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'SINAMI': a tool for the economic evaluation of forest fire management programs in Mediterranean ecosystems

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Abstract. Historically, in Spain and most European countries, forest fire budgets have never been subjected to an objective and rigorous economic analysis indicative of the returns on investments in fire management protection programs. Thus far we have witnessed expansive growth of costs without any investment planning. New economic realities and more focussed oversight by regulating organisations are forcing agencies with fire protection responsibilities to formally justify their fire protection budget requests. The fire economics evaluation system described here (SINAMI) is the first attempt by Spain's National Forest System to help agencies with fire responsibilities perform an economic analysis of their budget requests for fire management and protection. SINAMI uses a marginal analysis and the economic criterion of cost-plus-net-value change (C+NVC) to determine the most efficient program and budget level for fire protection for a simulated fire season. The results are used in establishing strategic fire management plans to respond to historical fire situations. The model also provides information on number of fires and area affected by fire intensity level, as well as the number and type of firefighting resources used through the simulated fire season. The SINAMI model is based on the original structure of the National Fire Management Analysis System developed by the USDA Forest Service, expanded and adapted to Spanish conditions.

Additional keywords: fire behaviour, natural resources, net-value change, strategic fire planning, suppression budget.

Introduction

Wildland fires are a societal problem threatening many ecosystems, affecting millions worldwide, and causing major economic impacts at local, regional, national, and global scales. In the USA alone, for example, in the last decade wildland fires have affected more than 28 million hectares of wildlands at direct suppression costs of over US$11 billion (Table 1). Worldwide, the problem is similarly worsening.[A] External factors such as global warming and resulting climatic conditions, changes in social and economic concerns, and changes in fire management policies at the national level affect the capabilities of agencies to deal with the problem.

Fundamental changes in Spanish society during the last 25 years have contributed to a significant increase in the allocation of financial resources to the country's wildland fire problem. One of the most important contributors to this increase was the break-up of the country into 17 Autonomous Regions or Communities plus a central government in 1984. As a result, the majority of the State responsibilities for wildfire protection were transferred to the Autonomous Communities. The central government retained responsibility for the provision of aerial fire suppression support, elite national firefighting crews that could operate throughout the country and national training support.

Table 1. Area affected and suppression expenditures for US federal agencies with fire protection responsibilities, 1997–2007

Year	Area affected (million hectares)	Suppression expenditure (US$ billion)
2007	3.78	1.800
2006	4.00	1.900
2005	3.52	0.876
2004	2.75	0.890
2003	1.99	1.326
2002	2.81	1.661
2001	1.45	0.918
2000	3.41	1.362
1999	2.29	0.523
1998	0.94	0.329
1997	1.33	0.256
Total	28.27	11.442

The immediate impact of this reorganisation was the establishment of a wildland fire protection program in each Autonomous Region similar to the one that existed at the national level. Instead of one centralised program serving the whole nation,

[A]For a worldwide perspective on the effect of fire on earth systems, see the recent article by Bowman *et al.* (2009).

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now there are 17 independent such programs, resulting in a level of expenditure much larger than before.

Concerned over the rapid increases in fire suppression expenditure during the last decade, the Spanish Ministry of the Environment Fire Protection Program funded a project to develop an economic analysis tool for efficient allocation of the government limited financial resources for fire protection programs at both the national and Autonomous Regions levels, an idea born during the annual training courses provided by the National Fire Protection Program to all Autonomous Regions. As part of these courses, personnel from the USDA Forest Service presented a fire economics evaluation system used in the Forest Service to evaluate the economic efficiency of their programs and to establish annual protection budgets. Over several years, these presentations sparked interest for such a tool to benefit the fire management programs in the Autonomous Regions. In response, the Director of the National Fire Protection Program in 2002 funded the University of Córdoba to develop a fire economics tool.

Although the Spanish system was modelled on the USDA Forest Service National Fire Management Analysis System (NFMAS) model, lack of the necessary data forced the first phase of the project towards development of the basic information needed to design the system. The model structure called for at least 10 years' worth of data, which slowed the initial phase of the project until the majority of databases could be developed. However, rather than wait until all data were collected to start the modelling process, it was decided to concentrate on the development of a prototype for the province of Huelva in southern Andalusia's Autonomous Region. In the following sections, we will describe the process of development of the model, the necessary inputs and outputs, and the potential policy implications of the cost-plus-net-value change (C+NVC) prototype.

Project phases

In general, five development phases were considered in this project: documentation, knowledge, geographic area, model development, and model implementation. Following is a brief description of those five development phases.

During the *Documentation* phase of the project, we collected and reviewed the bibliography related to the NFMAS model developed and in use by the USDA Forest Service. This was harder than expected as the majority of the bibliography was found in the grey literature. Nevertheless, we developed a good understanding of the system, what it is intended to do, and its general organisation. As part of the literature review, we also compiled a list of real-case applications of the NFMAS model in the USA.

In the *Knowledge* acquisition phase, we examined the structure and operational basics of the NFMAS model. To fully comprehend the working capabilities of the model, we decomposed the model's code into its basic components. Doing so allowed us to identify the core functions without which the model would not work, and the set of fundamental relationships between model components. In this way, we were able to select the set of functions, relationships, loops and commands genuinely exportable from the NFMAS model to start developing our application under Mediterranean conditions.

