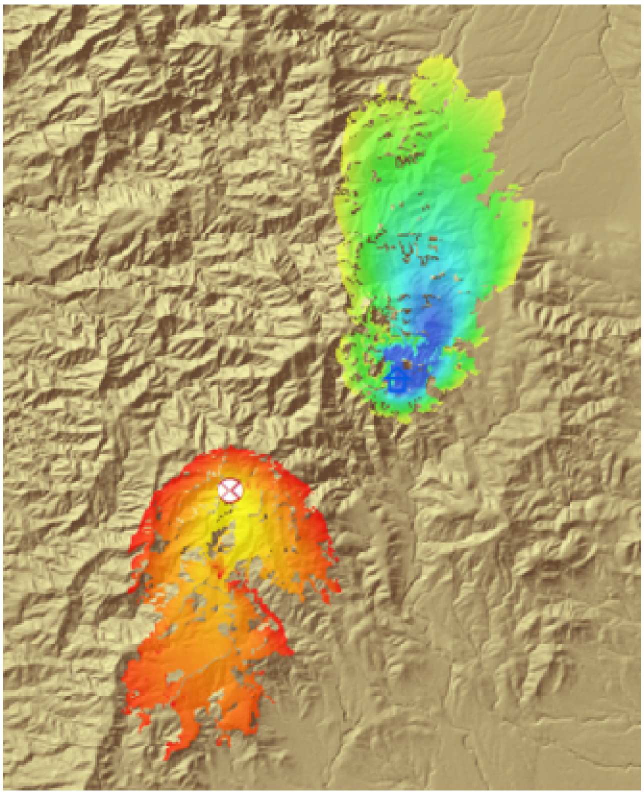
PAU COSTA FOUNDATION

STUDENTS DOSSIER

WILDFIRE SIMULATORS FOR PREVENTION MANAGEMENT



In collaboration with:

FIREfficient

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INDEX

ACRONYMS

CPS: Campbell Prediction System

HRZ: Homogeneous Regime Zones

LWF: Large Wildfires

NFR: Natural Fire Rotation

SMP: Strategic Management Points

WUI: Wildland Urban-Interface

INTRODUCTION TO THE FOREST FIRES

Forest fires are natural processes which without human intervention would be started by lightning, linked to thunderstorms and seasonal climate typical to the Mediterranean systems, generating discontinuities in the forest stands.

These fires have been happening over thousands of years, living with the human being and the rest of the nature, making a model of what we nowadays know as Mediterranean landscape, and propitiating the formations and biodiversity we currently know, adapted and with great capacity of answer facing disturbances.

Integrated in the natural ecosystem, humans have relied on natural resources and have been modifying them according to their necessities. As the human population increased, extraction of resources continued while nature produced more resources for their use and enjoyment in an almost unlimited way. Agriculture, stockbreeding, fire and wood consumption constitute traditional exploitations, which have been able to change the disturbances system in many of our landscapes.

The abandoning of the historical usage, such as cultivation or traditional mountain resource management, have brought about the consolidation of the great continuous woods and forests with important fuel loads of available combustible; which combined with adverse weather conditions, provoke uncontainable kind of fires for the common extinguishing systems. All of this justifies that, currently, the large forest fires (from now on will be referred to as LWF) are the main forest stand agents. Even though, in current society they do not have a good reputation as they are usually related to natural disasters which entail destruction and, sometimes, human victims.

We could say that the forest fires have happened in the past and will occur in the future. It is not neither reasonable nor possible to eliminate forest fires from the Mediterranean ecosystem. The partial or temporary removal of these fires can create more destructive fires.

Although from the ecological point of view there exist fire systems which are natural and totally sustainable, the large quantity of housing constructed in our mountains make some of them unsustainable from a socioeconomically standpoint. This creates many conflicts in the management of the territory. Fire ecology, the branch of science that studies the fires' function in the organisms and ecosystems, provides the scientific basis to improve the territory's management in surroundings where fires have a principal role.

In order to carry out a sustainable management of the resources, it is necessary to have a solid base in the implied processes and to have the basic knowledge to be able to manage our forests with success.

The greatest success in the management of these Mediterranean systems associated to fire is the coexistence of the most sustainable way with the forest fires; encouraging a management focused on rising a better response time from the forest to atmospheric disturbances not just the modification of its fuel and taking into account the ecological and social processes.

GENERATIONS AND INTENSITY OF FOREST FIRES IN SPAIN

Abandonment of fields and the reduction of activities such as pasture technology have meant an increase of the woods and forests, leading to a more aggressive spread of the forest fires. This evolution of the landscape, linked to other socioeconomic changes, has involved variations on the typology of the fires and determines their generation.

The answer to the current difficulties of forest fires has been a reinforcement of the extinguishing polices (provide resources with the extinguishing systems) to increase their extinguishing capacity. However, these incidents of LWF have brought to light the limitation of controllability of these extinguishing systems from technologically developed countries, which have been exceeded for the intensity and velocity of the head of the fires. In these situations, it is decided that the fire surpasses the extinguishing capacity.

Nowadays, we are in the fourth and fifth fire generations, characterized for the easy continual spreading of fires because of the mass of crop-gardens-houses. This is due to vegetation density in the gardens and the continuity of the fuel load between forests and urbanized zones.

1st GENERATION

Fire spread Determined by the availability of a continuous fuel layer, especially scrubs and grasses. The cultivated land is abandoned and vegetation cover reaches continuity. The lack of opportunities for anchor points allows large perimeters.

Fuel accumulation period From 2 to 15 years.

Period Began in Catalonia during the late 1950s to 1960s.

Fire behaviour Surface fires of medium intensities with very large perimeters, burning between 1,000 and 5,000 ha, predominantly by wind-driven fires

Fig.1. Large fire front without discontinuity, characteristic of first generation fires. Source: Bombers de la Generalitat de Catalunya.

Preventive measures Creation of linear preventive infrastructure and water points to facilitate anchor points and to grant better access to the area.

Suppression measures The local response is reinforced with seasonal firefighters.

Development High intensity fires can overcome the linear preventive infrastructures.

2nd GENERATION

Fire spread Fuel accumulation caused by abandonment of land and traditional land management allows fires that spread with high intensities and a fast rate of spread, advancing with spot fires.

Fuel accumulation period From 10 to 30 years.

Period Started to occur in Catalonia in the 1970s – 1980s.

Fire behaviour Fires of high intensity and rate of spread, consuming 5.000 to 10.000 hectares in wind and topography driven fires. The rate of spread overruns the control lines.

Fig.2. High intensity fire exceeding the capability of conventional water-based resources. Source: Bombers de la Generalitat de Catalunya.

Preventive measures Reduction of the time needed for the suppression forces to arrive on scene (detection, distribution of fire stations).

Suppression measures Increase of water-based resources and aerial means for a more forceful attack.

Development Spot fires can overcome linear infrastructure andrapid interventions. Crown fires overcome the suppression efforts of aerial means.

3rd GENERATION

Fire spread Through high intensity crown fires because of vertical continuity of forest fuels and forest homogeneity due to neglected forest management and the suppression of all fires of low and moderate intensity.

Fuel accumulation period From 30 to 50 years.

Period Began in the years 1990 to 2000.

Fire behaviour Occurring during heat waves and generating fires from 10,000 to 20,000 ha, with crown fires, convective columns, and massive spot fires at large distances. This results in very little suppression opportunities and an easily changing fire behaviour, surpassing the capacity of the chain of command to react to information.

Fig. 3 Crown fire which overcomes the suppression capacity. Source: Bombers de la Generalitat de Catalunya.

Preventive measures Risk modelling to adapt the availability of resources to the probability of a large wildfire. Switching from a preventive strategy for fire elimination to a preventive strategy to have tolerable fire regimes.

Suppression measures Analysis of similar fires to anticipate fire behaviour instead of only reacting to it. Confinement strategies. Amplifying fire suppression techniques: reintroducing fire as a tool, power and hand tools, heavy machinery, reinforcing aerial attacks and improving the efficiency combining these measures. Logistics units are installed and the level of decision-making is lowered for a quicker response to changes in fire behaviour. Development Spot fires can overcome linear infrastructure and rapid interventions. Crown fires overcome the suppression efforts of aerial means.

Development Large wildfires with massive spotting potential affecting the Wildland-Urban Interface (WUI). Simultaneity of large wildfires

4th GENERATION

Fire spread Large fires which spread through forests, residential areas and houses without any differences because of the density of backyard and garden vegetation and the resulting fuel load continuity between forests and urbanized areas. Episodes with simultaneity of Large Wildfires in one zone

Period Began approximately in the year 2000.

Fire behaviour Fires that can start and end in the WUI, and burn more than 1,000 ha. Independent crown fires during heat waves.

Fig. 4 High intensity fire moving through a residential area. Source: Bombers de la Generalitat de Catalunya

Preventive measures Pyro-gardening, promoting fuel treatments within inhabited zones, fire resistant buildings.

Suppression measures Attacking the fire while defending houses and people in a new defensive situation. GPS and GIS technologies to trace resources in real time. High importance of fire analysis as a tool. Strike forces to prioritise defensive measures.

Development Simultaneous large wildfires crossing the wildland urban interface (WUI).

5th GENERATION

Fire spread Simultaneous large wildfires in high risk areas with extremely rapid, virulent fire behaviour, crossing urban and peri-urban areas.

Fire behaviour Simultaneous crown fires affecting also the WUI.

Preventive measures Necessity to incorporate fire into forest management directives and guidelines.

Fig.5 High intensity fire front overcoming conventional water-based resources from San Diego (USA). Source: Dave Christenson.

Suppression measures Necessity of cooperation and exchange of resources, information and experiences. Coordination between regions. Continuous learning and exchange platforms.

Development Simultaneous large wildfires crossing the WUI.

FIRE ECOLOGY

Fire is a perturbing element of the ecosystem that generates change based on its affect on in the forest crop. These originate from secondary successions and generate a structure from landscape characterised by a mosaic of zones with a different successional stage. They also influence the animal and vegetation, population dynamic, in terms of nutrients' balance and the availability of soil resources. We must keep in mind their impact on the security of properties and people. Thus, fire is a process belonging to the ecosystems and relevant in its functioning.

The regime of fires has significance in different aspects of the functioning of the natural systems. To understand the regime of the fire allows each type of forestry structure, a response from the stratum as a whole (herbaceous, hedgerow of bushes, arboreal) facing the path of the fire. The knowledge of these processes is essential to define the basis of an integrated management, which considers the disturbances as another characterizing element of the ecosystem. An integrated practise in these ecosystems' conservation must take into consideration that fire is, in its own, a management object and not only a resource to get other purposes like the fuel's reduction, or the improvement of the vegetation and animal population.

The management of fire allows for a large range of possibilities: from avoiding any fire and extinguishing it as soon as it starts to doing nothing and letting the fires' regime follow their dynamic. Another option is an active involvement in the ignition processes, carrying out controlled burnings which imitate the fires' natural regime or that simply lessens the possibility of having LWF. Any of these activities affect the fires' regime, thus managing it. This integration of fire in the ecosystem allows the establishing of management guidelines adapted to the fire's regime, determining the aims and forestry treatments in the creation and maintenance of fire resistant structures, which reduce LWF performance and maximize the offer of direct or indirect properties.

