satisfactory for several reasons. The negative value for the FWI variable did not coincide with expectations based on its physical meaning, given

that the value should actually increase in step with the fire risk. Furthermore, the selected variables would require relatively complex daily calculations and continuity from the meteorological data, which cannot be guaranteed.

The building of models related to the risk indices showed the DGNC's probability of ignition index, FDFM, to enjoy a predictive capacity which was apparently superior to that of the KBDI and FWI. Models which depended exclusively on these indices (together with a constant) correctly predicted 61.1 percent of the observations for the FDFM, 59.7 percent for the KBDI and only 50.5 percent for the FWI. Use of the FDFM index with Elevation provided a correct prediction rate of 67.7 percent of the observations. Adding proximity to power lines (powli) and wind speed (Wsaverage) pushed the performance of the model up to 68.6 percent.

The weakly related subsets which had been selected manually led to the creation of two interesting models. One model consisted solely of the Tmax and average elevation of the square, and was capable of correctly predicting 70.5 percent of the observations. When brushwood fuel models (models 4, 5 and 6) were incorporated into the model, the value rose to 73 percent, although this would mean incorporating 3 variables which might be difficult to update in real situations.

In view of the (meaningful) statistical data, the robust nature of this particular model and the limited amount of data input, as well as the foreseeable updating of forest maps which can be converted to fuel maps, this model was considered to be the best. The formulation, statistics and classification table are presented in *table 3*. Tests using data which had not been used in building the model also resulted in a correct prediction rate of 73.5 percent of the validation observations.

Table 3—*Formulation and classification table for the best prediction model for human caused forest fires.*

$$P(Y=1) = \text{Exp}(Z_i) / (1 + \text{Exp}(Z_i)), \text{ where}$$

$P(Y=1)$ is the likelihood of the occurrence of at least one forest fire in one cell and day

$$Z_i = 0.1294 * \text{TMAX} + 0.0577 * \text{MOD4} + 0.0136 * \text{MOD5} + 0.0162 * \text{MOD6} - 0.0032 * \text{ELEVINT} - 2.9845$$

Association of Predicted Probabilities and Observed Responses										Analysis of Maximum Likelihood Estimates					
										Standard Wald					
										Parameter	DF	Estimate	Error	Chi-Square	Pr > ChiSq
Percent Concordant	79.3		Somers' D		0.588					Intercept	1	-2.9845	0.7454	16.033	<.0001
Percent Discordant	20.5		Gamma		0.589					ELEVINT	1	-0.00320	0.000618	26.781	<.0001
Percent Tied	0.2		Tau-a		0.294					TMAX	1	0.1294	0.0255	25.721	<.0001
Pairs	55448		c		0.794					MOD4	1	0.0577	0.0151	14.638	0.0001
Classification Table															
Correct		Incorrect			Percentages										
Prob	Non-	Non-			Sensi-	Speci-	False	False							
Level	Event	Event	Event	Event	tivity	ficity	POS	NEG							
0.450	192	143	96	40	71.1	82.8	59.8	33.3	21.9	MOD5	1	0.0136	0.0160	7.233	0.0395
0.500	184	160	79	48	73.0	79.3	66.9	30.0	23.1	MOD6	1	0.0162	0.0129	15.837	0.0208
0.550	164	175	64	68	72.0	70.7	73.2	28.1	28.0						

Application of this model to real validation data from 1996, 1997, 1998, 1999 and 2000, i.e., to all the available data, produced an overall rate of precision of 70.3 percent, 72.3 percent, 62.2 percent, 67.6 percent and 77.5 percent respectively, although the percentage of correct predictions of forest fires in these years was 80.8 percent, 81.0 percent, 72.3 percent, 83.3 percent and 33.3 percent of the observations. It should be borne in mind that the data available in 2000 was extremely limited and

fragmented due to problems with the automatic weather station network, consisting of no more than 1,164 observations, of which 3 were forest fires.

Once this particular model had been selected, it was fully tested on a day-to-day basis at the headquarters of the Catalanian Regional Government's Directorate-General of Emergencies and Civil Protection (DGECP), where the necessary programs were developed to carry out the daily automatic computation of the probability maps for the occurrence of forest fires and the task of disseminating them on the Directorate-General's Intranet.