Once the decision was made to develop a prototype for the Huelva province, it was necessary to perform an on-the-ground survey of the *Geographic area* to select management areas for the prevention and suppression programs.

The next phase, *Model development*, was hampered, as mentioned earlier, by a lack of the necessary data. As we created the basic databases necessary to implement the model, we simultaneously developed the model components, including all computer codes in C^{++}, and links with Geographic Information System (GIS) tools.

Before *Model implementation*, we performed a model calibration and validation in the field under actual firefighting conditions. We then developed and compiled applications and a user manual for the model. The final tasks of the model implementation phase were delivery of the model to the Director of the National Fire Protection Program, and a schedule of training sessions for model users.

Considerations in development of the model

The main objectives of the model are to evaluate the economic efficiency of wildland fire protection programs for strategic fire planning purposes and develop annual budgets that reflect the evaluation. Therefore, it is important that the model is well grounded in sound economic theory. The model incorporates the economic theory of marginal analysis, and the criterion for economic efficiency is the 'cost + net value change' of the resources affected (Mills and Bratten 1982). That is, the most efficient fire protection program is that in which the combination of presuppression and suppression expenditures results in the lowest total C+NVC. Theoretically, as the fire suppression expenditures increase, damage is supposed to decrease, and as the presuppression investment increases, suppression expenditures decrease. The result of this analysis is a U-shape function, with a minimum point that represents the optimum presuppression level. For a more in-depth explanation and analysis, and historical development of the C+CNV concept, see González-Cabán (2007). This type of analysis provides a formal and objective process to evaluate the economic efficiency of wildfire protection programs and represents a decision support tool for fire managers.

However, Donovan and Rideout (2003*a*) argue that in the C+NVC model, suppression is incorrectly portrayed as a model output and that suppression and primary protection (presuppression) are incorrectly modelled as negatively correlated. They further argue that these errors '…have serious implications for the model's capacity to correctly identify the most efficient level of fire management expenditures' (Donovan and Rideout 2003*a*, p. 318). The two implications of their argument are that the analysis may result in a C+NVC function without a global minimum, and that even if a minimum is obtained, it may not coincide with the minimum of the unrestricted C+NVC function. They propose an integer programming[B] model to optimise

[B]The Forest Service has pursued this possibility further in developing a new generation of fire management program economic analysis but has encountered serious problems in the process.

resource allocation for wildfire containment as a way to overcome what they present as error in the traditional C+NVC representation (Donovan and Rideout 2003*b*). Although we recognise the potential implications of their analysis, we consider that, as a first step, the model proposed in this paper is an improvement because it applies economic analysis to fire management and protection programs in the Mediterranean basin countries, where none is applied today. As a decision support tool for fire managers, the model would help them identify potential benefits of different fire management options and potential economic consequences, even if a global minimum could not be guaranteed.

In determining the model capabilities, we considered the following operational and computational possibilities: (1) an assessment and comparison of the efficiency and effectiveness of fire protection program alternatives; (2) an estimation of area burned and number of fires by size and intensity. This allows evaluation of specific prevention and protection programs by estimating how long firefighting resources are committed to a fire. (3) The ability to evaluate dispatch and protection response options to specific types of wildfires. With this in mind, we considered the following relevant information for inclusion and development of the model: historical fire occurrence; fire history maps of fires for the model analysis planning period and the fire management prevention program's analysis areas; potential risk of fire occurrence; incorporation of different forest fire prevention management areas in the potential hazards map; mobilisation time and access to resources; terrain conditions; difficulty in carrying out fire suppression activities; fire behaviour, and average number of fires by fire intensity level; productivity of firefighting resources assigned to a fire; specific fire size at time of control and elapsed time to control; evaluation of potential for escaped fires; fuel characteristics; and seasonality and frequency of dominant fire weather phenomena. (4) Information gained from procedures used in actual firefighting. Using the national wildland fires database permits us to incorporate results from the past 10 years of work in fire suppression. In addition, we documented the effectiveness and fire suppression costs for the 2002 and 2003 fire seasons; and finally (5) computation of the Area Contraction Factor (ACF). This factor permits incorporation of the effectiveness of suppression activities in determining final fire size. The ACF is obtained by comparing the theoretical final fire size of a simulated free-burning fire (no suppression actions taken) with the final fire size of the same simulated fire incorporating fire suppression activities. The difference between these two estimates is the ACF.

Model inputs

The required model inputs may be divided into the following general categories: fire behaviour, derivatives of behaviour and productivity of firefighting resources, organisation and fire suppression procedures, existing natural and manmade barriers to fire progression, and the value of natural resources considered.

The fire behaviour category includes parameters for the intensity level at the fire front, surface and crown rates of fire spread, generation of spot fires, transition from surface to crown fires, and flame length interval to compute fire intensity level.

The derivatives of behaviour and productivity of firefighting resources category includes parameters for area and perimeter control by fire intensity level, time to perimeter control, and firefighting resources available.

The category of organisation and fire suppression procedures refers to the type of suppression organisation in place and how firefighting resources are dispatched for fire suppression activities, including designation of firefighting resources as individual resources, attack teams, and task forces.