The concept of forest fire is understood as an own ecological process of the ecosystem, which is distinguished from the concept of wildfire as an uncontrolled fire which is an intimidation from the human perception.

Characterisation of Fire Regimes

A fire regime is a generalized description of the role fire plays in an ecosystem. It is typically a statistical concept and can be characterized best through the following parameters: Intensity, Severity, Extent, Frequency, Fire Return Interval and Seasonality.

Forest types develop a distinct structure under the influence of a specific fire regime as a result of the interaction between the different parameters and the ecosystem. Considering the purpose of this document, the parameters characterising fire regimes can be described as follows:

Intensity

Fire intensity measures the physical extent of fire disturbances. It specifies the power of a fire in terms of energy release and is strongly dependent on stand structure, defined by the available fuel load and its horizontal and vertical distribution. The energy release (kW) is expressed per unit of length (m) of a linear fire front. As this is difficult to measure, observed flame length can be related to fire intensity and can serve as a rough estimate of fire line intensity.

Severity

Severity is a qualitative measure of the immediate effects of a fire on an ecosystem. It refers to the degree of loss of organic material, mortality, effect (% of crown scorch in trees) and survival of both above- and belowground biomass. It is determined by the heat released both above and below ground.

Extent

Extent refers to the area affected by fire. A clear distinction is made between outbreaks (fires smaller than one hectare), wildfires (fires between 1 and 500 ha) and large wildfires (associated with fires larger than 500 ha). Fires that become large in size usually reach their extent because they have exceeded suppression capacity, although this depends also on other variables such as the suppression system, the ecology and topography of the area, etc.).

Frequency

Frequency refers to the number of disturbances which occur in a specific area and over a certain period of time. It is defined as the number of fires per time unit in a particular area.

Fire Return Interval

The return interval is the time needed until an area may again be affected by the same disturbance. It can be calculated as the inverse of the frequency in years between the disturbance events.

Seasonality

Seasonality refers to the physiological state of the vegetation at the time a disturbance occurs. The effects of a disturbance and also its development are depending on the processes of plant development, dormancy, reproductive control, and stress physiology that creates a structural heterogeneity in vegetation.

Effect of fire as a disturbance on species dynamics

Fire can act as a disturbance factor resulting in a **stand replacement** or in a **maintenance** fire regime, depending on the intensity with which it affects a forest stand.

Stand replacement

Stand replacement results from high intensity fires and causes high mortality in all structural layers, implicating a substitution of the major part of the individuals through regeneration or resprouting, see Figures 6 and 7. Stand structure disappears, forest resources are lost and the mid- and long-term management objectives will have to be totally reconsidered.

Figures 6 and 7. Fire as a stand replacing disturbance factor in *Pinus halepensis* after fires of high intensity (left). The disturbance results in a structural change of the forest stand and in the occurrence of new light demanding species (right), Zuera (Zaragoza/ Spain). August 2008. Source: Bombers de la Generalitat de Catalunya.

Maintenance

Maintenance is a process associated with low and medium intensity fires. The herbaceous and shrub layers may be partially or fully affected, and the tree layer partially. The stand structure does not completely disappear, Figure 8. The fire resistance of the stand is increased, Figure 9, timber capital is maintained and the basic management goals will not need to be modified

Figure 8. Fire acting as a maintenance factor in a *Quercus suber* stand affected by a rapid surface fire, destroying the herbaceous and shrub layers. The tree layer is not severely damaged, and shade conditions are preserved (left).
Figure 9. *Pinus nigra* regeneration in canopy gaps opened up by fire disturbance (right). Source: Bombers de la Generalitat de Catalunya.

Vulnerability of forest structures

Generally, a fire regime can be directly linked to vulnerability of vegetation structure. However, since a wide range of fire intensities, from crown fires to Surface fires, can result in the mortality or survival of individuals, depending on the ecology of the species and other factors, it is not easy to see the link. Different stand structures, when affected by the same fire, will show different degrees of vulnerability to fire occurrence.

Silvicultural treatments may modify a fire regime that is linked to a forest stand through altering stand structure, i.e. accelerating processes at the most vulnerable development stages and maintaining those structures least vulnerable to fire over time. The frequency and type of silvicultural treatments in any stand structure may mitigate its vulnerability or maintain its resistance, depending on the characteristics it shares with the fire regime that defines it.

Vulnerability depends on type of stand structure (referring to stand characteristics, dominant species, spatial distribution of individuals and succession cycles), terrain and weather conditions. Below (Figures 30, 31 and 32) a qualitative approach is used to illustrate vulnerabilities on a relative scale, where the colour code indicates that vulnerability is high (red), medium (orange) or low (yellow).

Fig. 10. Dense structure with vertical continuity from ground to Crown. Source: Bombers de la Generalitat de Catalunya.

Fig. 11. Dense structure but with vertical discontinuity between the pine needle bed and the live branches of the crown base. Source: Bombers de la Generalitat de Catalunya .

Fig. 12. Structure cleaned and pruned. Source: Bombers de la Generalitat de Catalunya .

Explanation of the colour bars: The probability that a stand will burn in a certain way (and thus display low, medium or high vulnerability to fire disturbance) is directly related to its structure (owing to silvicultural treatments) and development stage. The colours indicate the vulnerability of a stand (low, medium or high vulnerability); the length of the coloured bar resembles the relative importance of the degree of vulnerability to fire impact.

Natural Fire Rotation and Homogeneous Regime Zones

Natural fire regimes refer to the role of fire in landscapes without human intervention, however, including aboriginal fire use. In ecosystems fire regimes can be characterised through a set of parameters (see above). Natural fire regimes, however, are modified by human activity, increasing fire occurrence (e.g. in the western Mediterranean basin) or decreasing it (e.g. in boreal forests where fire suppression has decreased fire frequency and extent). In fact, referring to a natural fire regime makes little sense in regions with strong anthropogenic influence, such as the Mediterranean basin. One has to go far back in time where climatic and vegetation conditions were different from today to find a hypothetical situation with only little impact by humans

For Catalonia there are hardly any data on fire severity and intensity, whereas a lot more information on number of fires and burnt area is available. In this context, it appears the most viable way to characterise a fire regime through the calculation of fire frequency over a determined time period. The Natural Fire Rotation (NFR) is calculated to obtain area frequencies. The NFR represents the time period necessary to affect the whole of a homogeneous fire regime zone under a given synoptic situation. As an example, for Catalonia the Homogeneous Regime Zones (HRZ) were calculated, see Figures 13, for a period of 40 years, where existing data were extrapolated and processed.

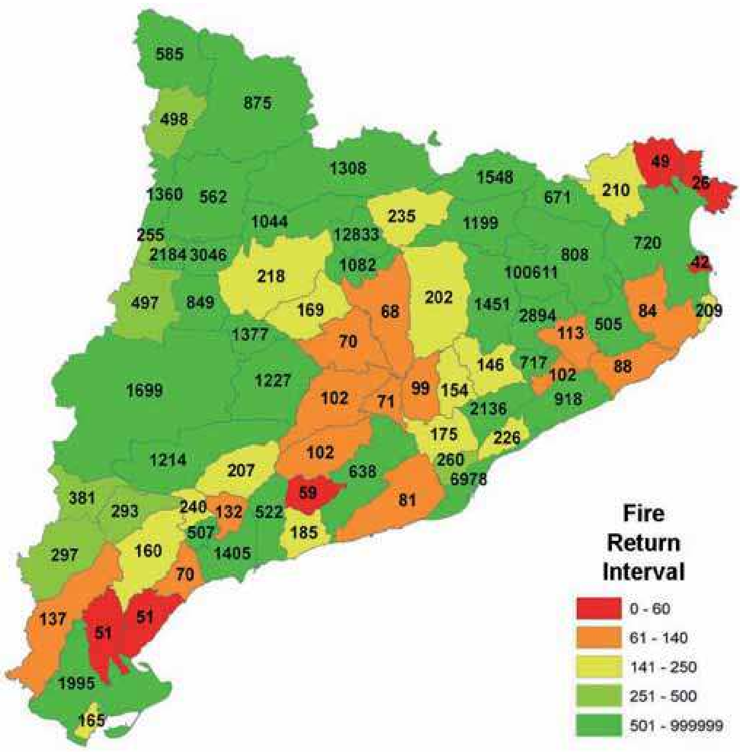


Fig. 13 Based on the analysis of fires over the past 40 years in Catalonia. Fire Return Intervals are shown for each zone. Source: Castellnou et al, 2009.

CAMPBELL PREDICTION SYSTEM

The entire methodology for the characterisation of the spread of each Fire Type is based on the Campbell Prediction System (CPS) and on observed fire behaviour.

The Campbell System is a practical methodology to use in the disaster area, through direct observations of the fire to determine the expected behaviour of the fire, the development of strategies and accurate tactics to the aforesaid behaviour. In the CPS, the observed behaviour of the fire becomes the base line create predictions of the fire's behaviour. The CPS is a methodology which allows us to predict the potential behaviour of the fire and locate where it is possible that the fire would overtake the extinguishing capacities or, otherwise, the points which will be more effective to control it. Establishing which points the forest fire changes its performance, will allow us to:

- *Apply the extinguishing resources of the fires in more efficient areas.*
- *Avoid the areas where the firemen's security can be compromised.*

The CPS has combined the scientific investigation with the firemen's knowledge to explain the behaviour of the fire. In CPS, logic replaces intuition, promoting a rational development on the tactical application.

The **basic factors** affecting fire behaviour are too complex to be considered when making real time and on site fire behaviour predictions. The most important factors have to be reduced to three basic ones to come to a practical analysis approach.

The facts that affect and determine the performance and dissemination of a forest fire are assorted. In the basic fire's triangle, figure 14 (heat, oxygen, fuel), we must take into account the: Meteorology, Topography and Fuels. In this context, we understand fuel as the forest vegetation.

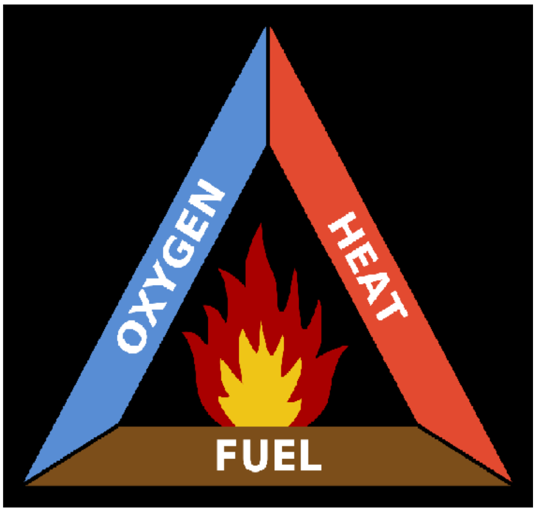


Fig. 14. Fire's triangle diagram. Fuente: The Fire triangle created by Gustavb using Inkscape. == License ==

Aspect

Aspect determines fuel surface temperature and flammability through solar radiation. The higher the fuel temperature, the shorter is the preheating process, and thus the intensity and speed of the combustion process is increased. The impact of solar radiation on fuel flammability changes during the course of the day and can be classified sequentially: east, south and west, or, by order of intensity, south, west and east (in the case of the northern hemisphere).

