Policy Sciences **35**: 361–377, 2002.

Forest fires: Evaluation of government measures

XAVIER BALLART[1] & CLARA RIBA[2]

[1]*Profesor Titular, Facultad de Ciencias Politicas y Sociologia, Universidad Autónoma de Barcelona, 08193 Bellaterra, Spain, E-mail: Xavier.Ballart@uab.es;* [2]*Profesora Titular, Facultad de Ciencias Económicas, Universidad Pompeu Fabra, Ramon Trias Fargas 25–27, 08005 Barcelona, Spain, E-mail: clara.riba@econ.upf.es*

Introduction

In the last 20 years, there have been dramatic forest fires in the north east of Spain and in the south of France. Forest fires have been particularly intense in 1986 and in 1994 while they were important but less damaging in 1980, 1981, 1983 and 1998. In other regions along the Mediterranean shore such as in Greece, forest fires take place occasionally, but in some years reach proportions of a human and natural catastrophe. In almost every continent of the world, similar problems happen with regularity, for example in California and Chile, New South Wales in Australia and South Africa.

Systems of prevention and extinction work rather well with most fires but seem to fail completely with the few bigger fires that have the worst consequences in terms of loss of life, destruction of forest vegetation and wildlife, and loss of economic opportunities. These large uncontrolled forest fires also have the worst effect on people's trust, generating a sense of frustration in the population that literally observe their country burning to ashes. This is an area of policy where government could be said to be 'playing with fire,' since success can turn into a radical failure from day to night. Regional and local governments have taken a number of actions to prevent fires in the north east of Spain. But the summers of 1994, and to a lesser extent 1998, have put into question the whole policy given the size of the areas burnt and the feeling of disaster among the population.

As in the case of other policies where public administrations deal with risk, effectiveness can not be judged on the basis of one single parameter. There are many factors that lead to the undesired result and it would not be correct to judge only on the basis of injured or dead persons, hectares burnt or total value of economic damage. At the same time, some strategies and some actions may be more effective than others in given contexts and therefore, it is urgent to find out what works best. The ultimate measure of effectiveness with regard to forest fires would be the number of lives saved, the area of forest that did not burn or the damage that was not produced because of the action taken to prevent, control and extinguish forest fires. But the hypothetical question of what would have happened if measures had not been taken is not simple to address.

The purpose of this paper is to examine the relation between government measures, human participation, climate variables and forest fires, using data from the regional administration of Catalonia in the north east of Spain.[1] Findings may be relevant for any other Mediterranean region or for any other region in the world where there is a recurrent problem of uncontrolled and simultaneous forest fires at times of particularly adverse weather conditions. This type of research is expected to provide additional evidence on the relative effectiveness of specific government measures and on the participation of volunteer associations.

The analysis is both quantitative and qualitative. The quantitative analysis is based on an observational approach in order to select forest fires with a certain size. A multiple regression analysis is conducted to find significant relations between policy instruments under the control of the government and the number of hectares burnt in each case. The analysis controls for the effect of weather conditions and other contextual variables in order to find what strategies and tools are more effective. The qualitative analysis is based on two case studies that were used as a source of information on the actions taken by the different actors at the peak of a crisis due to large simultaneous forest fires. The interviews and the visits to the locations were very valuable in providing a sense of reality and in enriching the interpretation of the hard data.

Theoretical basis of fire prevention and extinction policies

Policies of fire prevention and extinction are based on the assumption that it is possible to determine where and when forest fires may start, to distribute resources rationally over the territory and to optimize the surveillance and the extinction of potential fires. As it happens in police work, effectiveness is determined by the resources available and by the management capacity to place them in the locations where they will be closer to those events with a highest potential of destruction (Mladenka and Hill, 1978; Whitaker et al., 1982).

The resource constraint is particularly important since it is not possible to reach the level of resources that would guarantee that no fire goes out of control. Public administrations face the dilemma of whether to increase their investment in personnel and equipment. Public decision-makers have to decide to what extent they run the risk that an insufficient level of resources evolves into a situation that has unacceptable social and environmental consequences.

The second assumption underlying fire prevention and extinction policies is that community mobilization, through volunteer fire-fighters and other volunteer associations that do prevention tasks, can help to detect fires and keep them under control. Volunteers responding to different sets of incentives are expected to have a significant contribution, mobilizing the community in defense of the nature and the population living in the countryside.