The existing natural and manmade barriers to fire progression category include firebreak lines and areas, roads, and natural features such as rivers, lakes and gravel pits that could stop or delay fire progression.

For the natural resources values category, we conducted an economic evaluation of the impact of fires on selected natural resources for each fire management analysis zone (ZAMF in Spanish). Special algorithms were developed to measure the impact on the following natural resources: timber, forage, underbrush, fruits, water, fishing, fauna, recreation, hunting, and landscape.

For example, the following two algorithms were developed for the economic evaluation of immature and mature timber in the SINAMI (Sistema Nacional para Análisis del Manejo de Incendios) model.

Timber

(a) Immature timber[C]

$$\text{Economic impact} = \varphi KS \qquad (1)$$

where φ is a harmonic equation[D], K is the percentage of ground shaded by canopy, and S is the area affected by fire for each species.

The harmonic equation is given by Eqn 2:

$$\varphi = \frac{aEB_i}{E + bB_i} \qquad (2)$$

where a and b are coefficients, E is the computed timber value, including the reforestation cost and the forest land price by hectare, and depends on the forest age; and B_i is a variable depending on (immature) timber volume by hectare, price, age and potential mortality, as measured by fire intensity level. The value of B_i is estimated from Eqn 3:

$$B_i = \left[\frac{VP^{*}c^{n}}{1.04^{n}}\right] \times \left[1 - \left(\frac{c}{1.04}\right)^{e}\right] \times [1 + Xh\rho] \qquad (3)$$

where V is the estimated future volume to cut ($m^3\ ha^{-1}$); P^* is the stumpage price (euros, €) of timber harvest by hectare (m^3);

[C]All equations presented and used in this manuscript were developed by the authors. Some may have an initial foundation in the NFMAS model, but are not copied from it.

[D]This equation is the resulting combination of the selected variables, which are themselves affected by a numerical coefficient that indicates their relative importance in the equation.

c is a numerical coefficient that captures the increment in timber price over time; n is number of years to harvest; e is the stand age; X is a mortality coefficient, which depends on ρ; h is the percentage of immature (subscript i) and mature (subscript m) species in the total forest; and ρ is the percentage of forest affected by fire (estimated by fire intensity level, FIL, which depends on fire behaviour). Finally, E is estimated from Eqn 4:

$$E = C_R t K[i^e + g(i^e - 1)] + A[i^e - 1] \quad (4)$$

where E is the computed timber value as defined before; C_R is the reforestation cost per hectare (€ ha^{-1}); K is as defined earlier; i is a numerical coefficient representing the stand growth, which can take four different values from fast (1.06) to slow (1.015); g is a price increase factor dependent on harvest age that varies by species growth from fast (1.27) to slow (1.43); A is the price by hectare of forest land; and e is the forest age.

(b) Mature timber

The potential losses for mature timber are estimated from Eqn 5:

$$\text{Potential losses} = (a\varphi\alpha)/(\varphi + b\alpha) \quad (5)$$

where α is a second harmonic equation; φ and coefficients a, b are as defined earlier.

The value of α in the second harmonic equation depends on the economic productive value of different species groups (Tragsatec, unpubl. data). The values of α for five species groups used in our model for Huelva are: coniferous, €1650 ha^{-1}; deciduous, €2175 ha^{-1}; mixed forest, €1878 ha^{-1} [E]; brushwood, €795 ha^{-1}; and grassland, €948 ha^{-1}.

The economic impact for mature timber is computed from Eqns 1 and 2 defined previously. However, the value of B_m, a variable depending on (mature) timber volume by hectare, price, age and potential mortality, as measured by fire intensity level, is computed differently (Eqn 6) because with mature timber there is no future harvest value.

$$B_m = V h_i \rho [MP + (1 - M)P_m] \quad (6)$$

where V is the harvest volume (m^3 ha^{-1}); h_i is the percentage of maturity of species i in the total forest; ρ is as previously defined; M is the percentage mortality of timber not salvaged; P is the current stumpage price of mature timber (€ m^{-3}); and P_m is the current stumpage price of marketable mature timber affected by fire (€ m^{-3}).

Before the total forest has reached harvesting age, the value of E_i is given by Eqn 7:

$$E_i = \frac{\rho C_R}{z}[g^e + \gamma(g^e - 1)] + \frac{s\rho C_R}{z}[g^e + \gamma(g^e - 1)] \quad (7)$$

where E_i, C_R, ρ and g are the same as before; z, s, γ are coefficients dependent on harvest age; and e is the forest age.

For the total mature forest, E_m is computed from Eqn 8:

$$E_m = [PV - P_{m_1} V_{m_1}] + P_t V m \left[\frac{i^{t-e} - 1}{i^{t-e}}\right] \quad (8)$$

where E and e are defined as before; P is as defined earlier; V is the volume of timber (m^3 ha^{-1}); P_{m_1} is the price of timber with commercial value affected by fire (€ m^{-3}); V_{m_1} is the volume of timber (m^3 ha^{-1}) with commercial value affected by fire; P_t is the average price of mature timber (€ m^{-3}) (m^3); and i is a numerical coefficient that varies depending on forest and harvesting age.