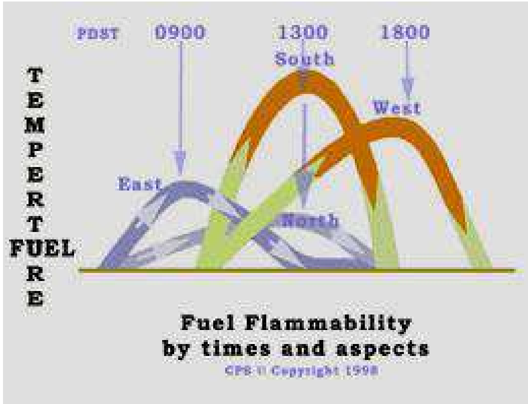


Fig. 15. Fuel flammability through solar radiation by time of day and aspect. Source: Campbell, 1995

The slopes oriented to the South are exposed to a higher solar heating: the temperature is higher and the moisture is lower. The combustibles are hotter and drier. This warming changes throughout the day, as the sun moves to the West. This makes the behaviour of the fire different depending on whether the slope is hot or cold.

This rule of cold and hot mountainside depending on the orientation has to be applied to interpret the combustible reaction in the combustion. Its temperature changes because of the solar radiation. This fuel temperature rising affects both the intensity and velocity of the spread propagation. Thus, the position determines the fuel's inflammability curve.

Slope

Upslope fire spread is faster and more intense due to the fact that distance and angle between the inclined flame and the fuel is shorter, which facilitates the preheating of the combustible material ahead of the fire front. Down slope fire spread produces less preheating and is slower, due to greater distance between flame and fuel.

Fig. 16. A fire coming down backwards a descendant slope can change its performance when it reaches the bottom of the valley and change the direction of the slope mountainside. Source: NWCG

It is important to determine the relative position of the fire in the slope or mountain range, as it will define the potential path that the fire will follow. The situation of a fire in the bottom of a ravine in the middle of a slope or at the top of a summit is very different: its spreading power radically changes. Equally, we must take into account if the fire is inside a pool, in other words, if it is surrounded in its two sides by ascendant slopes.

When the fire reaches a ravines' knot, the fire could spread to one of the two slopes, depending on:

- The direction of the valley's winds, affected for the orientation and the time of the day.
- The dominating winds in the bottom of the ravine.
- Whirlwinds on the split of the ravine.
- The availability of fuel in the split zone.

We have to keep in mind all the time that the land's configuration affects the patterns of the wind and the spread of the fire. The topography interacts with the wind in a powerful way: depending on the wind's prominence the direction, intensity can change and even whirlwinds can be created.

Fig. 17. A fire spread on a slope adopts a characteristic wedged-shape. Source: Bombers de la Generalitat de Catalunya.

Wind

Just like slope, wind accelerates fire spread due to its effects on pre-drying and reinforcing radiative heat transfer on fuels, and impelling and oxygenating the combustion: flames are inclined in a narrow angle to the ground due to wind effect. This implies:

- Larger flame lengths and therefore a larger quantity of fuel that is readily burning and interacting.
- Pyrolysis rates are increased when more fuel is exposed to flames.

In a fire without presence of the wind or slope, the convection and radiation transference affects in less intensity the fuel near the flame, the convection dispels to the vertical and radiation.

In the same case, but with wind presence, the flame will give a closed angle in relation to the floor, which will involve a higher quantity of fuel which in each moment is burning and interacting, and will give a higher longitude of flame and an increase of pyrolyzation of the nearer fuel.

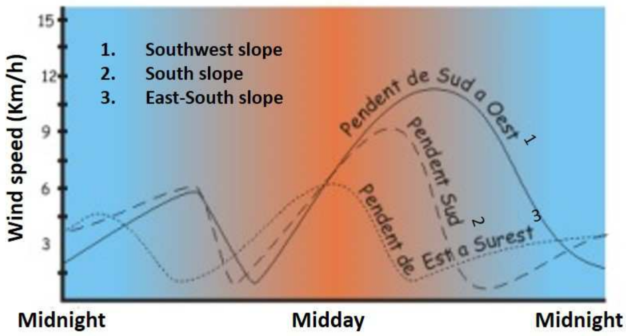


Fig. 18. Local Winds Speed in relation to the time of the day. Source: Bombers de la Generalitat de Catalunya.

The winds which affect a topographic fire are local winds, as a result of the differences of the local degrees and air pressure. The land has a considerable affect on the local winds. The more varied the land is, the higher is the influence. During the day sea breeze blows from the sea to the land and during the night the land breeze blows back to the sea. During the day, the valley and slope winds blow from the lower to the higher parts and, during the night, the air movement is upside down.

CPS Field Logic

The Campbell Prediction System (CPS) can be defined as a simple operational tool using the basic fire spread factors - aspect, wind and slope – as input variables to provide a logic and brief analysis for suggesting tactics based on predicted fire behaviour that are limited in space and time (time tags). The logic of the system is based on the **alignment of forces (figure 19), a concept that describes how the three basic fire spread factors coincide in favour for or against the fire and how they affect the fire front.**

AlignmentofForces	
Aspect	
Slope	
Wind	
Full Alignment (3/3)	+ +
Medium Alignment (2/3)	+ +
Small Alignment (1/3)	

Fig. 19. Example of CPS language. Source: Campbell, 1995.

*Example: A fire occurring at the bottom of a south-facing slope at 12:00 hrs with a southerly wind is burning in **full alignment**: the fire can run upslope, with the wind and in hot fuel. The same situation at 08:00 hrs a.m. is burning only in **2/3 alignment** (wind and slope), since at this time of day the hot slopes are the east-facing ones. When in this situation the wind changes from the north, the fire burns in 1/3 alignment (slope). When the fire starts at the top of the slope, the fire is burning **out of alignment** as it has to **spread downslope against the wind on a slope with cold fuel.***http://www.dougsfire.com/

SPREAD PATTERNS

The studies of the spread patterns allow us analyse that, in the same topography and meteorology (synoptic situation), the fire can spread following similar blueprints, changing its intensity depending on the availability of. The type of extinguishing opportunities and the changes of the behaviour respect the orography will be the same.

The "spread pattern" concept is referred to the key element that allows us schematise the way as the fire moves itself through the topography, and let us distinguish three types of fires depending in their spread patterns:

- Topographic fires: The combinations of local winds, differences in the warming level of combustible because of its orientation and the gradient of the slopes will determine the pattern of the fire spreading on the land.

- Wind-driven fires: They are fires spread in the direction of the wind and they are roughly speaking adapted to the land morphology. These types of fires are very fast and continuous, with shoot up flanks and less powerful and slower lines.

- Plume-dominated fires: They are fires where the fuel accumulation, in a great quantity, allows the third dimension of the fire atmosphere formation, the vertical, in charge of its development and intensity. It spreads because of secondary seats in mass, which interact between them generating a high intensity and reinforcing the warmth transference and new secondary seats for convection, feeding back the system.

Topographic fires

The topographic fire is such that the main influence on the behaviour of the fire will have to be found in the topography characteristics. The topography is the key to understand the fire movement and its spread.

In these fires, we have to analyse in each place and moment what the fire is doing and why. The logical analysis which has to be applied is to determine the force aligning which commands the behaviour of the fire in each flank or front of the fire, and on its future change.

Unlike fires driven by wind and fuel, the topographic fires give much variability in each of its fronts depending on the combination of the spread strength.

Wind-driven fires

The potential of a wind-driven fire is determined by the general wind interaction with the topography and availability of fuel. The head of the fire will always find the maximum velocity line of the wind, as a continued fluid performance would display.

When the power of the wind dominates the fire spread, predicting the probable fire behavior, which will be brought depending on the wind function, power and duration of the meteorological term that causes it, it is easy enough.

Fig. 20. The wind-driven fires have as a characteristic inclined columns and extended and narrow perimeter. Forest fire of Ventalló, 2006. Source: Bombers de la Generalitat de Catalunya .

The pattern of the movement of these fires can be evaluated knowing the wind movement on the expected topography. The column of smoke will be the best sign of this interaction, supplying a lot of proof of the power, direction and interruption of this flow of wind. To predict the changes in the wind is critical as the wind changes can represent a serious menace for security.

The secondary seats would almost be created in favour of the wind and are one of the principal contributors of the fire propagation. When the fire burns in old woodland masses with heavy fuels which have the capacity to generate hot ashes in a long-term and the convective elevation is reinforced, winds of 60 km/h can produce secondary seats from 500 to 1.000 meters ahead the main fire.

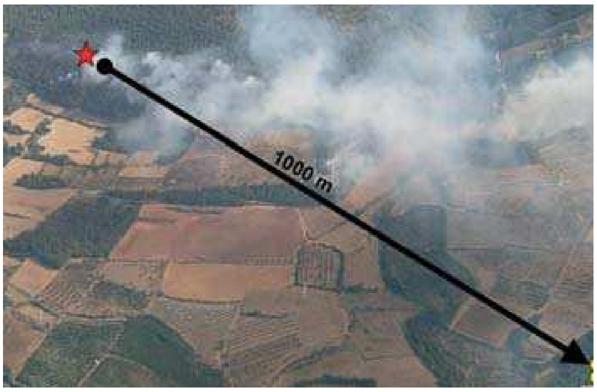


Fig. 21. Forest fire in l'Espluga de Francolí, 2006. The star indicates the starting point of the main track and the yellow dots, a secondary seat. Source: Bombers de la Generalitat de Catalunya.

Equally, it is pretty probable that a crown fire turns up, supported by the strong winds at the height of the canopy tree when the fuel moisture is low, regardless of the topography.

Observing a wind-driven propelled fire, we can see a broken convective column or directed by the wind. When the column is inclined on the floor, the convection of the heat helps to warm up the combustible that is ahead the fire, rising the propagation and intensity.

A fire directed by the wind can become a fire directed by convection, when the emitted energy by the fire generates a convection column of which ascendant power becomes higher than the wind.

Also, as the general wind loses velocity, it can become topographic, producing certain confusion when changing the type of propagation, with the possibility of creating new fronts.

Special attention should be paid to the wind bracing zones (winds in opposite direction from the general wind), which are created because of the general wind interaction with the topography.

The main characteristics to identifying a fire directed by the wind are:

- High velocity of propagation spread.
- Secondary seats being created at long distance.
- The direction of propagation spread is easy to predict.
- The propagation spread of the fire flanks and tail is slow and they are also easily attacked.
- The wind changes can represent a serious security problem.

Fig. 22. Forest fire in l'Escala, 2001. Emphasising the falling zone of the smoke column, where the fuel is preheated before the fire arrives and can present secondary seats. Source: Bombers de la Generalitat de Catalunya.

Plume-dominated fires

The plume-dominated fires are conflagrations where the convection column is generated because of the big burning of fuel, and the developed winds are the predominant strength for it. The fire in its own influences in the winds map which affect it. They are normally associated to synoptic episodes characterised for low relative moistures without night recuperation. These kind of fires usually take place in LWF which affect the peninsula; for example the fires in Bages (1994) and Las Hurdes (2003), where the synoptic situation combined with a prolonged drought period promoted the ideal conditions to become connective fires with a great capacity of propagation.