From a policy science perspective, it is important to find out whether there are variations in the effects depending on the management strategies and on the

contribution of volunteers and other non fire-fighting professionals. There could be variations in effectiveness depending on the ability of management to use available resources and on the ability to involve volunteer associations and other groups. In our interviews with the professionals, we felt that volunteers were not welcomed since they were 'bothering' and 'creating problems' in particularly difficult situations. On the other hand, local representatives and volunteers argue they were often left alone fighting against the fires, given the insufficient level of resources in instances of high simultaneity. According to these groups, had it not been for volunteers, fires would have expanded more rapidly posing a threat to human life and other valuable resources.

Finally, in a discussion of forest fires, there is the question of the impact of contextual variables such as the climate and the characteristics of the territory. It appeared critical to us to determine to what extent natural factors explain the undesired results and whether human intervention can have a marginal impact in specific situations and times when there are particularly adverse atmospheric and topographic conditions.

Problem definition

The analysis of policies is contingent on the definition of problems (Kingdon, 1995). In the case of forest fires, it appears as a multi-causal problem where different factors contribute to the ignition and extension of fires. As illustrated in Table 1 and discussed below, the problem of forest fires can be managed in different ways, depending on the perspective that is taken and on the political and technical feasibility of measures.

a) A problem of forest continuity?

There is ample evidence that, in the last 70 years, the extension of forest mass in the north east of Spain has significantly increased due to the decline in the population of rural areas and to the migration to the cities and metropolitan areas. The reduction in agricultural uses did not translate into the commercial exploitation of the forest since there were no economic incentives for doing so. The result of natural reforestation has been the accumulation of ignitable material in a major part of the countryside. The arboreal mass occupies 61% of the territory.

Some policy alternatives center on the idea of dividing the forest into plots. The strategy to fight the fires with the artificial divisions of the forest is seen as an adequate measure to stop fires and to facilitate access to fire fighters. But this measure is also seen as ineffective and politically risky, given the difficulty to maintain the divisions clean of vegetation and the reluctance to accept that in order to save the nature it is necessary to cut trees and open spaces in the forest.

Other policy alternatives are based on the idea to bring people back to

Table 1. Policy alternatives and policy actions.

Policy alternatives	Policy actions
Direct provision	*Direct provision*
1. Artificial division of forests into smaller woods	1. Not implemented
2. Investment in human resources	2. Increase in the number of professional firefighters and rural agents
3. Investment in equipment and vehicles	3. Investment in equipment and vehicles, including control towers and water points
	4. Investment in technology to analize daily risk
Public regulation	*Public regulation*
1. Regulation of risk activities	1. Regulation of landfills, electricity towers, perimeter of residential areas, cleaning of sides of road and railways
2. Regulation of activities that may cause erosion	2. Not implemented
3. Coordination	3. Emergency plans to achieve better coordination
Economic incentives	*Economic incentives*
1. Facilitate the return of the population to the countryside and to rural life	1. Not implemented
2. Facilitate the natural process of succession of species	2. Not implemented
3. Facilitate the artificial regeneration of the forest	3. Aid to forest owners
4. Financial aid to volunteer associations	4. Aid to forest defense associations (ADFs)

Source: X. Ballart and C. Riba.

farming and to the traditional activities associated with agriculture and forest management. Farmers traditionally cleaned the forest, cut wood for heating and burned bushes when necessary. Others argue that similar results could be achieved with the work of forest owners if their activity was financially sound. Forest owners have become an active pressure group that is asking for public aid on the basis of the ecological and social benefits that society obtains from forests.

b) A problem of urbanization?

The north east of Spain, like the rest of the northern Mediterranean shore, is a highly populated area. The natural beauty of the landscape and the proximity to important cities of Spain and other European countries has translated into the frequent visiting of the forests by urban residents. Mass tourism during the

summer season also poses a serious threat to the forest, increasing the chances of uncontrolled fires. The Mediterranean climate, with four clearly marked seasons, long dry summers with high temperatures and occasional strong winds such as the *Tramontana* in the Lyon gulf, also increase the chances of fire.