Given that the chosen model employed a small number of variables, it was only necessary, from a technical point of view, to use the digital maps for: a) a 10 x 10 km square, b) elevations and c) fuel⁵ which were already available (*fig. 2, fig. 3 and fig. 4*). The main difficulty consisted of the need to acquire a daily map of predicted maximum temperatures (Tmax) for the study area, to be combined with these other maps by means of the logit model and to generate a map of probability values between 0 and 1 which would could be transformed into map showing those areas where a forest fire was unlikely that day ($p < 0.5$), and those areas where there probably would be a fire ($p > 0.5$). The reliability of the prediction for the following day would obviously depend at all times on the precision with which it was possible to predict the Tmax variable.

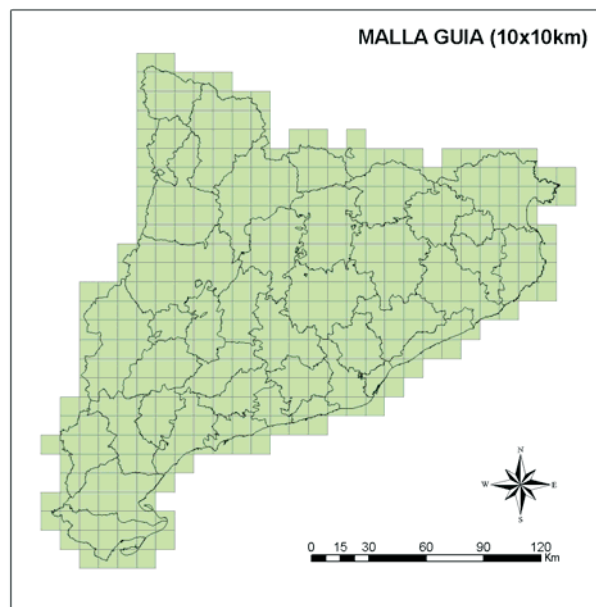


Figure 2— Regular 10 x 10km grid used to calculate the probability of forest fire ignition through human causes, including the local municipal areas within Catalonia.

⁵ Cabe destacar que en el momento de la redacción del presente documento (tres años después de la construcción del modelo) ya estaban disponibles los mapas de combustibles para toda Cataluña, como se refleja en la *Fig. 4*.

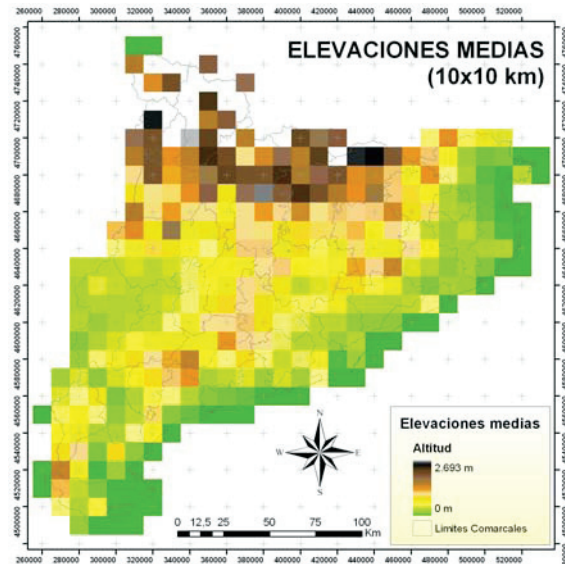


Figure 3—Map showing the average elevation in each cell of the 10x10 km grid, used for calculating the probability of ignition.