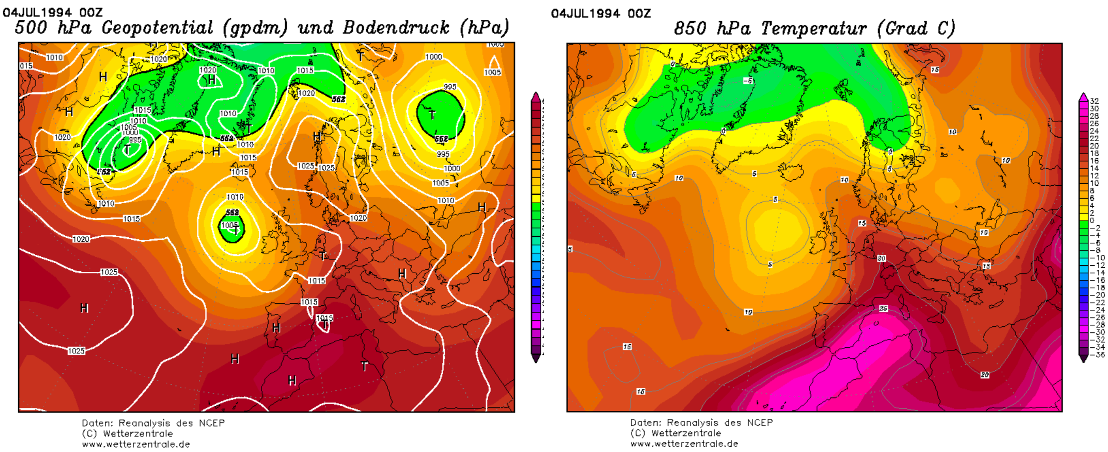


Fig. 23. Synoptic situation from 04/07/1994. Source: www.wetterzentrale.de

They are fires which it is not easy to predict the direction and velocity propagation. The propagation of the fire is dominated by two main factors: the ambient of the fire created with its own fire and the secondary seats. Given the availability of heavy fuels, it produces secondary seats in mass and all directions, which interact to each other and generate other high intensity fires, reinforcing the warmth transfer and new secondary seats, feeding back to the system. This kind of propagation causes an impetus or hindrance of progress of the fire.

Only when the fuel is finished or the meteorological conditions change significantly (rise of the relative moistures, descent wind, decrease of temperatures, etc.) or macro-topographic (basins of first order and main mountain chains), the fire changes its behaviour and allows its control.

Fig. 24. Forest fire in Castellnou de Bages (2005). Plume-dominated fire, the propagation is observed from different the front of the fire points. Source: Bombers de la Generalitat de Catalunya.

EXAMPLE OF SYNOPTIC SITUATIONS WHICH GENERATE LWF IN CATALONIA

Definition

The analyses of the different synoptic situations that affect Catalonia are useful to carry out a classification of the synoptic conditions that more commonly cause LWF during the warm period. The starting point is based on the analyses of different geopotencial height maps at 500 hPa and the surface pressure and the map of temperatures at 850 hPa. These two maps can be checked in the German web of meteorology where we have registers since 1887.

Northern wind situation

They are usually characterised by strong and dry winds from the centre of Europe. To identify these kinds of situations we must take a look on the map 500hPa where we have to identify a low pressure “T” in the Mediterranean and anticyclone “H” in the northwest of the Iberian Peninsula. The fires that are developed in this situation are usually propagated by the wind, as if it is joined with a great availability of fuel causes an increase in the distance secondary seats launches. A good example of these kinds of fires is the fires in St. Feliu de Guíxols (2003), Jonquera (2012).

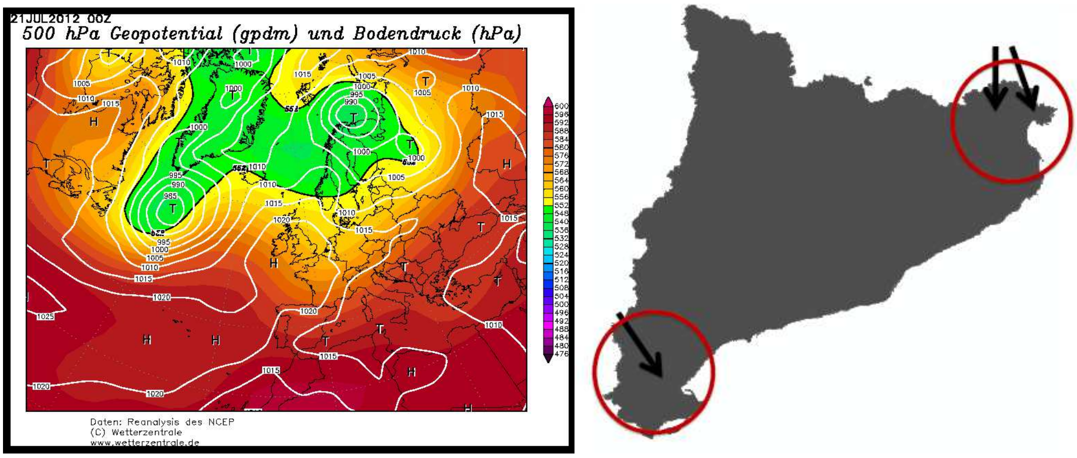


Fig. 25. North-dominated wind synoptic situation. Source: www.wetterzentrale.de

Western wind situation

They are usually characterised by dry winds coming from the West of the Iberian Peninsula. To identify these kinds of situations, we have to look at map 500hPa where we have to identify a low pressure "T" in the northwest of the Iberian Peninsula which brings an air circulation from the West to the East making the air go through all around the peninsula. The fires that are developed in this situation are favoured by the overheated and very dry wind provoked by the Foehn effect. When this wind usually arrives in Catalonia, it stops the marinade entrance (sea breeze) avoiding recovering the night moistures. This synoptic situation usually develops plume-dominated fires. Good examples of them are Gualba (1994) and Rubió (1986).

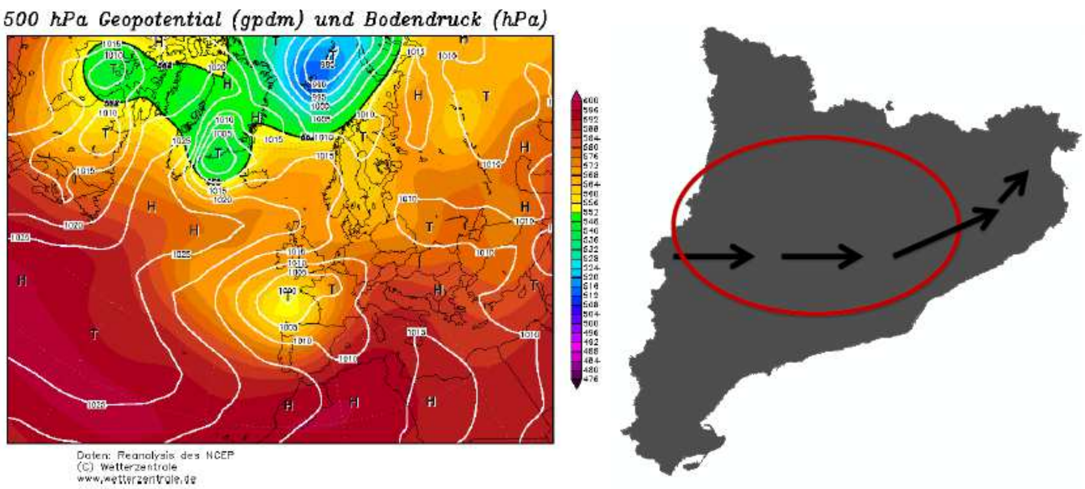


Fig. 26. Northern wind synoptic situation. Source: www.wetterzentrale.de

Southern wave situation

They are usually characterised by high temperatures and rather low moistures. We must differentiate two situations: if the south entrance is produced through the sea, the humidities will not be so low but if the south entrance comes from the inside of the peninsula the humidities will be very low. To identify these kinds of situations we have to take a look on map 850 hPa where we can to identify pressure “T” in the West of the Iberian Peninsula which implies an air circulation from the South to the North making the air going through the whole peninsula and the isotherm of 20 or 25 settled on Catalonia. The developed fires in this situation can be favoured by the South or Southwest wind and can cause plumed-dominated fires. A good example of them is the fires of Solsonès (1998).

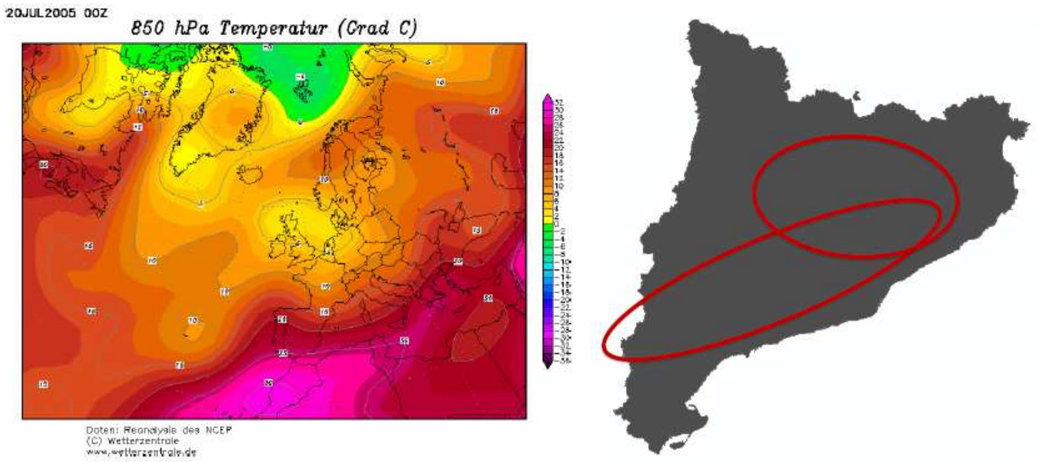


Fig. 27. Southern wave synoptic situation. Source: www.wetterzentrale.de

FIRE TYPES

When analysing historical fires it becomes obvious that under the same topography and weather (synoptic situation) conditions, fire spreads following similar spread schemes. The Fire Types are derived from the analysis of common factors in these spread schemes.

A certain Fire Type does not necessarily implicate certain fire behaviour. It is the difference in the fuel structure, land use or in ignition points, which causes variation in fire behaviour. However, the spread scheme typically is maintained. In addition, the types of suppression opportunities and points where fire behaviour changes will be the same when the relief is taken into account.

The starting point to determine whether a Fire Type follows a common spread scheme is the spread pattern as the dominant factor in the wildfire. The concept of spread patterns refers to the key element to outline the way in which the fire spreads over the terrain. Depending on the spread pattern, three main types of fire can be distinguished.