Various policy alternatives focus on the contact points between nature and human activities: the regulation of residential areas, cycling and hiking paths, town landfills, highways, railways and electricity lines are expected to reduce the number of fires starting at those points. Regulation can suggest or induce a desired behavior or it can impose serious constraints to specific human activities. Some of the measures may even prohibit certain activities at times or places where there is a high risk of ignition. However, regulations are not effective unless there is a threat and certainty of a punishment for a prescribed behavior and surveillance and sanctions are maintained over time. Implementation difficulties can easily make public measures ineffective (Ross, 1982; Ballart and Riba, 1995).

c) A problem of coordination?

According to local authorities, during the summer season of 1994 and to a lesser extent in 1998, professional fire fighters in the north east of Spain experienced serious problems of coordination. Internal coordination problems arose on specific days where there could be up to 28 uncontrolled fires at the same time. Urgency to act at various places at the same time made decision-making very difficult at the headquarters. Certain areas had to wait because professional fire fighters were busy attacking fires somewhere else. External coordination problems also appeared when local governments and local volunteers were the first to arrive at places where new fires were starting. According to professional fire fighters, volunteers were sometimes putting their safety in jeopardy. Other times they were diverting their attention. Local representatives such as mayors were often on the side of volunteers who had a direct interest in the preservation of their environment and properties.

However, professionals, local representatives and volunteers agree on the need to increase human and material resources as part of the solution to the problem of simultaneity. For the regional administration, it is not possible to increase resources to the level that may be required to cover the risk of fire, but it is possible to improve coordination with the adoption of a plan for action at the local level when there is an emergency.

d) A problem of non-natural succession of species?

Another definition of the problem is concerned with the natural process of substitution of species in the forest. The Mediterranean vegetation includes pine groves, oak groves and cork groves. There are also beech groves with taller

trees and less bushes in humid and mountainous areas. According to natural biologists, the vegetation forming the underforest is at present more pyrophite than it used to be, burning more quickly and spreading the fire faster. There is a process of substitution of species that may progressively change the ecosystem and have an effect on the spreading of fires. The ecological succession of species would have prevented the current situation that has been accelerated by both human intervention and forest fires.

Any policy measures that would help to restore the woods to what they would naturally be can help to preserve the natural succession of species. Reforestation of pine groves, oak groves and cork groves, is one alternative that has been debated. Other measures are directed to control the risk of erosion by regulating the felling of trees after a fire to sell the wood that is half burnt. The sad aspect of a burned area and the opportunity to make some money out of a disaster work contrary to policy options that would impose limitations on the property rights of owners in a critical situation.

Policy alternatives and actual actions

The evaluation of government measures requires the previous definition of the specific actions taken to both prevent and extinguish forest fires. Given the complex nature of the problem and the various avenues that can be taken to attack the problem, an effort is made to concentrate on actions that have been implemented.

a) Formal authority and coordination

Following a general process of decentralization, the Spanish central government transferred the management of forest fires to the region of Catalonia in the early eighties. Another agency in charge of civil protection issued in 1993 a basic instruction on forest fires[2] which was developed by the regional government in the so called INFOCAT, an emergency plan for local authorities. INFOCAT was approved in September 1994 after one of the worst summers in history in terms of forest fires.[3]

b) Fire prevention and extinction services

In 1986 the regional government started a prevention program known as *Green Fire*. Since the creation of this program, the system of prevention is based on three pillars:

- the daily map of risk which is prepared through remote sensing and geographical information systems applied to forest fire management;

– the surveillance units on the territory and in the air – rural agents with police functions, surveillance towers and helicopters;
– the volunteers forming 'forest defense associations' (or ADFs) on the basis of existing groups and associations that traditionally had organized themselves to defend their property and environment.

The system of extinction was less subject to innovation in its policy and operations. It is a traditional structure of fire fighters that have seen how resources experienced a slow incremental growth through the years.[4] The regional fire services never undertook an aggressive policy of artificial division of the woods or fighting fire with controlled fire during the winter season.

c) Regulation and incentives

The regional government has been regulating multiple activities and imposing obligations with a prevention objective. Some examples are the regulation of the distance where landfills can be authorized, the obligation to clean the corridors under electricity towers, the establishment of a minimum perimeter for residential areas in the forest and the obligatory cleaning of road and railway sides.