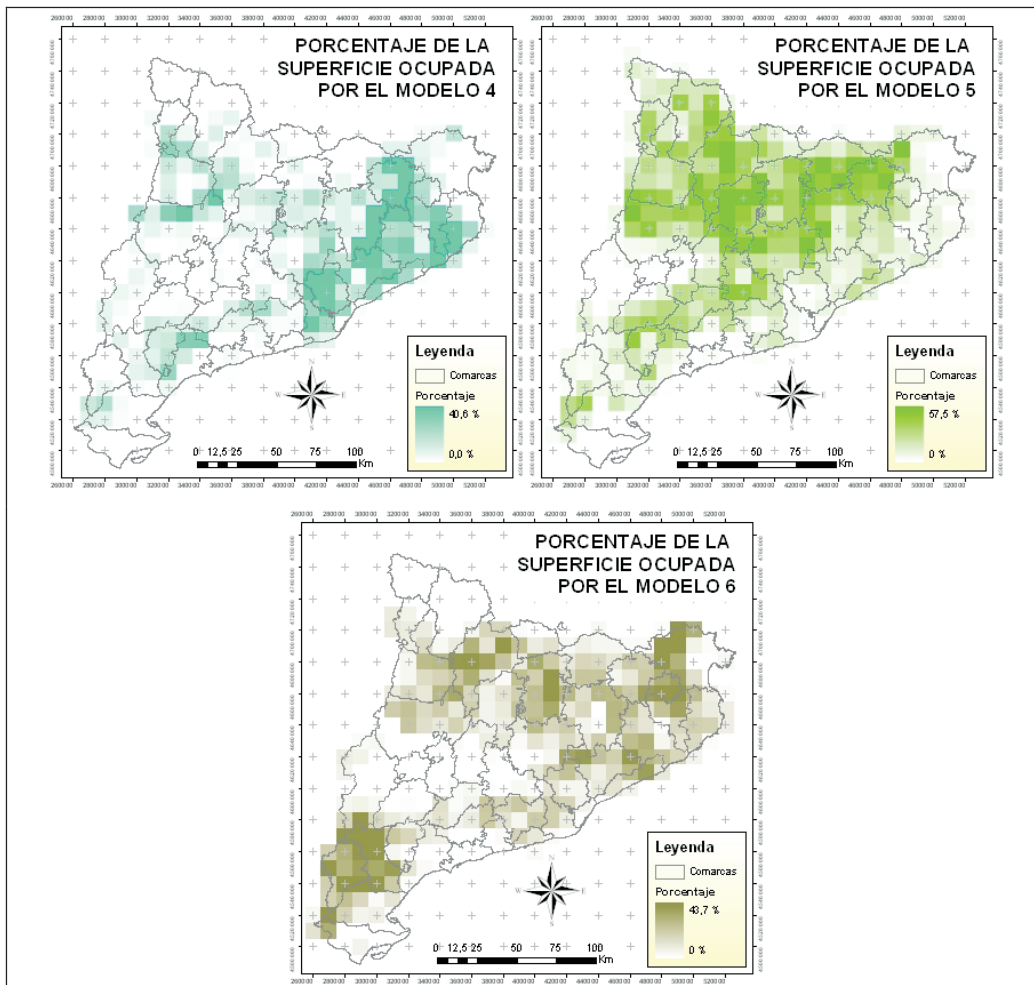


Figure 4—Maps used to calculate the probability of ignition showing the percentage of surface area taken up by fuel models 4, 5 and 6.

The predicted Tmax data were generated using the MASS model (*Mesoscale Atmospheric Simulation System*) developed at the University of Barcelona and Tmax was assumed to be the temperature predicted for 12:00 am UTC. The calculation produced a matrix of evenly-spaced grid points, 15 km apart, and was interpolated on a daily basis to the corresponding predicted Tmax value, using the ArcInfo (ESRI 2002) Spline command, to create a continuous surface in the space for the predicted temperature values (*fig. 5a* and *fig. 5b*).

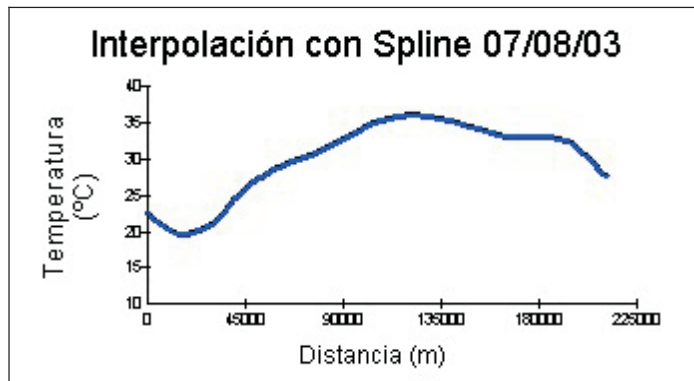


Figure 5a—Graph representing the temperature tendency created by the Spline along the observed line in *fig. 5b*.

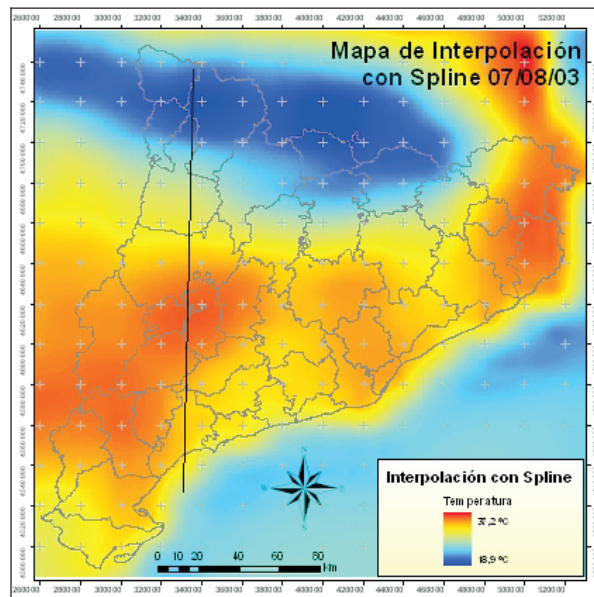


Figure 5b—Map resulting from the Spline interpolation using ArcInfo (ESRI 2002).