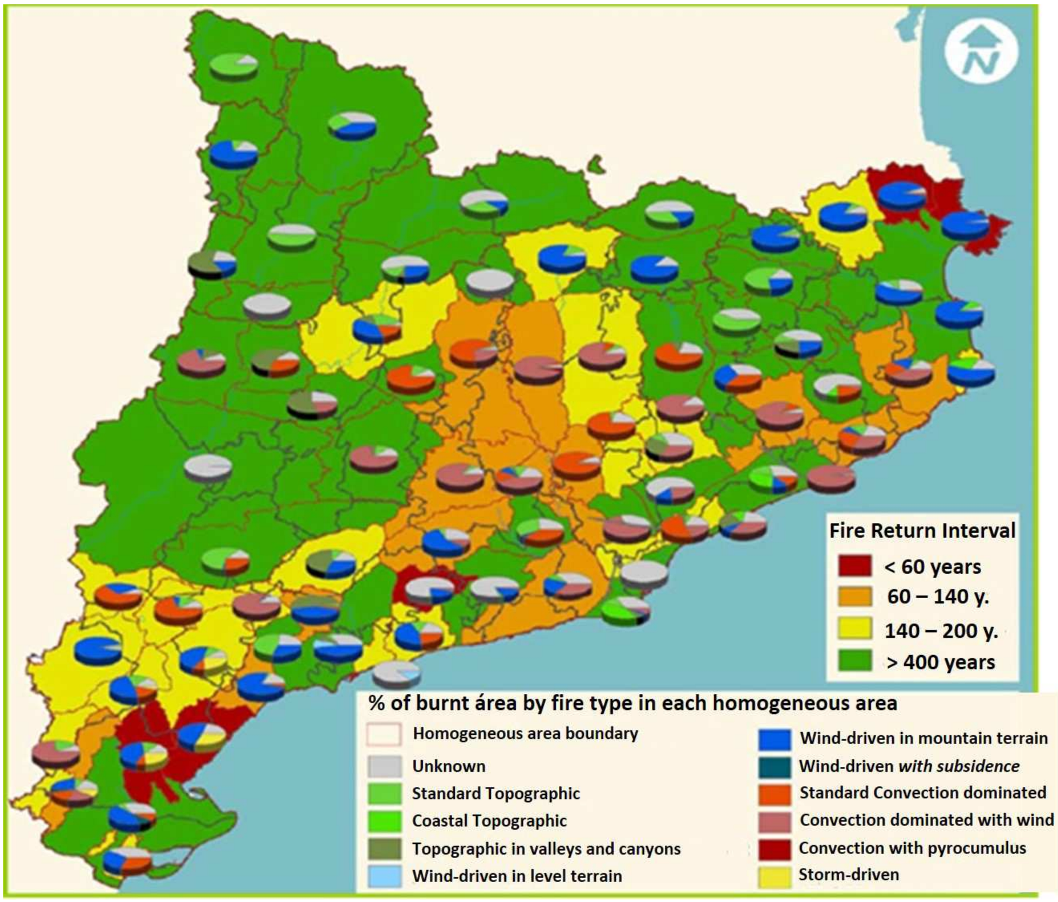


Fig. 28. Agrupation of HRZ by intervals of the fire period rotation. A percentage of the burnt area in each fire type is shown in the different HRZ. Source: Piqué et al., 2011.

Standard Topographic Fires

The standard topographic type fires are denominated for a warm meteorological situation, which will facilitate the local convective winds and the difference in the combustible on the sunstroke situated in different orientations, creating warm slopes, where the fire goes through with intensity and cold mountainsides, where it slows down.

Spread Pattern

The propagation of a topographic fire is distinguished during the day. During the day, the fire will follow the maximum slope and the sunstroke mountainside (warmer fuel) raising its speed. In the afternoon, there are descending winds, with a medium calmed period, so, the tail of the fire, which had this change in the direction of the local wind, can become a new front of the fire. The dynamics head/tail is linked with the slope and sunstroke. These kinds of fires are ever changing.

Diurnal Standard Topography Fires are the most common fires because they coincide with the time period of highest risk and therefore, with the highest number of ignitions. The local winds are in this case upward winds (both valley and slope winds). Fires starting at lower parts of a basin have the biggest spread potential since they have wind and slope in favour, see Figures 93 and 94. On the contrary, when a fire is burning in the upper parts of a basin its spread potential is lower because of down slope and counter winds. If a fire spreads in the bottom of a ravine it develops a head on each slope with the respective flanks. The fire spread in this case is determined by the progression of the flanks upstream which give each slope the opportunity for new runs.

During Nocturnal Standard Topography Fires, the wind flow is down valley and down slope and solar radiation is not a factor. The balance between the downward wind and the topography determines the direction of the fire spread. This is the biggest difference to the diurnal topography fires where fires spread along the upper parts of the crest lines and are dissociated in two heads every time they arrive at the junction of two crest lines.

Coastal Topographic Fires

Coastal topographic fires are dominated by the sea temperature. These fires are usually important when the relative moisture of the air mass is low (dry maritime air) and the sea temperature is high, generating strong maritime airs (sea breeze). They are usually given by wedged-shaped anticyclones which let dry continental air out to the sea. This situation can be reinforced by southern waves, intensifying the fire performance.

Spread Pattern

During the day, the coastal topographic fires follow the highest slope and the turn of the sea breeze, defined and expected. They are normally started at the low parts of the coastal slopes, spreading upwards through the hottest hillsides. When the fire gets to the summit, it finds wind bracings that stop the propagation. It can help to create many secondary seats in the high parts of the hillsides if it finds general winds in a favourable height to the propagation.

Fig. 29. In the topographic fires, a ravine knot (in red) is a critical point. In yellow, the potential surface available to get burned. Source: Bombers de la Generalitat de Catalunya .

In the course of a day wind direction associated with the sea breeze changes. A sea breeze is a wind caused by thermal compensation between sea and land surface. Its direction changes during the day with the influence of solar radiation when the sun moves along the slopes. This phenomenon occurs whenever there is direct influence from the sea, i.e. when the land relief is not a significant barrier.

Catalonia, for example, the direction of the sea breeze changes from an easterly direction at the beginning of the day towards the west at the end of the afternoon, breezing from the south during noon. It is important to understand the defined and expected rotation of the sea breeze in connection to the total local wind flow and its effects on the area burning.

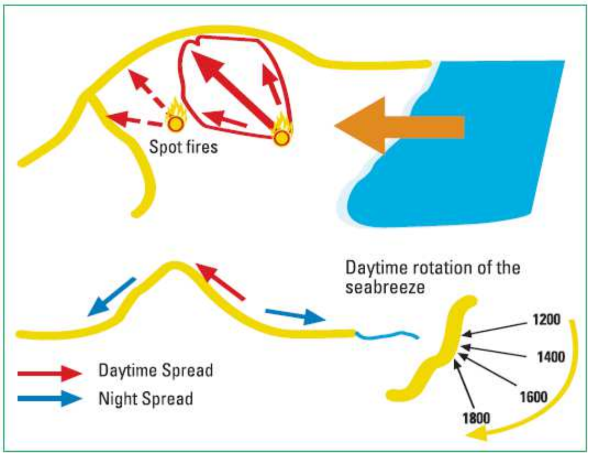


Fig. 30. Spread scheme of a topography fire on slopes in coastal areas. Source: Bombers de la Generalitat de Catalunya .

The spread pattern of these fires at night is similar to the one of the nocturnal standard topography fires: the flow of valley and slope winds is descending and solar radiation is not a factor. The balance of forces between the descending wind and the topography determines the direction of fire spread.

Topographic Fires in main valleys and canyons

The unique characteristic of this kind of topographic fire is that a suction of the fire is produced towards the main valley by the *Venturi* effect. This suction in the main valley shows the highest axis of the fire spread.

If the fire is placed in the main valley, the behaviour will be topographical, losing its alignment when it arrives to the summit. If the fire is outside the main valley, it will try to get in the main valley through the summits.

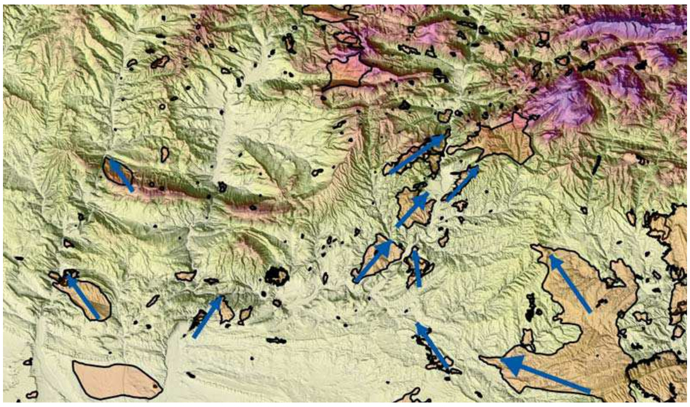


Fig. 31. Perimeters of fires affected by the suction of Segre main valley. Source: Bombers de la Generalitat de Catalunya.

Spread Patterns

Diurnal: The main valleys of important hydrographical basins have a more intense local wind regime and a greater air volume flow than in secondary valleys. The phenomenon of the movement of large air volumes with greater intensity than the surrounding air where valleys are narrowing generates underpressure and the suction of surrounding air towards this area (Venturi effect). Therefore, fires burning in secondary valleys close to a main valley tend to converge towards the air flow of the main valley.

Fires occurring on slopes in narrow valleys typically have a spread scheme similar to the one of main valleys. The wind speed in canyons increases and can suck the fire into its interior, thereby creating fire runs in the canyon and an extension of the front at the opposed exit of the canyon. The zones not influenced by the canyon winds are affected by general and topographic wind, thereby increasing the perimeter of the fire.

Nocturnal: The flow of valley and slope winds is decreasing and insolation is not a factor by night. The balance between the downward wind and the topography will determine the direction of the fire spread. The descending valley winds dominate the descending slope winds. Consequently, the perimeters of nocturnal topography fires tend to spread their flanks following the direction of the main valley.

In extreme cases (e.g. near canyons close to main valleys), the descending valley wind is the only factor dominating the fire spread and head fires are running in the direction of the canyon or in parallel direction to the main valley without respecting the topography.

Wind-driven fires in level terrain

In level terrain and plains wind-driven fires follow the wind direction and are opening with an angle between 30º and 60° depending on the strength of the wind. In the initial phase of a fire the flanks are opening and generate new runs while at the same time the wind prevents the back of the fire from spreading.

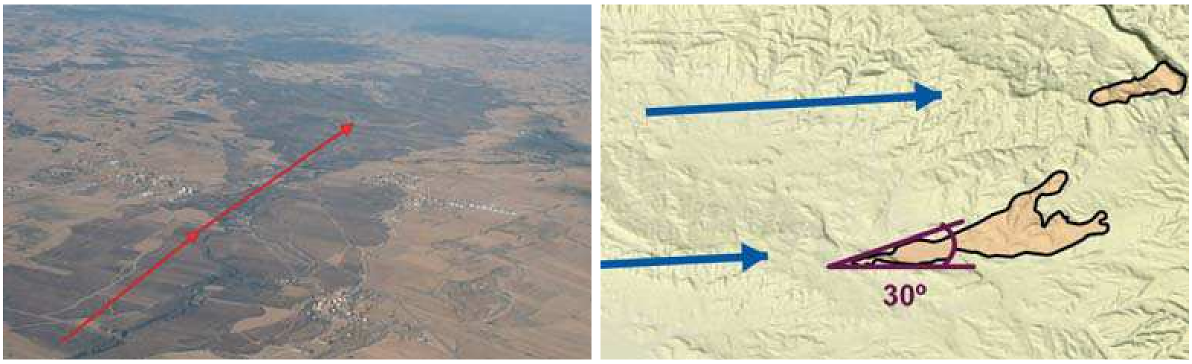


Fig. 32. Ossó i Selvanera Fire, 2003. The red arrow indicates the spread direction of the fire. Perimeter opening at 30º and main runs following the direction of the wind. Source: Bombers de la Generalitat de Catalunya.