Sometimes, the regional government offered some economic aid as an incentive to induce activities that were perceived as directly related to preventing fires or repairing their consequences. That was the case with the creation of a special fund for the artificial regeneration of forests or the program to help farmers to acquire a specific breed of goat with a powerful capacity to clear weeds.

In sum, the actions of the regional government did not develop the full potential of policy alternatives that were discussed by the policy area experts. These alternatives included:

– improving the technical capacity to forecast the event of a significant forest fire, with the aim to reduce response times;
– sustaining the development of volunteer groups through the distribution of equipment, training and other resources that would make them more efficient;
– increasing the budget for both personnel and equipment of professional fire fighters, bringing the level of spending closer to other southern European regions, in particular those of France;
– establishing the functions of both civilian and professional forces during the extinction of forest fires in order to avoid coordination problems and conflicts with local authorities;
– distributing aid to forest owners to induce private investment in the cleaning and general maintenance of private forests;
– regulating the activities that can be developed in the proximity of forests with the aim of eliminating probable causes of ignition.

Research design and data sources

As described in the previous section, public intervention is actually a combination of actions that may have a marginal effect in the production of a fire. Some of the actions are more the result of political pressure to do something than the consequence of careful and exhaustive analysis. Other actions make sense to any professional in the sector but may have a small contribution towards the desired effect.

The present study uses multiple regression analysis to determine the impact of different types of variables in the extension of forest fires. The available data for the period under study allowed the testing of a model where human intervention and some weather and contextual characteristics are considered. The variables considered cover fairly completely the extinction policy – personnel and vehicles, response and control times – but they do not include any information that may be related to the actions taken to prohibit certain activities or financially assist forest owners.

The analysis follows a strategy that estimates the dependent variable, the extension of forest fires, on the basis of three different groups of factors. A model is estimated for each group of variables and all significant variables are included in a final model. In order to measure the significance of each fire, three alternatives were considered: economic loss, number of people who died or were injured, and number of hectares burnt in each case. Since data was incomplete regarding economic loss and the number of injured persons is relatively low, the analysis is based on burnt hectares.[5] This variable is considered a good representation of the significance of each fire but has some limitations, the main one being that two fires with the same extension can destroy areas with very different types of vegetation (trees, brushwood or farm fields) and value.

Variables that are used in the analysis are grouped in the following categories: climate, prevention and extinction factors.

1. Climate variables include information on atmospheric conditions, topography, location where the fire ignited and simultaneity with other incidents during the same day.
2. Prevention variables refer to whether the fire was detected by a permanent guardian and to the daily evaluation of the risk by the prevention services.
3. Extinction variables include human resources and material resources. Human resources can be professional fire fighters, volunteers, army soldiers, police forces, forest rangers and other public sector personnel. Material resources include fire engines, tractors, helicopters, fire prevention and attack planes and hydroplanes.

Data includes all forest fires that took place in the Catalan provinces of Barcelona, Tarragona, Girona and Lleida in the north east of Spain from 1992 to 1995 (a total of 3,132 cases). The selection of years is based on the fact that the biggest crisis occurred in 1994.[6]

Table 2. Size of forest fires (1992–1995).

	Percentage	Cumulative percentage
Burnt area $<$ 1 Ha	68.8	68.8
1 Ha $\leqslant$ burnt area $<$ 3 Ha	16.3	85.1
3 Ha $\leqslant$ burnt area $<$ 50 Ha	12.0	97.1
50 Ha $\leqslant$ burnt area $<$ 6,000 Ha	2.8	99.9
6,000 Ha $\leqslant$ burnt area	0.1	100.0

Source: Data from DGMN, Generalitat de Catalunya.

The fact that most fires are rather small, with an extension of less than one hectare, while a few fires may extent over thousands of hectares, introduces a strong asymmetry in the distribution of the dependent variable, with a long tail on the right (Table 2). For this reason, cases with an extension smaller than a 1/100 Ha were excluded (15% of the cases). In the remaining cases, the analysis uses the logarithm of the number of hectares burnt in each fire as the dependent variable in order to reduce the effect of the outliers.[7] The final number of cases is 2,653.