Prevention and suppression programs annual cost determination

To determine annual prevention and suppression costs, the following components were considered: unit costs per mission during firefighting operation; average cost per hectare during initial attack; average cost per hectare during extended attack; average cost per hectare during large fires suppression; and the net value change of affected natural resources for each of the previous four situations.

The budget allocation process in Spain's Autonomous Regions is similar to the USDA Forest Service process. There is an initial annual budget that pays for the presuppression organisation (including prevention, detection, fuels management and initial attack), and suppression expenditures after firefighting resources are dispatched to fires. All Autonomous Regions contract a minimum number of aerial firefighting resources. However, the largest fleet of fixed and rotary wing airtankers is provided free of cost to the regions by the central government. The budget allocation process used in SINAMI is much the same as in the NFMAS process. The initial budget is allocated between different firefighting resources based on a historical distribution. Different fire management options can be tested, changing the emphasis of the firefighting resources of the initial attack organisation. For example, one option could be weighted more towards aerial attack than ground attack. This would have an impact on the type of organisation that is established to test its planned fire season.

Economic evaluation of post-fire recovery operations in affected areas

An economic evaluation of the post-fire recovery operations involves the following steps: (1) identification and listing of the effect of fires on the resources; (2) mapping of these effects; (3) quantification of the effects and development of appropriate economic measurements; (4) determination of annual production of the resources evaluated without fires; (5) determination of total production for the planning period without fires; and (6) determination of total production of the resources evaluated for the planning period with fires.

Additional components and applications

The following weather data are required to determine fire behaviour: temperature, humidity, wind speed and fuel

[E]Computed as $\alpha = (1650 \times \text{coniferous} \div \text{total surface}) + (2175 \times \text{deciduous} \div \text{total surface})$.

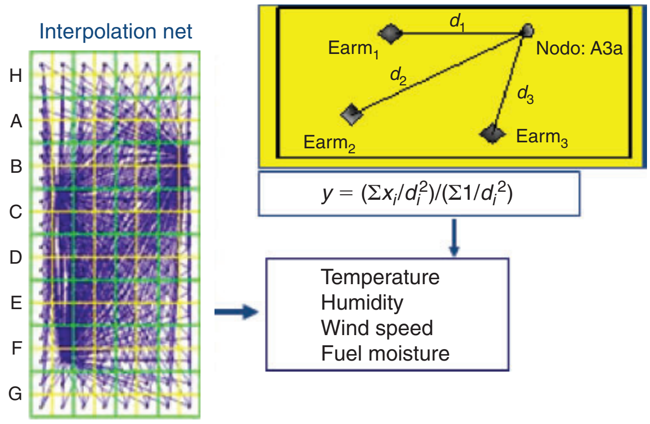

Fig. 1. Interpolation procedures for computation of weather parameters of temperature, humidity, wind speed and fuel moisture. In this equation *y* is the interpolation value of the variable measured (e.g. temperature); *i* is an automatic weather station; *d* is the distance between automatic weather stations and the interpolation point to be estimated; and *x* is the meteorological variable for which the interpolation is being estimated.

moisture. Weather conditions affect flame length and rates of fire spread, and consequently fire suppression actions. For example, low humidity and high wind speed would increase flame length and rate of spread. To determine weather conditions by ZAMF, we use historical data (ASCII format) from the National Meteorology Institute (NMI). Because the weather stations network does not provide full coverage to all the ZAMF, we used an interpolation method to map weather variables (Fig. 1).

Other components of the system are: thematic cartography models of fuels and forest cover; annual number of fires by intensity level; the 50th and 90th rate of spread percentiles; area at detection time; fire history referenced geographically from national fires statistical database; escaped fires final size; and methods for determining economic damage from forest fires. This allows one to perform a pre- and post-fire evaluation to estimate the impact due solely to the fires.

Model development and implementation

Minimum requirements to implement the SINAMI model computer program

At a minimum, SINAMI will consist of the following functionalities: control commands for management of program utilities; printing options for documents produced by the model; database management of files produced by the storage, recovery and indexing of documents; identification of work unit, protected space, forest land, and local area; and information on the ZAMFs for the prevention and control programs (Fig. 2).

General procedure for model execution

A SINAMI application begins with the development of a base case situation reproducing correctly the historical fire management program for the area of interest. This involves conducting a historical analysis of forest fires, and an analysis of interrelations of input parameters, such as individual fire suppression resources, suppression attack teams, fuel models, suppression difficulty computed from the suppression technical difficulty