Wind-driven fires in mountainous terrain

The potential of a wind-driven fire is conditioned by the general wind interaction with the relief and the fuel availability.

The head of the fire will always search for the maximum wind speed line, as the performance of a continuous fluid would show. The movement pattern of these wind fires can be evaluated by knowing the wind movement on the expected relief. We can find three kinds of fire typologies depending on the relief disposition in relation to the general wind direction.

Fig. 33. Cap de Creus Fire. The perimeter follows the mountain ranges parallel to the prevailing winds. Source: Bombers de la Generalitat de Catalunya .

Mountain ranges parallel to wind Direction

The head fire is spreading along the ridges of the mountain ranges in alignment with the wind direction, usually affecting both slopes. Opportunities are at the end of the water divide, or where the mountain ranges have a change in aspect, at a bifurcation or when backwinds occur.

Mountain ranges perpendicular to wind Direction

A mountain range perpendicular to the main wind direction produces turbulent winds. Since the wind takes the shortest way to overcome the mountain range, these zones can produce sudden changes of the wind flux, remaining almost without wind (leeward) or even generating local fluxes against the dominant direction (backwinds). The occurrence of leeward or counter winds depends on the height of the mountain range which is perpendicular to the wind, the wind speed and the main wind channels on macro scale. In high relief the wind escapes along the lower elevations while in inverted and complex relief the wind escapes over the upper elevations.

The propagation of the fire is leeward descending from the topographic summit and wind bracing, until the dividing point, where the general wind stops its propagation. If the tail overtakes the wind bracing line, the general wind can affect the secondary summits parallel to the general wind. In this situation, the fire will have two heads, the wind bracing until the summit and the head directed by the main wind.

Fig. 34. Coll de Nargó Fire, 2004. Left: Point of origin (red star), direction of the general wind (blue arrow), ridge axes perpendicular to main wind direction (black arrow), backwinds (blue circles). Right: Fire affected by backwinds at night. Source: Bombers de la Generalitat de Catalunya.

Mountain ranges diagonal to wind direction

The interaction of mountain ranges diagonal to the main wind direction produces a distinct spread scheme, burning either with the main wind in favour (direct) or against it (indirect). Diagonal mountain ranges and turbulent wind zones produce fire runs that spread differently from the main wind direction and create difficult situations for specific direct attack operations.

Fig. 35. Montgrí Fire 26/09/2008. Left: Point of origin (red star), main wind direction (blue arrow), fire perimeter (red line), mountain range diagonal to the wind direction (purple line). Right: The general wind restrains the left flank and prevents it from descending downslope (green line). Source: Bombers de la Generalitat de Catalunya.

Wind-driven Fires with *subsidence*

This phenomenon occurs in coastal mountain ranges in the extreme south of Catalonia when diurnal topographic winds have the capacity to compensate high altitude northerly wind. At night, the northerly winds are descending on the Surface being reinforced by the also descending topographic winds. During daytime, the fire behaves like a standard topographic fire and like a wind driven fire at night time. This dynamic fire behaviour implies that the back of the fire during the day can transform into the head of the fire at night and vice versa:

- The fire during daytime behaves like a topographic one. On the high parts, the NW wind can originate strong accelerations of the fire. The column goes up but it inclines to the SE in height (obvious indicator). Winds from 5 to 20 km/h.

- During the night time the northwest wind dominates with maximum force around 2 and 3 in the early morning, with winds of 50 and 60 km/h, which creates strong accelerations of the fire searching the coast line. A width is produced in a descending way which a wind performance in parallel mountain ranges. The width of the head (b) or tail (a) depending in the position and ignition.

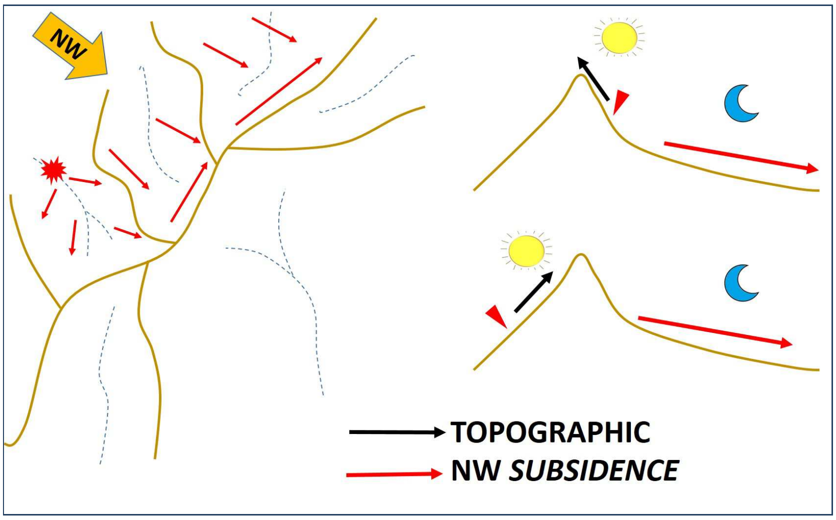


Fig. 36. Spread scheme with subsidence winds. Extension of the backfire (a). Extension of the head fire (b). Source: Bombers de la Generalitat de Catalunya.

Standard Convection Dominated Fire

Non general meaningful winds fires which follow the macro-topography and different air streams generated by their own fire environment. Fires with an extreme fire behaviour and head fires overcoming the suppression capacity because of:

- High rates of spread (rate of linear fire spread up to 6 km/ hr).
- High fire intensity (flame lengths more than 60 mtrs).
- The surface affected (fires can consume500 ha/ hr).

The spotting distance can range from 500 to 2000 meters, even though larger distances may have been unregistered. In this context, topography does not directly produce changes in the fire behaviour (like in the case of topographic fires) because the fire is able to jump from one valley to another without having to cross valleys and slopes to keep spreading. General meteorological conditions have little impact once the fire environment is established. The smoke column often shows the tendency to go in north direction and can only be influenced by air masses following the main river valleys. See Topographic Fires in Main Canyons and Valleys.

Convection Dominated Fires with wind

This Fire Type displays a convection dominated fire behaviour, but with the wind affecting its spread velocity. The wind increases the spotting distance, creating new ignition points out of the influence zone of the convective column and accelerating the general spread of the fire. The tendency of the smoke column follows the main wind direction while the fire is burning big topographic basins and spotting is determining the main direction of the fire spread.

In Catalonia these fires can be produced in westerly warm winds situations and very occasionally with southern entrances.

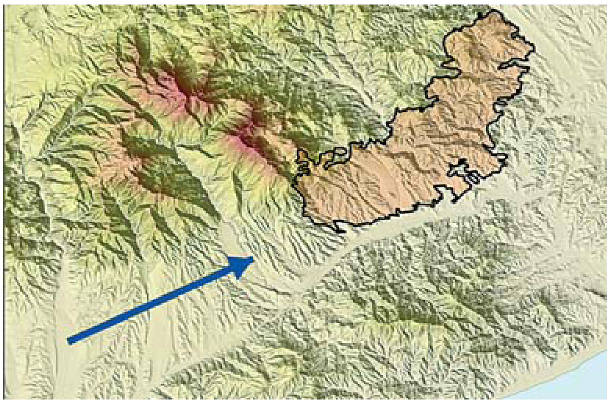


Fig. 37. Gualba Fire, 1994. The perimeter shows the general tendency of the fire, dominated by the general west winds. Source: Bombers de la Generalitat de Catalunya .

Convection dominated fires producing pyrocumulus clouds

Some convection dominated fires allow the formation of pyrocumulus clouds in the upper parts of the convective column. This phenomenon is only possible when stable and cold air masses dominate the high altitudes. These act like a tap for the vertical development of the column, which condensates once it reaches these air masses forming the typical mushroom form of a pyrocumulus cloud.

Fig. 38. Cardona Fire (2005). Pyrocumulus plume in high altitudes during its formation process. Source: Bombers de la Generalitat de Catalunya .

Once the pyrocumulus condensates it starts gaining weight until it collapses. This happens when the fuels are almost entirely consumed and the temperatures of the convective column start sinking, or when the air masses acquired by the pyrocumulus exceed their sustaining capacity.

The collapse of the pyrocumulus as a cold and condensed cloud leads to the descent of cold air along the exterior of the column, thereby generating massive spotting and an extension of the fire in all directions. This is a dangerous phenomenon because of the possibility of trappings during the collapse due to the sudden extension of the fire. By knowing and identifying the evolution of a pyrocumulus cloud those situations can be avoided.

ORGEST

The Guidelines for Sustainable Forest Management in Catalonia (ORGEST) are based on the identification and definition of the forest typologies and the definition of the forestry models for the mass management according to the priority aims established in each hill or management unit; which must select in function the own parameters in the economic context, environmental and social of the territory property, and having in mind the forest formation characteristics and their producing capacity of the different goods and services.

The ORGEST study is divided in two parts:

- The first part, formed foe the forest typologies of Catalonia, with the arboreal, bushy growths and herbaceous, linked to the forest management of the territory.
- A second part, formed by the management models of the forest typologies, according to the preferential chosen aims.

http://cpf.gencat.cat/ca/cpf_03_linies_actuacio/cpf_transferencia_coneixement/cpf_orientacions_gestio_forestal_sostenible_catalunya/

FUEL MODELS

During the 1970’s some American scientists were dedicated to analyzing the specific warmth of each species and the quantity of organic matter typical from each vegetal formation. Additionally, they analysed the propagation speed of the majority of models either in the field or in the laboratory, except the fires which detach a great amount of energy as can be crown fires.

The main goal is to classify the forest ecosystems depending on the way they burn and extract a series of models. These researchers were Rothermel, Anderson y Albini.

The combustibility is the parameter used to typify the spreading of the fire within a vegetation structure. It can be analysed through structural models associated to the performance of the fire and its propagation.

This is the approach developed in the United States under the name of fuel models and it considers 13 types distributed in 4 groups: p**astures, scrubs, fallen leaves under woodlands, wooden cutting remains and other forestry operations.**

The main criteria are to determine the type of fuel, which let the front of the fire go on (this means selecting one of the four main groups). The secondary criteria to define the model of fuel are based on the vegetation structures, the main species inflammability, the quantity of accumulated combustible, its amount of compression and moisture, etc. Normally, the fuel models identification is done through a photographic clue adapted to the Mediterranean conditions.

Grass and grass-dominated Group

They are usually formations with little woodlands plenty of more or less thick herbaceous stratum and with a changeable height, depending on the fire propagation.

