## P1.9 ASSESSMENT OF FIRE SEVERITY IN A MEDITERRANEAN AREA USING FLAMMAP SIMULATOR

Michele Salis*[a,c], B. Arca[b,c], V. Bacciu[a,c], P. Duce[b,c], D. Spano[a,c]
[a] Department of Economics and Woody Plants Systems (DESA), University of Sassari, Italy
[b] National Council of Research, Institute of Biometeorology (CNR-IBIMET), Sassari, Italy
[c] Euro-Mediterranean Center for Climate Changes, IAFENT Division, Sassari, Italy

### 1. INTRODUCTION

Mediterranean ecosystems are often characterised by the occurrence of large wildfires driven by strong winds and summer droughts. In the last years (2000-2008) the South Western European Countries (Italy, France, Spain, Portugal, Greece) were characterized by about 60,000 wildfires per year, with about 450,000 hectares of burned areas per year (JRC–IES, 2009).

Fire occurrence is determined by different anthropic and environmental factors. Several studies reported that most of the variability in the burned areas is related to weather/climatic factors, while fire ignitions is related to human factors and lightning (Flannigan and Harrington, 1988; Viegas and Viegas, 1994; Flannigan and Wotton, 2001; Pausas, 2004; Chuvieco et al., 2008). Changes in spatial and temporal fire behaviour occur in relation to changes in the environmental conditions, and weather is the most variable component changing rapidly in both space and time (Pyne et al., 1996).

Several authors proposed the use of fire simulators as a convenient methodology to derive fire probability and severity maps in function of different environmental conditions and fuel reduction treatments (Farris et al. 2000; Stratton et al., 2003; Stratton, 2004; Finney 2005; Ager et al., 2007; Arca et al., 2007; Finney et al., 2007; Noonan, 2007; Ager and Finney, 2009).

FlamMap (Finney et al., 2003; Finney, 2006) is a fire behaviour mapping and analysis simulator used to compute the potential fire behaviour characteristics over defined landscapes for given weather, wind fields and fuel load and moisture conditions. FlamMap is able to make BehavePlus-like calculations for all points on a landscape using one set of environmental conditions. The simulator makes fire behaviour calculations for each location, independent of one another (Finney, 2006). FlamMap output lends itself well to landscape comparisons and for identifying hazardous fuel, weather and topographic combinations, thus aiding in prioritization and assessments of fire hazard and providing useful information on fire management and operative phases (Stratton et al., 2003).

In this work, we compared several fire severity maps (rate of spread, fireline intensity, flame length, etc.) provided by FlamMap simulator for the whole island of Sardinia, Italy, under several weather and fuel scenarios, to predict the impacts of different environmental conditions on potential fire behaviour.

*Corresponding author address:* Michele Salis, Dept. of Economics and Woody Plants Systems (DESA), Univ. of Sassari, Via De Nicola 9, Sassari, Italy; tel: +39 079 229372; email: miksalis@uniss.it

### 2. MATERIALS AND METHODS

#### 2.1 STUDY AREA

The study area is represented by Sardinia island, Italy, the second-largest island in the Mediterranean Sea. Sardinia, with a surface of about 24,000 km², is located in the western part of the Mediterranean Basin, between 38°50'-41°15' North latitude and 8°08'-9°50' East longitude (Figure 1).

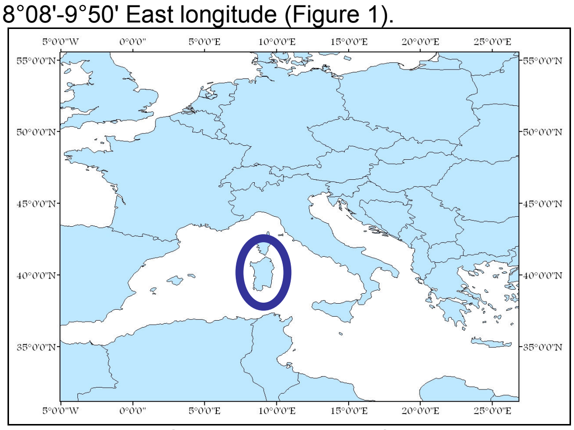



Figure 1. Geographical map of the western Mediterranean Basin.

The Sardinian orography is generally hilly-mountainous, with the highest point being 1834 m in the center of the island. The largest plains are located in the western parts of the island (Figure 2).

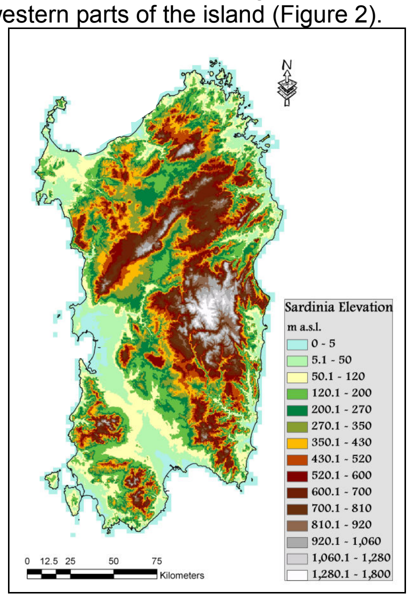



Figure 2. Sardinia elevation map.

Sardinian vegetation composition, physiognomy and structure are the result of the complex interconnections between physical factors (climate, elevation, aspect, soil characteristics, etc.) and anthropogenic factors (fires, grazing, etc.). Wood and forest represent approximately 15% of Sardinian vegetation, and are mainly represented by Quercus ilex L., Quercus suber L., Quercus pubescens Willd.. The coniferous stands (represented by Pinus spp.) are very limited (2%).