The automatic calculation of the probability of ignition map in ArcInfo (ESRI 2002) and publication of the map on the Directorate-General’s Intranet was arranged in the space of a few days (*fig. 6*). However, the co-operation which was sought in order to test whether the model was of any practical value for the specialists responsible for planning fire suppression activities was subject to considerable delay.

The delay was principally caused by bureaucracy, as the three members of staff chosen to evaluate the model did not belong to the same department at the DGECP which had automated the calculation of the model.

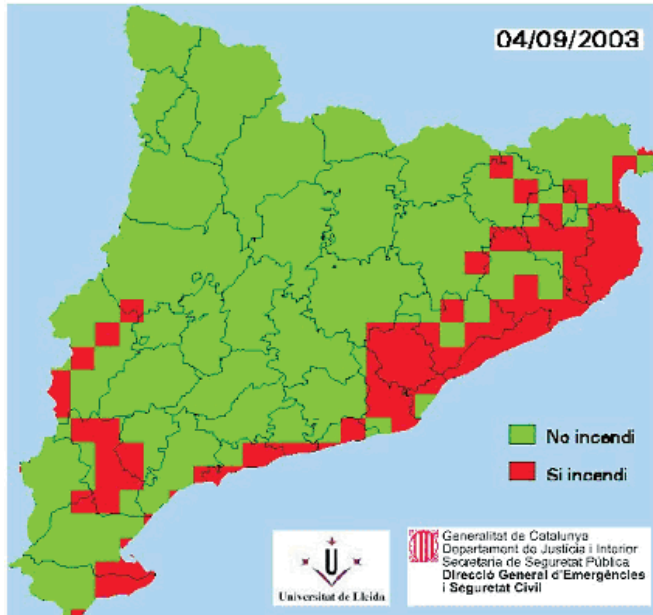


Figure 6—Specimen map published daily on the DGECP’s Intranet.

The evaluation was intended to consist of a daily survey, early in the morning, of the results produced by the model and a comparison with the specialists’ own perception of risk for that particular day based not on the results, but on their practical experience. It is clear from the reports submitted by the specialists, that the type of evaluation required of them had not been explained with sufficient clarity, as they all comment that there did indeed appear to be a close correlation between the predictions generated by the model and the number of vegetation-based fires attended by the Catalonia Government Fire Brigade. On the other hand, they make no reference to any correlation between the model and their own personal predictions concerning the risk of ignition.

The behaviour of the model was tested three years after the period when the original dataset had been obtained in order to build the model, and the results are presented in *tables 4* and *5*. Attention should first be drawn to the fact that the total number of ignitions in each of the two tables is not exactly the same (212 in the table presenting the predicted temperatures, and 200 in the table for real maximum temperatures). This is the result of the failure of certain meteorological stations which made it impossible to gather Tmax values and, therefore, the probability of ignition for some of the fires. However, the prediction file for maximum temperatures was obtained without problems throughout the whole test period.

As would be expected, the model was more effective if used with real temperatures, at a correct prediction rate of 77.5 percent for ignition occurrences, than with the temperature predictions, where the correct prediction rate, although perfectly acceptable, dropped to 70,7 percent. It is foreseen that this difference in effectiveness would be reduced by analysing alternative sources for maximum temperature predictions and other methods of interpolating these sources.

Table 4— *A comparison of the number of ignitions predicted by the model, calculated using the maximum temperature predictions from the MASS model and the real ignitions occurring in the same period of time.*

Ignition predictions	Yes	No	Total
Yes	150	5,958	6,108
No	62	8,446	8,508
Total	212	14,404	14,616

Table 5— *A comparison of the number of ignitions predicted by the model, calculated using the real temperatures and the real ignitions occurring in the same period of time.*

Ignition predictions	Yes	No	Total
Yes	155	6,414	6,569
No	45	6,842	6,887
Total	200	13,256	13,456

The most negative result was the high number of false alarms provided by the model, i.e. the predicted ignitions which did not actually occur. In this particular case, the percentage was practically the same, independently of the temperature values employed. It is nevertheless hoped to be able to reduce this percentage significantly through small adjustments over successive summer campaigns.