Fire Behaviour Fuel Model 1

Fire spread is governed by the fine, very porous, and continuous herbaceous fuels that have cured or are nearly cured. Fires are surface fires that move rapidly through the cured grass and associated material. Very little shrub or timber is present, generally less than one third of the area. **Grasslands and savannah** are represented along with **stubble, grass-tundra, and grass-shrub combinations** that met the above area constraint. Annual and perennial grasses are included in this fuel model.

Fig. 39. Fuel Model 1.
Source: http://www.wildfireanalyst.com/

Fire Behaviour Fuel Model 2

Fire spread is primarily through the fine herbaceous fuels, either curing or dead. These are surface fires where the herbaceous material, in addition to litter and dead down stem wood from the open shrub or timber over story, contribute to the fire intensity. **Open shrub lands and pine stands or scrub oak stands that cover one-third to two-thirds of the area** may generally fit this model; such stands may include clumps of fuels that generate higher intensities and that may produce firebrands.

Fig. 40. Fuel Model 2.
Source: http://www.wildfireanalyst.com/

Fire Behavior Fuel Model 3

Fires in this fuel are the most intense of the grass group and dislay high rates of spread under the influence of wind. Wind may drive fire into the upper heights of the grass and across standing water. Stands are tall, averaging about 3 feet (1 m), but considerable variation may occur. Approximately one-thrid of more of the stand is considered dead or cured and maintains the fire. Wild or cultivated grains that have not been harvested can be considered similar to tall prairie and marshland grasses.

Fig. 41. Fuel Model 3.
Source: http://www.wildfireanalyst.com/

Shrub Group

Corresponding to woodland formations with a more or less developed hedgerow of bushes stratum where the fire would spread. It can be divided in two subgroups (moderate load and high load) depending on the quantity of the burning available material.

Fire Behaviour Fuel Model 4

Fires intensity and fast-spreading fires involve the foliage and live and dead fine woody material in the crowns of a nearly continuous secondary overstory. **Stands of mature shrubs, 6 or more feet tall** are typical candidates. Besides flammable foliage, dead woody material in the stands significantly contributes to the fire intensity. Height of stands qualifying for this model depends on local conditions. A deep litter layer may also hamper suppression efforts.

Fig. 42. Fuel Model 4.
Source: http://www.wildfireanalyst.com/

Fire Behaviour Fuel Model 5

Fire is generally carried in the surface fuels that are made up of litter cast by the **shrubs and the grasses or forbs in the understory**. The fires are generally not very intense because surface fuel loads are light, the shrubs are young with little dead material, and the foliage contains little volatile material. **Usually shrubs are short and almost totally cover the area**. Young, green stands with no dead wood would qualify

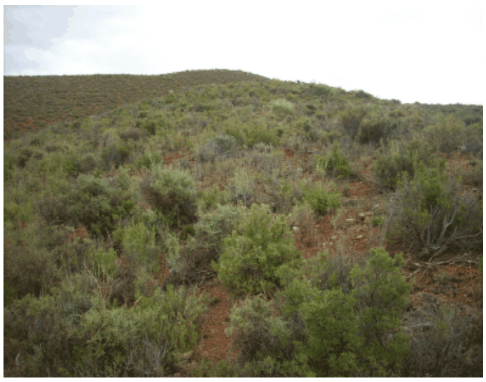


Fig. 43. Fuel Model 5.
Source: http://www.wildfireanalyst.com/

Fire Behaviour Fuel Model 6

Fires carry through the shrub layer where the foliage is more flammable than fuel model 5, but this requires moderate winds, greater than 8 mi/h (13 km/h) at mid flame height. Fire will drop to the ground at low wind speeds or at openings in the stand. The shrubs are older, but not as tall as shrub types of model 4, nor do they contain as much fuel as model 4. A broad range of shrub conditions is covered by this model.

Fig 44. Fuel Model 6.
Source: http://www.wildfireanalyst.com/

Fire Behaviour Fuel Model 7

Fires burn through the surface and shrub strata with equal ease and can occur at higher dead fuel moisture contents because of the flammability of live foliage and other live material. Stands of shrubs are generally between 2 and 6 feet (0.6 and 1.8 m) high. Palmetto-gallberry understory-pine overstory sites are typical and low pocosins may be represented.

Fig. 45. Fuel Model 7.
Source: http://www.wildfireanalyst.com/

Timber Group

They are usually woodland formations with a hedgerow of bushes and herbaceous scarce stratum but with a lot of dead leaves on the floor where the fire would spread.

Fire Behaviour Fuel Model 8

Slow-burning ground fires with low flame lengths are generally the case, although the fire may encounter an occasional "jackpot" or heavy fuel concentration that can flare up. Only under severe weather conditions involving high temperatures, low humidities, and high winds do the fuels pose fire hazards. Closed canopy stands of short-needle conifers or hardwoods that have leafed out support fire in the compact litter layer. This layer is mainly needles, leaves, and occasionally twigs because little undergrowth is present in the stand. Representative conifer types are white pine, and lodge pole pine, spruce, fir, and larch.

Fig. 46. Fuel Model 8.
Source: http://www.wildfireanalyst.com/

Fire Behaviour Fuel Model 9

Fires run through the surface litter faster than model 8 and have longer flame height. Both long-needle conifer stands and hardwood stands, especially the oak-hickory types, are typical. Fall fires in hardwoods are predictable, but high winds will actually cause higher rates of spread than predicted because of spotting caused by rolling and blowing leaves.

Fig. 47. Fuel Model 9.
Source: http://www.wildfireanalyst.com/

Fire Behaviour Fuel Model 10

The fires burn in the surface and ground fuels with greater fire intensity than the other timber litter models. Dead-down fuels include greater quantities of 3-inch (7.6-cm) or larger limb wood resulting from over maturity or natural events that create a large load of dead material on the forest floor. Crowning out, spotting, and torching of individual trees are more frequent in this fuel situation, leading to potential fire control difficulties. Any forest type may be considered if heavy down material is present; examples are insect- or disease-ridden stands, wind thrown stands, over mature situations with deadfall, and aged light thinning or partial-cut slash.

Fig. 48. Fuel Model 10.
Source: http://www.wildfireanalyst.com/

Logging Slash Group

It belongs to diverse types and structures of woodland formations with the common peculiarity of containing remaining vegetation (generally from pruning) of different size and, more or less, abundant where the fire would be propagated. In the elaboration of the fuel model maps, the assignment of models of this group was avoided as they represent a momentary situation and not a natural evolution condition of the forest, as it is model 10.

Fire Behaviour Fuel Model 11

Fires are fairly active in the slash and herbaceous material intermixed with the slash. The spacing of the rather light fuel load, shading from overstory, or the aging of the fine fuels can contribute to limiting the fire potential. Light partial cuts or thinning operations in mixed conifer stands, hardwood stands, and southern pine harvests are considered. Clearcut operations generally produce more slash than represented here.

Fig. 49. Fuel Model 11.
Source: http://www.wildfireanalyst.com/

Fire Behaviour Fuel Model 12 Rapidly spreading fires with high intensities capable of generating firebrands can occur. When fire starts, it is generally sustained until a fuel break or change in fuels is encountered. The visual impression is dominated by slash and much of it is less than 3 inches (7.6 cm) in diameter. The fuels total less than 35 tons per acre (15.6 t/ha) and seem well distributed. Heavily thinned conifer stands, clear cuts, and medium or heavy partial cuts are represented. The material larger than 3 inches (7.6 cm) is represented by encountering 11 pieces, 6 inches (15.2 cm) in diameter, along a 50-foot (15-m) transect.	 **Fig. 50. Fuel Model 12.** Source: http://www.wildfireanalyst.com/
Fire Behaviour Fuel Model 13 Fire is generally carried across the area by a continuous layer of slash. Large quantities of material larger than 3 inches (7.6 cm) are present. Fires spread quickly through the fine fuels and intensity builds up more slowly as the large fuels start burning. Active flaming is sustained for long periods and a wide variety of firebrands can be generated. These contribute to spotting problems as the weather conditions become more severe. Clear cuts and heavy partial-cuts in mature and over mature stands are depicted where the slash load is dominated by the greater-than-3-inch (7.6-cm) diameter material. Situations where the slash still has “red” needles attached but the total load is lighter, more like model 12, can be represented because of the earlier high intensity and quicker area involvement.	 **Fig. 51. Fuel Model 13.** Source: http://www.wildfireanalyst.com/

Source: Anderson, 1982

CRITICAL POINTS AND SMPs

Introduction

Characterising the Fire Types of a region allows to identify the operational opportunities for the suppression systems during a large wildfire in a specific mountain range through identifying the key points where infrastructures need to be created or maintained to limit the extent of large wildfires. These points may resemble suppression opportunities, and are called **Strategic Management Points (SMPs)**.

The model fires concept allows understanding the main characteristics that describe the expected movement of a large wild fire in a particular area, pointing out its spread scheme. Accumulated operational experience and the working system of each suppression force make it possible to determine the most suitable opportunity for each fuel type and relief. It is therefore not necessary to wait for a potential fire to occur to look for suppression opportunities, when the fire front will constrain capacity for analysis. Instead, it is possible to plan in advance, identifying the potential opportunities and adapting them to the requirements of the suppression service.

This advance in planning allows to identify the SMPs -locations throughout a region where the modification of fuel and/or preparation of infrastructures enables the suppression service to carry out safe operations to attack and limit the range of a large wildfire.

SMPs can have different objectives:

- Specific points limiting the multiplying effect of frontal fire spread: points where fire behaviour changes (i) because of the interaction of topography and fire movement, extending the range of a wildfire. These can be crest line junctions (Fig. 53) in wind-driven fires, or ravine junctions (Fig. 52) in topographic fires.
- Points where ignition can be confined to facilitate anchoring of flanks and back of the fire: opening up of path sand tracks, agricultural areas or rocky terrain, forestry roads and areas with low fuel loads to facilitate the anchoring of an attack and to facilitate accessibility: opening of tracks for access to very long flanks (Fig. 54).

To meet these objectives it is necessary to know the type of fire behaviour that can maintain the forest structure of an SMP depending on the respective Fire Type for planning. It is therefore necessary to categorise fire behaviour and relate it to stand structure.

Fig. 52. Ravine junction. In yellow, the potential area and, in red, the ravine bottom. Source: Bombers de la Generalitat de Catalunya.

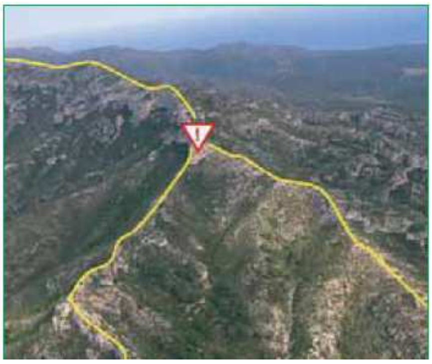


Fig. 53. Picture of a crest line junction. In yellow, potential area, in red, crest junction. Source: Bombers de la Generalitat de Catalunya.

Fig. 54. St. Boi Fire (2005). In red, tracks used for access and for anchoring long flanks. Source: Bombers de la Generalitat de Catalunya.