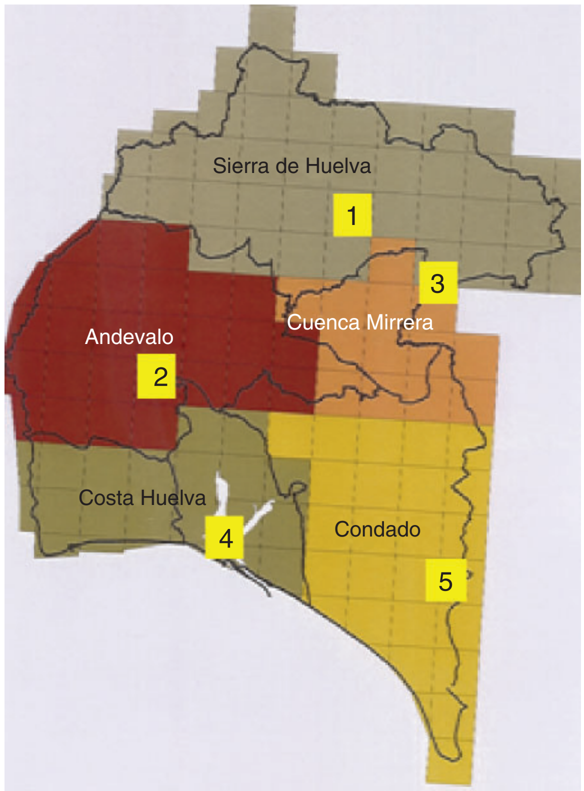

Fig. 2. Fire management analysis zones based on 10 years of statistical fire history within a 10 × 10-km cell. The numbers in the figure represent the order that they were listed in the model.

index (SDI) (Rodríguez y Silva 2000*a*), potential hazard computed from the potential hazard index (PHI) (Rodríguez y Silva 2000*b*), and weather conditions.

To perform the historical analysis, we used information and equations developed for the USDA Forest Service NFMAS system (Donovan *et al.* 1999; González-Cabán 2000*a*, 2000*b*), which include models for specific characteristics of the fire management analysis zones.

The system is structured in a modular format to facilitate updates and changes to individual modules without affecting other modules of the system. The following modules are part of the system: available suppression resources (type, results, and costs), fuel models (including topographical aspects), historical fire occurrence, detection procedures (including discovery times), fire suppression technical difficulty, dispatch procedures, arrival times, hazard potential by fire management analysis zone, rate of spread and fire frequency by fire intensity level and by initial size at the start of suppression work, and final analysis of the program based on comparisons between the amount of fireline constructed by the suppression resources committed to the fire and the growth in fire perimeter as estimated by the fire behaviour equations, the program and fire suppression costs, and the net value change in the resources affected by the simulated fires (Fig. 3).

The amount of fireline constructed by fire suppression resources by fuel models was obtained from studies by Porrero and Chico (2000) conducted under actual fire suppression

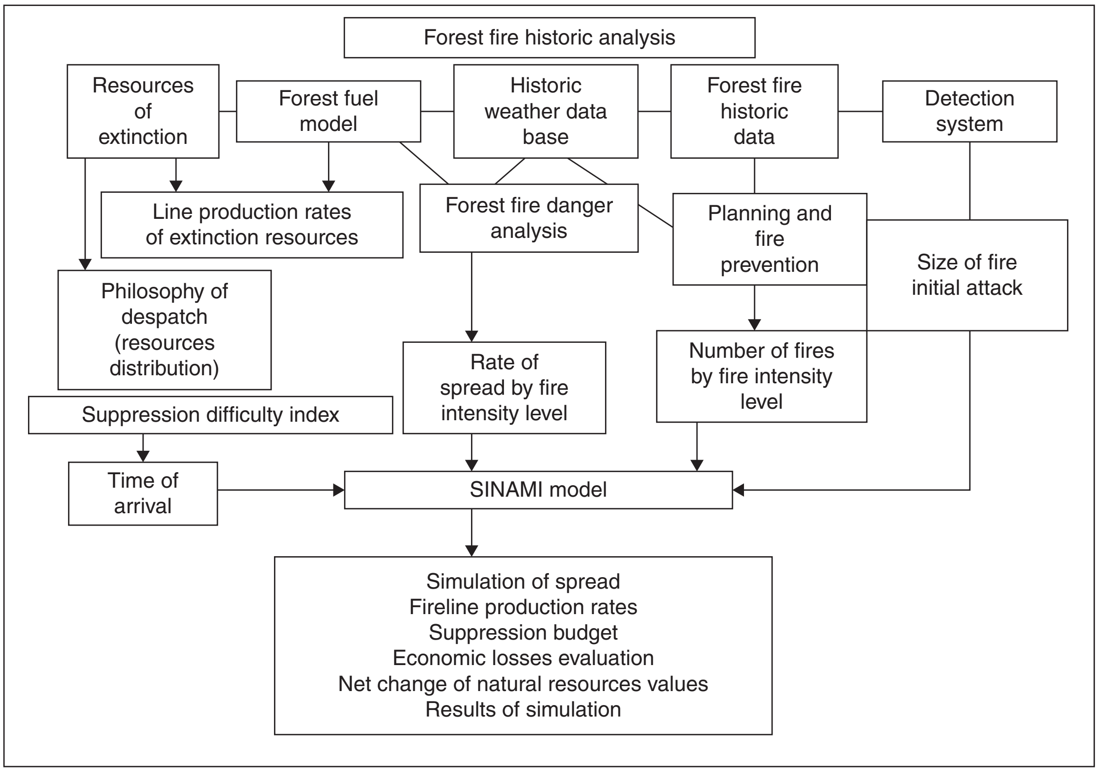

Fig. 3. Modular structure of SINAMI forest fire historical analysis.