Discussion and implications for managing forest fires

This paper has highlighted the clear difficulties referred to in so many studies of fire occurrences concerning the lack of source data, whether it be geographic or meteorological, given that an original 1,600 forest fires were reduced to 294 observations appropriate for building the models. This lack of data was noticeable not only when building the model, but also when evaluating its performance during the summer of 2003, when the lack of meteorological data made it necessary to eliminate 5.6 percent of ignitions from the analysis.

When the model was being built, variables related to topography, the presence of protected areas, fuels, power lines, housing developments, maximum daily temperature, solar radiation and risk indices were associated in differing degrees to the occurrence of fires in the study area.

Applying logarithmic regression techniques to the prediction of forest fires in Catalan municipalities using fuel model maps makes it possible to correctly predict, every day, the occurrence of at least one fire in 10 x 10 km squares with a likelihood of at least 70 percent.

The results also suggest that false alarms might be an obstacle to use of the model in the real world if users are not adequately instructed in the correct interpretation of the predictions.

Furthermore, the classification of probability in a map with only two classes (fire yes / fire no) reduces the information available on the risk in that area. As a result, it would be advisable to publish a map with a higher number of probability classes, preferably ten.

The usefulness of this statistical model in a Mediterranean environment was confirmed when it was installed at the DGECP during the summer of 2003, although there is room for improvement through analysis of other interpolation methods for the meteorological variables and alternative sources for the variables.

Bibliography

- Chow, Y.H., R.A. Minnich and R.A. Chase. 1993. **Mapping Probability of Fire Occurrence in San Jacinto Mountains, California, USA**. *Environmental Management* 17(1): 129–140.
- Cox, D.R. and E.J. Snell. 1989. **Analysis of binary data**. Second edition. Chapman & Hall, New York, New York, USA.
- ESRI. **ArcInfo** [Computer program]. 2002. Redlands, CA: Environmental Systems Research Institute, Inc. Available from: 380 New York Street, Redlands, CA 92373-8100, USA.
- Hosmer, D.W., Jr. and S. Lemeshow. 1989. **Applied logistic regression**. John Wiley & Sons, New York, New York, USA.
- Keetch, J.J. and Byram, G.M. 1988. **A drought index for forest fire control**. Res. Paper SE-38. Asheville, North Carolina. Southeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture; 36 p.
- Loftsgaarden, D.O. and P.L. Andrews. 1992. **Constructing and testing logistic regression models for binary data: Applications to the National Fire Danger Rating System**. USDA Forest Service, Intermountain Research Station, General Technical Report INT-286. 36 p.
- Maddala, G.S. 1988. **Introduction to econometrics**. Macmillan Publishing Co., New York, USA.
- Martell, D.L., S. Otukol and B.J. Stocks. 1987. **A logistic model for predicting daily people-caused forest fire occurrence in Ontario**. *Canadian Journal of Forest Research*, 17: 394–401.
- Martell, D.L., E. Bevilacqua and B.J. Stocks. 1989. **Modeling seasonal variation in daily people-caused forest fire occurrence**. *Canadian Journal of Forest Research* 19: 1555–1563.
- Prentice, R.L. 1986. **A case-cohort design for epidemiologic cohort studies and disease prevention trials**. *Biometrika* 73: 1–11.
- SAS Institute Inc. 1999. **SAS Online Doc. Version Eight**. SAS Institute Inc., Cary, NC, USA.
- Van Wagner, C.E. 1987. **Development and structure of the Canadian Forest Fire Weather Index System**. Government of Canada, Canadian Forestry Service, Ottawa, Ontario, Canada. Forestry Technical Report n. 35.
- Vega-García, C., P.M. Woodard, S.J. Titus, W.L. Adamowicz and B.S. Lee. 1995. **A logit model for predicting the daily occurrence of human caused forest fires**. *International Journal of Wildland Fire* 5(2): 101–111.
- Vélez Muñoz, R. 2000. **El concepto de combustibilidad**. pp. 7-1 to 7-16 in: Vélez Muñoz, R. (Coord.). 2000. *La defensa contra incendios forestales. Fundamentos y Experiencias*. McGraw-Hill, Madrid.
- Volk, G. **RADIATION** [Computer program]. 1997. Universitaet fuer Bodenkultur, Centre for Geo-Informatics, Daenenstrasse 6, A1190 Wien, AUSTRIA. Available at: <http://bzgserver.boku.ac.at/volk/>