Analysis and results

Climate, topography and other contextual factors

As expected, natural and context factors are clearly related to the occurrence of forest fires:

- Maximum temperature and wind speed have a positive and significant correlation with the extension of fires. There is also a significant negative correlation with humidity.
- Topographical variables also have a significant and positive correlation with the dependent variable. The more abrupt the territory is and the more it is oriented towards the sun, the more it tends to burn.
- The number of simultaneous fires in a day shows a clear and positive relation with the hectares that burn. Whether the fire was detected in the middle of the mountains, near some kind of dwelling or near a path or road is related to the size of the fire, but the correlation is not very significant. The distinction between forests and other types of vegetation that may burn (fields, bushes) does not seem to be related with the size of the fire.

Model 1, including the variables from this first group of factors, is significant and explains 14.4% of the total variation of the size of fires (Table 3, Model 1). All the variables introduced are significant except for the one indicating the

Table 3. Regression models for forest fires.

	Model 1	Model 2	Model 3
Humidity	–0.006[a]	–0.004[a]	–0.004[a]
Temperature (maximum)	0.006[b]		
Speed of wind	0.014[a]	0.005[a]	0.006[a]
Simultaneity of fires	0.017[a]	0.006[b]	0.005[b]
Slope	0.270[a]	0.110[a]	0.092[a]
Sunny side	0.145[a]	0.119[a]	0.108[a]
Detected by permanent guard		–0.070[a]	–0.068[a]
Risk of fire		–0.003[a]	–0.003[a]
Fire fighters		0.206[a]	0.157[a]
Civil personnel		0.033[a]	0.028[a]
Soldiers		–0.139[a]	–0.145[a]
Municipal workers		0.085[a]	0.061[a]
Technical forest personnel		0.065[a]	0.055[a]
Fire engines			0.010[a]
Hydroplane			0.175[a]
Helicopters			–0.047[a]
Planes			0.144[a]
Discharges helicopters			0.045[a]
Discharges planes			–0.072[b]
Constant	–1.060[a]	–1.307[a]	–1.124[a]
Adjusted R^2	0.144	0.540	0.563

Dependent variable = number of burnt Ha (log-transformed)[14]; entries are regression coefficients.
[a] Significant at 0.01 level; [b] Significant at 0.05 level.

place where the fire was first detected. Signs are as expected and the variables that seem to have a bigger impact are wind speed and slope of the territory.[8]

Prevention related factors: Risk evaluation and fire surveillance

The daily evaluation of risk and the surveillance of new fires both have a significant correlation with the size of the fire. But the inclusion of these two variables in Model 1 makes maximum temperature no longer significant. All the other variables continue to be significant and maintain the same signs and similar coefficients. At this step of the analysis, the model explains 15,4% of total variation.

One possible interpretation is that these two preventive measures may work reducing the response times of personnel and vehicles by land or air. The analysis shows that with regard to forest guards, there is a statistically significant difference between those instances where fires were detected by guards or not.[9] The daily evaluation of risk has a strong significant and negative correlation with terrestrial response times. There is no significant correlation of risk evaluation with aerial response times.[10]

Extinction related factors: Human resources

The number of different categories of people contributing to the extinction of a particular forest fire (fire fighters, civil personnel, army soldiers, municipal government workers, police forces and forest technicians) has a significant and positive correlation with the extension of fires.[11]

In all the instances where fire fighters were not present, they were substituted by another type of personnel, usually volunteer people, police or municipal workers, except for three exceptional cases.[12] In Model 2 all the variables are significant, except for the number of police officers. The signs of the coefficients are as expected (Table 3, Model 2).

All this stage of the analysis, the bigger size of fires appears to be related to the following factors:

- the speed of the wind and the low humidity in the air,
- the simultaneity of fires, the abrupt nature of the territory and the orientation towards the sun,
- the non-detection by permanent guardians and the estimation of a low probability of fire,
- the increasing number of human resources working on the extinction.

One interpretation of this last finding is the presence of inverse causality. As fires become bigger and bigger, more people are sent to control and extinguish them. The only exception to that pattern is the use of soldiers, with a negative regression coefficient. But soldiers were used only rarely when fires were so big that a catastrophe was likely to occur. When soldiers were involved in extinction tasks, fires were controlled sooner and burned a relatively smaller extension of the forest.