conditions. Fireline production rates for aerial resources depend first on the type of aerial resource to be used: fixed (airtanker) or rotary wing (helicopter). We used the following equations for computing the amount of water dropped depending on the fire behaviour conditions. For airtankers, Eqns 9–11 are used:

$$M = K(Cr)^{0.5}(Vp/0.35)^{(1/1.25Cr)} \ \ (\mathrm{L\,m^{-2}}) \tag{9}$$

where M is the amount of water to drop (dose),

$$K = 0.00481712 + 0.092607F \tag{10}$$

where K is a coefficient dependent on fuel density, and F is the amount of fuel (kg $\mathrm{m^{-2}}$),

$$Cr = 0.39194 + 0.332205Vp(\text{with wind and slope zero}) \tag{11}$$

where Cr is a parameter depending on combustibility, and Vp is the rate of spread (m $\mathrm{min^{-1}}$). Table 2 shows the parameters values for the 13 standard fuel models used in the system. The number of drops depends on fuel type. The time between drops is fixed at 10 min, but can be changed if needed. The resultant wet surface (area covered by the water drop) is given by Eqn 12:

$$S = (L/2)(W/2)\pi \tag{12}$$

where L is the length of the wet surface; and W is the width of the wet surface.

Table 2. Parameter values for the 13 standard fuel models used in the system to compute the volume of water to be dropped by airtankers on fires

See text for definition of terms

Fuel model	W (kg $\mathrm{m^{-2}}$)	Cr	K
1	0.16	0.925	0.01963424
2	0.89	0.663	0.08723735
3	0.67	1	0.06686381
4	3.59	0.466	0.33727625
5	0.78	0.400	0.07705058
6	1.35	0.588	0.12983657
7	1.09	0.475	0.10575875
8	1.12	0.550	0.10853696
9	0.77	0.475	0.07612451
10	2.69	0.478	0.25392995
11	2.58	0.438	0.24374318
12	7.74	0.550	0.72159530
13	13.01	0.625	1.20963419

For helicopters, the values of L and W are estimated from regression Eqns 13 and 14:

$$L = -39.8116 + 0.0327586Q + 0.3333H + 0.556213V; \mathrm{R}^2 = 0.87 \tag{13}$$

$$W = 6.19933 - 0.0792313L + 0.00466447Q + 0.137522H - 0.0152993V; \mathrm{R}^2 = 0.91 \tag{14}$$

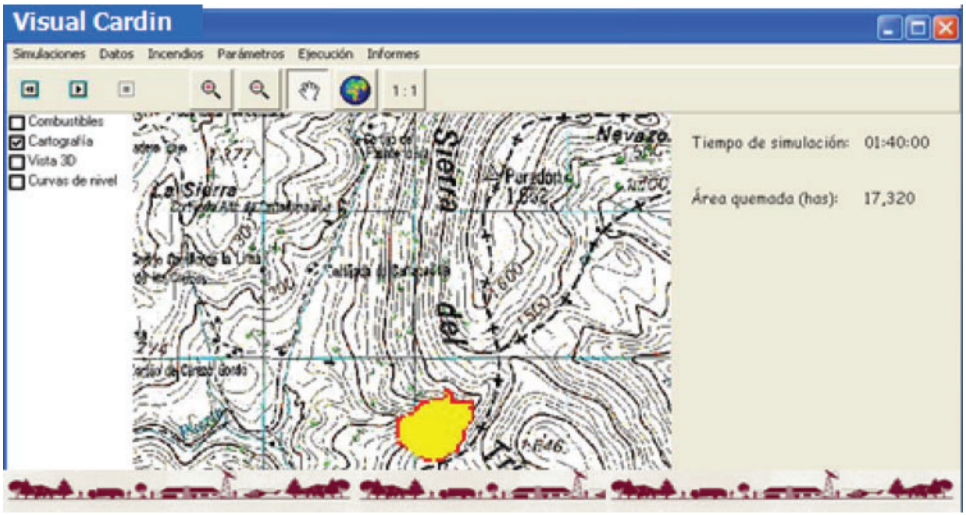

Fig. 4. Computation of firefighting resources rate of line production using the Visual Cardin fire simulation program (Rodríguez y Silva 1999, 2003).

For airtankers, values are computed with Eqns 15 and 16:

$$L = -155.232 - 0.633776H + 0.00810177Q + 1.24977V; R^2 = 0.90 \quad (15)$$

$$W = -12.5638 + 0.11452L + 0.0827265H + 0.000186821Q + 0.118964V; R^2 = 0.93 \quad (16)$$

where Q is the volume (L) of the drop; H is the height of the drop (m); and V is the aircraft speed (km h^{-1}).

The number of drops depends on the dose (D) and the volume of a drop (Q). If the dose D is greater than the volume Q, the system continues to request drops. However, if $M < Q$, the system requests only one drop.

Finally, the fireline production rate for aerial resources is given by Eqn 17:

$$\tau = (1/4)L(1/t) \quad (17)$$

where τ is the rate of aerial resources fireline production, t is the time (min) necessary to carry out the number of drops indicated earlier; and L is as defined in Eqns 13 and 14.