Identification of SMPs

Identifying where fire behaviour will change in favour of or against the suppression service is the basis for determining the priority areas for fuel treatments and for preparing preventive infrastructures. The priority SMPs to be identified and treated are those where fire behaviour not only overcomes suppression capacity but also pushes the organisation of suppression systems to the limit.

In this course we implement the study of SMPs supported by using geographic information system tools (GIS) and simulators, particularly those based on minimum itinerary time, which allow localising opportunities. There are mainly 3 objectives for which simulators can be used as a tool to support this methodology:

- Modelling fire behaviour in backwind zones.
- Modelling fire behaviour with spotting activity.
- Modelling changes in fire spread dynamics.

Active forest management allows to increase or reduce fuel loads, and to control spatial arrangement and fuel availability through changes in stand structure. Forest management therefore significantly contributes to change fire behaviour to the desired level (below the limit of suppression capacity) according to the established model fire and the determined fuel availability scenario.

Creating SMP

A series of management activities is associated with each SMP: fuel treatment to influence fire behaviour or to ensure safe operations, as well as creation of infrastructures, such as control or defense lines, and passing points on forest roads. The proposed forest management and prevention measures can be used to achieve the objectives set for a SMP in terms of managing and suppressing large wildfires.

PRE-EXTINGUISHING WORK

Fires types are based in big families of spreading patterns (wind-driven, topographic and convention dominated). There are some common advices for each type of propagation, and specific for some fires type, for example, subsidence fires or Topographic Coastal. The most common and necessary general guidelines are next described for optimal forestry planning and prevention of forest fires.

Topographic fires

Break of propagation multipliers and changing points.
Managing plots in ravines knots to avoid the fire burning new slopes and basins. In order to be able to attack the fire by water systems and confine manual tools the intervention should guarantee a surface fire. The plot must allow a secure location to terrestrial resources.

Limit the intensity of the fire itself.
Reduce the launch distance of secondary seats from high parts of the summits by reducing the majority dry combustible (10 to 100HR).

Confine the ignition.
Facilitate the flanks mooring, managed by the plots situated between the bottom of the ravines and the summit, if possible with a positive diagonal, to ease the flank extinguishing which is generated between the two points. This action must be complemented with a ravine knot plot to ensure its efficacy, facilitating the access to the zone.

Creating paths to give movement possibilities to the terrestrial extinguishing resources between hydrographical basins (secondary minimum), and ensuring secure zones every 700 meters. Preferentially, avoid south and west slopes to prevent the path being situated in an area where the fire may spread in full aligning. There should be a certain distance between the path and the summit in the parallel crest routes in order to minimise the radiation and convection effects generated by fire that may be burning in the adjacent basin.

Wind-driven fires

Break of propagation multipliers and changing points.
Keep the opportunities of work in leeward zones, upwind, at the end of the summits or before the aligned slope knots.

Limit the intensity of the fire itself.
Reduce the launch distance of secondary seats from high parts of the summits by reducing the thickest dry combustible (10 to 100 HR).

Confine the ignition.
Facilitate the flanks mooring by keeping the mooring lines in a diagonal way in respect to the direction of the slope wind.

Convection dominated fires

Break of propagation multipliers and changing points.
Managing plots in ravines knots to avoid the fire burns new slopes and basins. In order to be able to attack the fire by water systems and confine manual tools the intervention should guarantee a surface fire. The plot must allow a secure location to terrestrial resources. Prioritize the intervention of greatest order knots, as well as the plots situated at the bottom of ravines which are in a perpendicular way from the main axis, in order to contain secondary seats and descending fronts.

Limit the intensity of the fire itself.
Reduce the launch distance of secondary seats from high parts of the summits by reducing the thickest dry combustible (10 to 100 HR). Prioritize the gradients which are totally aligned with the winds that dominate this kind of fire. In the case of Catalonia, it is about the southern and western orientations.

Confine the ignition.
Facilitate the flanks mooring, managed by the plots situated between the bottom of the ravines and the summit, if possible with a positive diagonal, to ease the flank extinguishing which is generated between the two points. It must be complemented with a ravine knot plot to ensure its efficacy.

FOREST FIRES SIMULATORS

Simulators need a lot of time, specific combustible models data and an accurate meteorological (mainly wind) and topographic interaction knowledge in a smaller and large scale. Its application is limited in extinguishing as fires usually last less than 48 hours (the majority of them happen in the Mediterranean Europe). In the planning, the simulators allow us predicting general and approximated movements; in case of finding an interaction of the wind and landscape source, adapting the performance on the basis of the area historical fires, forest fires simulators are a useful tool to establish extinguishing strategies and fire prevention.

Now we will take a look on the different kind of simulators we have that give support to our planning decisions. To increase information about Forest Fires Propagation Models, we recommend taking a look on *'Large forest fire risk assessment and fuel management: operational tools and integrated approach'* from FIREfficient project.

FARSITE

FARSITE calculates the forest fires' development and performance during long periods of time in heterogeneous conditions of land, fuel and climate. It uses the existent models of the fire behaviour for the surface fire spreading (Rothermel 1972), crown fire beginning (Van Wagner 1977), and the propagation of the fire (Rothermel 1991), post-frontal combustion (Albini and others 1995; Albini and Reinhardt, 1995) and the dead fuel moisture (Nelson 2000).

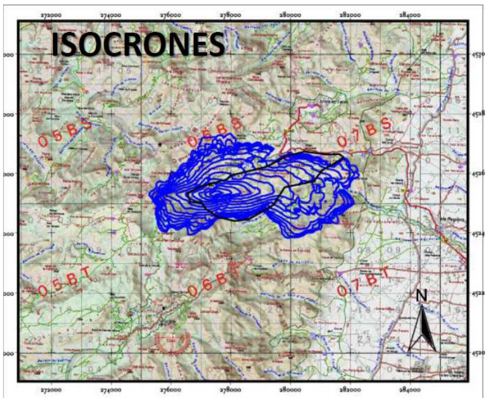


Fig. 55. FARSITE isochrones exit. Source: Pau Costa Foundation.

It is a deterministic modelling system, which means the simulation results can be compared straight away with the entries. This system can be used to simulate air and ground suppression actions, as well as for the fire "game", asking numerous "what ifs" to the questions and compare the results. This is a spatial modelling fire system which generates compatible results with PC work and SIG software stations for its later analysis and visualisation. It accepts raster data issues either GRASS or ARC / INFO GIS.

FLAMMAP

A program that describes the potential behaviour of a fire for constant environmental conditions (combustible climate and moisture). The behaviour of the fire is calculated for every pixel in the landscape file in an independent way, therefore FLAMMAP does not calculate the fire spreading through its landscape.

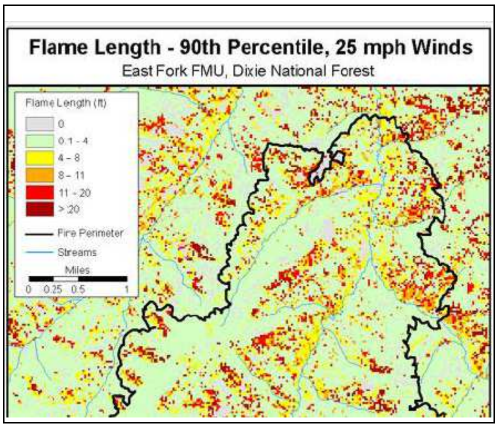


Fig. 56. Flame length exit. Source: PCF

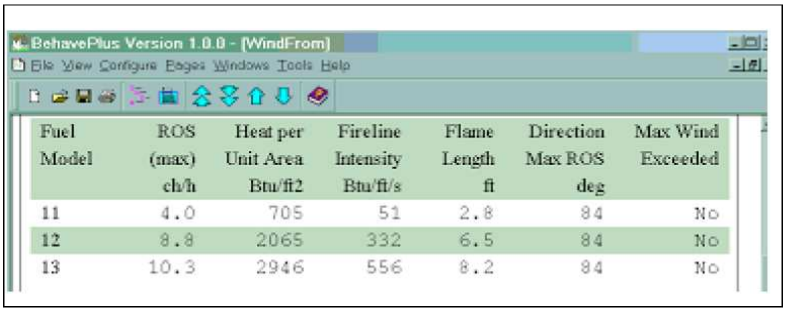
The potential fire performance calculi include the surface fire spreading (Rothermel 1972), the beginning of the crown fire (Van Wagner 1977), and the fire perimeter spreading (Rothermel 1991). The dead fuel moisture is calculated by using Nelson's model (Nelson 2000) and FLAMMAP allows the remodelling of the dead fuels in each pixel depending on the pending, shading, height, aspect and climate.

In the environment conditions simulation they are constantly maintained, therefore FLAMMAP does not simulate the temporal variations of the behaviour of the fire caused by the climate as FARSITE does. These limitations must be kept in mind when the exit values are evaluated.

BEHAVEPLUS

BehavePlus fire modelling system is a computer program based on Windows which can be used in any fire management application that involves the fire performance modelling and its effects. The system is formed by a mathematics model collection which describes the fire performance, the fire effects and the fire environment.

The program simulates the propagation speed of fires, distance detection, flame height, trees mortality, fuel moisture, wind adjustment factor and many other fire behaviours. It is also used to predict the fire behaviours in different situations.



Fuel Model	ROS (max) ch/h	Heat per Unit Area Btu/ft2	Fireline Intensity Btu/ft/s	Flame Length ft	Direction Max ROS deg	Max Wind Exceeded
11	4.0	705	51	2.8	84	No
12	8.8	2065	332	6.5	84	No
13	10.3	2946	556	8.2	84	No

Fig. 57. BEHAVEPLUS data exit. Source: PCF

NEXUS

NEXUS utiliza para comparar el perímetro potencial de fuego por diferentes stands, y comparar los efectos de los tratamientos de combustible alternativo sobre el potencial del fuego. Este simuladores también incluye varias herramientas visuales útiles en la comprensión de cómo los modelos de superficie y el perímetro del fuego interactúan.

WILDFIRE ANALYST

Wildfire Analyst is created from the necessity of simulating the fire in an efficient and fast way to satisfy the operative necessities in real time. The simulation rapidity and the incorporation of new simulation models make this simulator quality take a leap forward. It has been used in Catalonia, Valencia and United States fires (among others).

The main purpose is to be able to offer realistic simulations in active fires and offer outputs to support in a real operations surrounding in less than two minutes. Apart from its use in extinguishing operations, it is also used in analysis and planning preventive actions and also in the post-fire analysis.

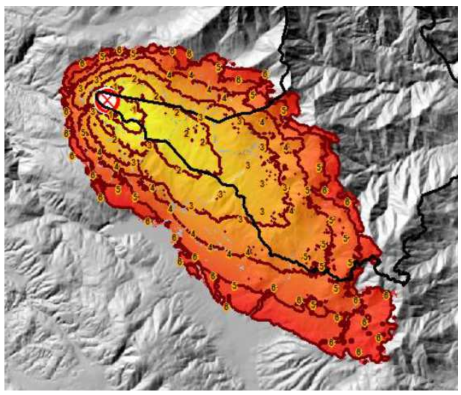


Fig. 58. WildFire Analyst isochrones exit. Source: Pau Costa Foundation.

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