Extinction related factors: Material resources

The last group of variables refers to the use of various types of vehicles and to the number of times different types of planes and helicopters release their tanks of water from the air on a forest or piece of land on fire.[13]

Both number of vehicles and water discharges appear to be significantly correlated. The regression model that forecasts the extension of the fire on the basis of the variables containing information on material resources is significant and explains 42% of the total variation. In this model, all the variables are significant, except for the number of helicopters due to its strong correlation with the number of water discharges from helicopters.

As in the case of human resources, the positive regression coefficients on the material resources variables suggest that there is also inverse causality since bigger fires attract more vehicles. However, the negative sign of the water discharges means that, with the same number of vehicles, more discharges are more efficient in reducing the size of the territory that is finally destroyed.

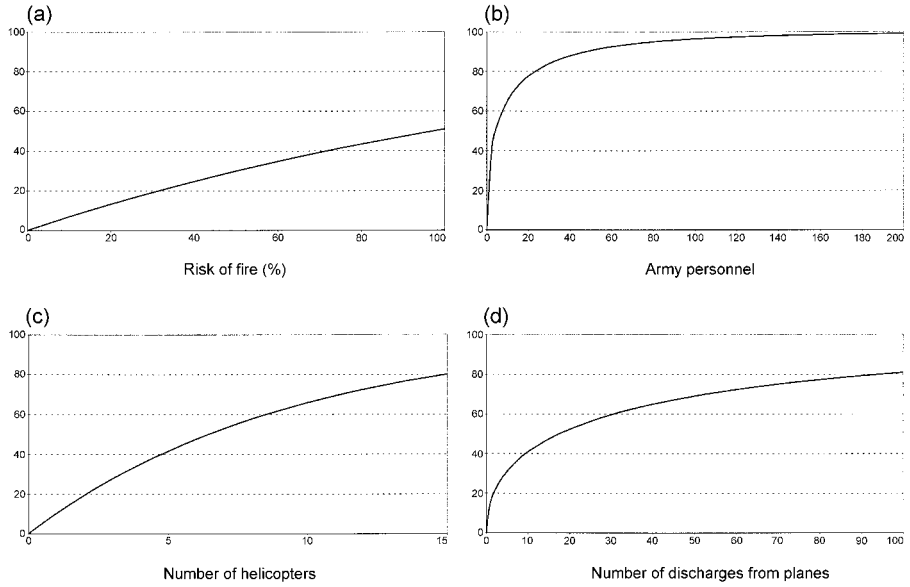

Fig. 1. Percent reduction in the number of burnt Ha: (a) Risk of fire (%); (b) Army personnel; (c) Number of helicopters; (d) Number of discharges from planes.

Model 3 is the result of adding this group of variables to the previously estimated model. The new model explains 56% of the total variation on the basis of weather and location characteristics, prevention measures, human and material resources (Table 3, Model 3). The sign and the value of the estimated coefficients are very similar to those obtained with Model 2, indicating the robustness of the model. In the case of helicopters, signs are changed.[15]

Figure 1a–d, shows the percent reduction in the number of burnt Ha that is achieved with each of the four factors that the model predicted to have a negative effect on the size of the fire.[16]

Two case studies

The quantitative analysis is followed by a brief account of two examples of forest fires that occurred in the spring and summer of 1994 near Barcelona. The information obtained through interviews and visits to the location adds a qualitative perspective to the analysis.

The first example refers to the fire that took place in a location known as La Floresta on 11 August 1994. The fire destroyed six houses and three warehouses. It partially affected forty-two other dwellings. It burned a total of 168 hectares of white pine and oak forest within the natural park of Collserola on the mountains of the north-western side of Barcelona. The fire was first detected at 5.15 pm, achieved its widest front at 7 pm and declared under control at 1 am

the following day. A total of two sea-planes and six helicopters took part in the extinction of this fire.