The fireline production rate for fire engines is computed as shown below:

$$\Gamma = DW/Q_c \quad (18)$$

where Γ is the fire engine fireline production rate (m min^{-1}); D is the dosage (L m^{-2}); W is as defined earlier (standard, 10 m); Q_c is the firefighting pump capability (L min^{-1}); D is further calculated from regression Eqn 19.

$$D = -0.00644195 + 0.00163134 \times (C/S); R^2 = 0.98 \quad (19)$$

where (C/S) is the fire heat per unit area (kcal m^{-2} [4.2 kJ m^{-2}]) (depending on fuel model behaviour).

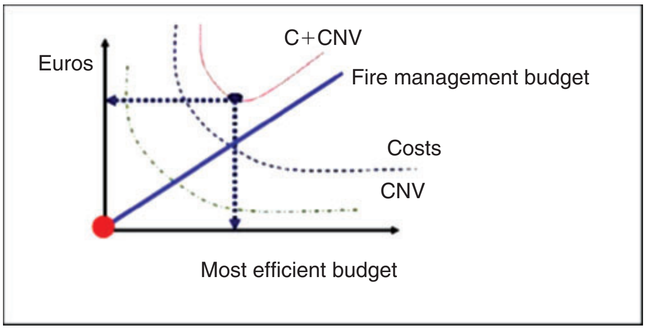

Fig. 5. Representation of the cost-plus-net-value (C+NVC) curve, showing the most efficient program budget level.

Standard values used in this computation are: engine water capacity = 3000 L, Q_c = 76.6 L min^{-1}, fire hose diameter 25 mm and nozzle size 7 mm.

The base case scenario in the historical analysis also includes the detection and prevention programs in place during the 10-year history of the analysis. The historical analysis must also consider the dispatch strategy for assigning firefighting resources, accounting for arrival times, detection size at time of arrival, fire rate of spread and fire frequency by intensity level.

To calculate the difference between the rate of fireline construction from assigned firefighting resources and the fire perimeter growth rate, we used the forest fire simulator 'Visual Cardin' (Rodríguez y Silva 1999, 2003), which was included in the model as a calculus tool (Fig. 4). The historical analysis yields a true representation of the 10-year average conditions.

Model outputs

SINAMI provides several useful results for strategic fire management planning and policy analysis, among them the identification of the most efficient defence program (Fig. 5), which attempts to minimise C+NVC.

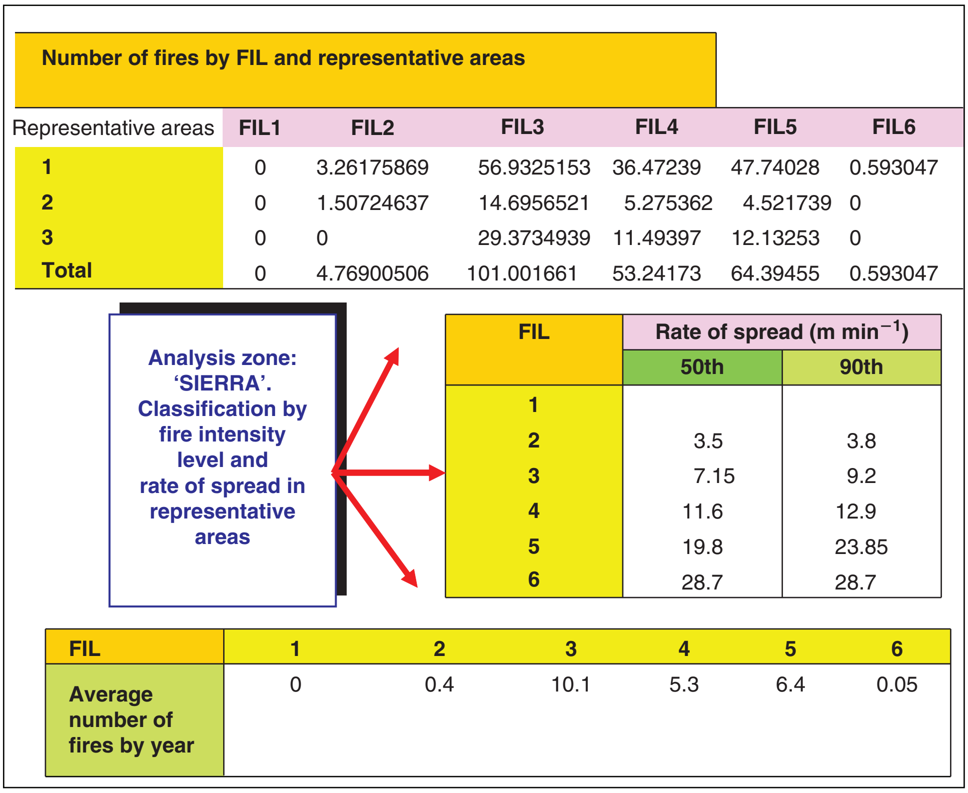

Fig. 6. Number of fires by fire intensity level (FIL) and rate of spread in representative areas within fire management analysis zones.

Table 3. Fire intensity level (FIL) categories used in the SINAMI model

Flame length (m)	FIL
<0.5	I
0.6–1.5	II
1.6–2.5	III
2.6–4.5	IV
4.6–6.5	V
>6.6	VI

Ancillary system outputs include information on the number of fires by fire intensity level, rates of spread at the 50th and 90th percentile (Fig. 6), fire intensity levels in the area of interest (Table 3), and the simulated annual resources.