This is a case of a fire inside a natural park that is very close to a big city and where there was a significant danger for some of the people living in the area. In this case:

- A guard detected the fire from a control tower. Firefighters were put on alert. A series of fires had already started in other parts of the region the day before and the risk was high.
- The first fire engine arrived at the houses that were closest to the flames 10 minutes after the fire had been detected. This vehicle was stationed in one of the roads that cross the park.
- Until the fire was attacked from the air, firefighters fought the flames that threatened private houses with water from tanks and fire engines.
- Local residents and volunteers helped fire fighters to find the paths leading to the houses. They also tried to stop the flames with buckets of water and garden hoses. They also helped to evacuate residents.
- Aircraft arrived one hour and sixteen minutes after the fire was detected. It took about six hours to control the flames.

The second example corresponds to a fire that started in the area of the Garraf on the southern coast of Barcelona on 9 April 1994 and burned 1,754 Ha of white pine and 2,559 Ha of bushes. The fire started around 2 pm. during a spring day with a relatively low temperature (maximum of 18 °C) but high-speed wind (89 km/h) after a long period of dryness (140 days with no precipitation). The fire was not declared under control until almost four days later. Four people were injured.

Some relevant facts about this fire:

- The same area had already burned in 1982. The fire of 1994 burned more than 100 Ha of white pine that had been replanted by the administration.
- This is a vast area of limestone with a small and scattered population. The villages are in the interior and on the coast.
- The first fire engine arrived 25 minutes after the fire was detected. A total of 80 vehicles participated in the extinction of the fire over the four days period.
- Fire fighters and volunteers fought the flames that were reaching farm houses. They also worked to protect the villages as the fire evolved.
- Aircraft were not used until the morning of the second day. Four sea planes and four helicopters could discharge intensively due to the proximity of the sea.

Conclusions

In this paper we have examined to what extent management capacity to use resources effectively can make a significant difference in the reduction of the negative consequences of forest fires. We were also concerned about the use of volunteers as a resource for both prevention and extinction tasks. Understanding that the climate and the characteristics of the territory and the vegetation are paramount, we have seen that the effective management of human and material resources can make a difference and that volunteers can have an impact in support tasks.

We have focussed on the problem of simultaneity, as it happened the weeks of 4 July and 10 August 1994 in the north east of Spain. In those situations, we have learned that mobilizing a significant number of aircraft and equipped people with access to water tanks may be the only way to control a crisis situation. Administrations, however, can be easily overwhelmed by the events unless they have access to a bigger pool of resources (army aircraft, soldiers) as soon as simultaneity does not allow for a quick and massive response in each case.

Overall, the two preventive measures that were included in the analysis seem to be effective. Having guardians that watch for the ignition of new fires has a positive effect, reducing the extension of burnt land particularly in the case of small and medium size fires. The *ex ante* evaluation of risk for a specific day and area also appears to have a positive effect. It may be interpreted that the alert system activates the response and, as a consequence, extinction tasks become more effective. This is exactly what happened in the example of the La Floresta fire.

For extinction purposes, helicopters seem to be the type of vehicle that is more valuable. Since governments have limited resources to invest on helicopters, they should try to maximize the number of water discharges from those helicopters as a way to effectively reduce the final extension of the forest that is burnt. Helicopters may be more manageable and better equipped to land in small spaces to refill their tanks with water from any source and to quickly discharge on the fires. Other types of aircraft seem to need more open spaces both in the air and at the time of landing. They are slower to fill tanks, take off and land. Their effectiveness is related to the number of discharges they release more than the number of units working simultaneously.

As it is illustrated in Figure 1a–d a quick response is vital since the first units are the ones that have a major effect on the control of the fire and on its final size. The more time that elapses between the moment the fire is set and the moment it is massively attacked by air, the more difficult it is to control and the more inefficient administrations appear to be.

Volunteers are important as substitutes and helpers. They are an alternative to the massive use of soldiers. They do critical work attacking flames that approach private houses or helping professionals to reach the places and evacuate people that are in danger. But their contribution to the extinction of the

fires is marginal and their potential effectiveness is dependent on the extent that they have equipment and professional training.

Notes

1. A number of studies have related forest fires to causes of ignition (Davis, 1959; Rothermel, 1972; Pyne, 1984; Burgan and Rothermel, 1986; Andrews, 1986), to fire history in one area (Johnson and Van Wagner, 1985; Dansereau and Bergeron, 1993), to the type of vegetation and weather characteristics (ICONA, 1982; Palmieri and Cozzi, 1983; Martell and Bevilacqua, 1989). Other studies have attempted to model the behavior of fire in specific spaces and times (Rothermel, 1972; Deeming et al., 1978; Pyne, 1984). Finally, a few studies relate volunteer participation and community institutions with fire control (Lozier, 1976; Kurien and Bakhshish, 1996).
2. *Boletín Oficial del Estado*, number 90, 15th April 1993.
3. INFOCAT regulates the tasks of various actors may have during emergencies and gives the commanding capacity to the professional fire fighters.
4. Excluding the city of Barcelona, with its own Fire Department, the extinction program included: 1,327 professional fire fighters, 70 parks, 1,700 volunteer fire fighters in 80 other parks, 725 vehicles of various kinds, 3 permanent helicopters and a variable number of planes and helicopters that were leased in 1994.
5. Cases being defined by the regional administration in their databases.
6. In 1998, the number of hectares burnt is also important but was mainly due to one big fire.
7. This also means that the effects of the explanatory variables will be in terms of percentage changes, not additive effects.
8. The degree of impact can be deduced from the values of the standardized regression coefficients.
9. For the purposes of a T-test analysis, cases were classified in three catagories with the following results:
   - In forest fires of less than 3 Ha, the average response time, both aerial and terrestrial, is reduced by 28% in those instances where the fire is detected by a guard.
   - In fires between 3 and 50 Ha, terrestrial response time is reduced by 60% and aerial response time is reduced by 62%.
   - In bigger fires, there are no significant differences in the response times due to the enormous dispersion in the response time and the relatively low number of cases. Simultaneity might play a role since vehicles can not reach all the places at the same time.
10. The correlational analysis shows in this case that:
    - In forest fires of less than 3 Ha, there is a small but significant negative correlation between risk evaluation and terrestrial response times: $r = -0.073$ ($p = 0.000$).
    - In fires between 3 and 50 Ha, the relation between the two variables is stronger: $r = -0.231$ ($p = 0.000$).
    - In bigger fires, the correlation between probability of ignition and terrestrial response times is also significantly negative and slightly stronger than in the two previous cases: $r = -0.264$ ($p = 0.015$).
11. These variables have been square root transformed with the purpose of making the relation more linear and to avoid functional specification problems. For a detailed description of the assumptions of the linear regression model and the use of graphical displays to detect violations, Hamilton (1992).
12. In a model that only includes variables relating to the number of people working on each case, the analysis shows some extraordinarily large residuals. They correspond to two cases that occurred on 4 July 1994 and 10 August 1994. These two days were the worst in the recent history of forest fires in this region with 28 and 23 simultaneous fires. Investigation of these

two cases revealed that there was no response to those fires, neighter by professional nor by non-professional fire fighters. This had only happened in one other instance, 6 April 1994, a day that also experienced a considerable number of simultaneous fires (11). In order to avoid the effect of outliers, these three cases were excluded from the model.

13. Water discharges were also transformed through their squared root with the purpose to make more linear the relation between the dependent variable and to void functional specification problems in the model.
14. In order to calculate the estimated value of burnt Ha (Y) it is necessary to apply the inverse of the logarithm transformation:
    $Log_{10}(Y) = b_0 + \Sigma b_i X_i$
    $Y = 10^{b0 + \Sigma bi\ Xi}$
    $Y = 10^{b0} (10^{b1})^{X1} (10^{b2})^{X2} (10^{b3})^{X3} \ldots (10^{bn})^{Xn}$ or: $Y = 10^{b0} \Pi (10^{bi})^{Xi}$
15. Once the inverse logarithm transformation is applied, the results in Table 3, Model 3 can be interpreted as:
    - In those instances that a permanent guard detected the fire, there is a 14.5% reduction in the total number of burnt Ha, all other factors remaining constant.
    - A fire that starts in a location that is considered to have a 10% risk of ignition will have a 6.7% smaller size than a fire that happens in a location that is considered not to be at risk.
    - Other circumstances remaining constant, increasing the number of helicopters will reduce the size of fire.
16. Figure 1c, for example, shows the evolution of the effectiveness of helicopters as a function of their number. From 0 to 1, the number of burnt Ha is reduced a 10%. However, from 7 to 8, the marginal reduction in the number of burnt Ha is 5%, having therefore a decreasing rate of performance.

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