Economic output includes fire suppression costs, estimates of fire effects and evaluation of resources used, and determination of the annual budget through estimation of the C+NVC for the simulation.

Model evaluation

Evaluation of initial attack

To evaluate the initial attack operations for the planning horizon, initial attack options are developed from the internal control program and budgets assigned for each fire management analysis zone, compiled from historical information (Schuster and Krebs 1999), such as firefighting resources mobilised, average cost per hectare, unit cost per mission, and number of escaped fires.

Once all desired options for evaluation are determined, the system considers all fires contained in the simulation, including area burned and escaped fires.

How the system works

To perform the analysis for a fire season for a province, the simulation starts with a random fire ignition. The fire grows according to the fire environment characteristics of the location (Representative Fire Location). The initial attack dispatch strategy determines the number and type of firefighting resources dispatched. Once the resources have arrived and are building a fireline to control the fire, the system compares the sum of the rate of fireline construction of all resources assigned to the fire with the fire's perimeter growth. If the fire perimeter is larger than the sum of the fireline constructed, additional firefighting resources are sent to the fire according to the dispatch strategy. This process continues until one of two possible results occur. First, the sum of the fireline production of all resources is equal to or greater than the perimeter of the fire. At this point, the fire is declared controlled, and simulation of the fire stops and the system collects all the necessary information on suppressions costs, area burned, changes in net value of resources affected, and other relevant information. Second, the time limit or the maximum area established for the simulation is exceeded. At this point, the fire is declared escaped and the system then goes to the escaped fires table to collect all the relevant information for computing the C+NVC. This process continues until a complete fire season is simulated. When the full fire season has been simulated, the system computes the C+NVC for the fire season and produces output reports for the manager. The C^{++} module that performs these calculations is called 'ECONOSINAMI'.

The sum of the total costs (presuppression and suppression) plus the net value change in the affected resources we call the demand ($\Omega = C+NVC$). Using an economic marginal analysis, we determine the most efficient budget level applied to the demand function (Eqn 20):

$$\Omega = \sum_{g}^{n} q_g \times p_g t_g + \sum_{j}^{m} CNV_j \tag{20}$$

where q_g is the number of firefighting resources of type g dispatched; p_g is the price by unit of time of resource type g (total costs); t_g is the operation time of resource type g; and CNV_j is the change in net value of natural resource j.

The most efficient program and budget level is given by the lowest point on the C+NVC curve.

Model reliability

The model presented here is still in a beta testing phase; therefore, we do not have enough information to judge its reliability. However, it is important to note that SINAMI is a model for strategic fire management planning and not intended for evaluation of tactical operations. As we are dealing with expected values of 10-year average initial attack fire suppression activities, how closely the model tracks an actual average fire season is a question that we are not able to answer at this time.

Conclusions

Wildland fires are a major problem worldwide, causing not only significant economic and natural resources losses, but also loss of life. The economic analysis of fire management and protection programs in the US has been operationalised since the early 1980s with the development of the NFMAS model in the USDA Forest Service. The model was developed as a budgetary tool to determine the most efficient fire management program.

Athough this type of economic analysis has been practiced in the US for almost 35 years, the same has not been the case in the rest of the world. Outside the US, Spain is the first country to develop an economic analysis model to evaluate the economic efficiency of their fire management and protection programs. Exposure to the NFMAS model in the training courses sponsored by the Spanish Ministry of the Environment Fire Protection Program raised awareness of the need to perform such an economic analysis to evaluate the return on the investment of fire protection programs at the national and Autonomous Regions level. This was in part triggered by political developments in the country, which resulted in 17 Autonomous Regions and a central government in 1984. This created 18 independent fire management and protection programs (including the central government), which increased the level of expenditure in wildlands fire protection.

Data requirements for fire economic models such as SINAMI are very high, which can pose significant problems for application in other Mediterranean basin countries where such data are scarce. However, Spain had the same problem initially but still managed to develop SINAMI. The policy implication in choosing to implement such an economic analysis model is that there will be an initial long-term commitment to data development. This phase can be costly, depending on the information available.

The economic analysis using the SINAMI model provides several useful results for strategic fire management planning and policy analysis. The potentially most relevant is the determination of the most efficient fire management program and budget levels. SINAMI enables managers to quantitatively justify budget requests and permits them to demonstrate potential consequences of budget reductions or reallocation in response to specific requests. Tradeoffs between budget levels, potential losses and program composition can be easily identified. In addition, information on the resulting total potential area affected and the annual firefighting resources dispatched for the simulated fire season could provide valuable information for fire management program composition and total number of resources to secure. The system also provides information on the potential fire effects on resources through the net value change (NVC) function. The model will be useful in strategic fire management and protection planning and budget request justification.

Although some limitations have been pointed out in the application of the C+NVC model, we consider that, as a first step, the model proposed here is an improvement in applying economic analysis to fire management and protection programs in the Mediterranean basin countries, where none is applied today. As a decision support tool for fire managers, the model would help them identify potential benefits of different fire management options and potential economic consequences, even if a global minimum could not at first be determined.

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