The most important vegetation type (30%) is represented by Mediterranean maquis and garrigue. Urban and anthropic areas cover about 2.5% of Sardinian landscape. The remaining fraction is represented by pastures and agricultural areas (45%), and by other land uses (Figure 3).

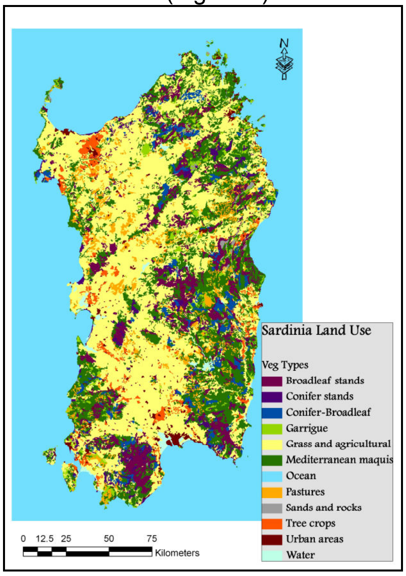



Figure 3. Sardinia land use map.

The Sardinian climate is classified as Mediterranean, with mild and rainy winter and dry and hot summer, and is characterised by a remarkable water deficit from May until September. The most of annual rainfall (650 mm on average) occurs in fall and winter. The mean annual temperature along the coast line is approximately 17 °C, with maximum temperature peaks higher than 30 °C during the summer season. The average wind speed is moderate-high (≈ 4 m s-1) in both winter and summer seasons (Chessa and Delitala, 1997). The prevailing wind directions are typically west and north-west, with a cumulative frequency greater than 50%.

In the period 1999-2008, on average, Sardinia experienced 2800 fires per year with about 18000 hectares of burned areas per year. The yearly fire trends, in terms of both numbers of fires and burned areas, are characterised by the presence of critical years (1993, 1994, 1998, 2007, 2009) with respect to ordinary trends. Basically, the critical years are linked to drought conditions, heat waves, strong winds, fine dead fuel accumulation. Sardinian fires are mostly concentrated in summer, in particular July and August; the other months are normally not affected by fires.

## *2.2 FLAMMAP SIMULATIONS*

FlamMap (Finney et al., 2003; Finney, 2006) is a fire behaviour mapping and analysis simulator used to compute the potential fire behaviour characteristics over defined landscapes for given environmental conditions. The simulator incorporates different fire behaviour models, considering Rothermel’s surface fire model (Rothermel, 1972), and crown fire initiation and spread models (Van Wagner, 1977; Rothermel, 1991).

Geographic Information System (GIS, ArcGIS 9.3.1, ESRI Inc.) was used to manage the spatial information, and to obtain all input layers needed to execute the FlamMap simulations. The grid resolution of all spatial information for the definition of the Landscape file was 250 m. A digital elevation model (DEM) was used to produce the maps of elevation, slope and aspect. Fuel and canopy cover maps were produced using the 1:25,000 land cover map of Sardinia from the CORINE project (EEA ETC/TE 2002), combining the fuel information to create a broad classification of the main Sardinian vegetation types and land uses. In particular, we splitted Sardinia in 12 different land uses, and for each land use a standard or custom fuel model was associated (Figure 3 and Table 1).

FlamMap simulations were run using custom fuel models for shrubland vegetation (Mediterranean maquis and garrigue) and pastures, and using standard fuel models (Anderson, 1982; Scott and Burgan, 2005) for the other vegetation types. The values of fuel moisture content for the 10-hr time lag dead fuel were determined calculating the relationship between observed FMC values and fuel moisture sensor measurements (model CS505, Campbell Sci., Logan, UT, USA) obtained during the summer season. The 1-hr and 100-hr dead fuel moisture content values were obtained from field observations and literature data (Fernandes, 2001; Baeza et al., 2002; De Luis et al., 2004; Pellizzaro et al., 2007). In order to improve the accuracy of information, a mass consistent model (WindNinja, Forthofer, 2007) was used: wind speed and direction data were input in FlamMap as raster maps, with a resolution of 2000 m. In this work, we simulated mistral wind (direction 290°), the most important wind associated with fire events in Sardinia.

Three main output parameters (rate of spread (ROS), fireline intensity (FLI), flame length (FL)) provided by FlamMap were used in order to describe the fire behaviour and to analyse the fire severity on the study area. The fire severity was evaluated (using the Spatial Analyst function of ArcGIS 9.3.1, ESRI Inc.) combining the values of fire behaviour simulations.

We tested with FlamMap simulations the effects of several summer scenarios of weather and fuel conditions on fire behaviour in Sardinia, and we evaluated the fire behaviour characteristics to define the fire severity in the study area. In particular, in this work we present the effects of different fuel moisture and wind speed scenarios on fire behaviour and severity.

A) FUEL MOISTURE SCENARIOS. Effects of different summer fuel dryness levels (moderate, moderate-dry, dry, extreme) on fire behaviour. In the extreme scenario, the live fuel moisture for shrubland vegetation was set at 50% and the dead fine fuel moisture was set at 5%. On the other hand, in the moderate scenario, the live fuel moisture for shrubland vegetation was set at 100% and the dead fine fuel moisture was set at 12%. The ranges for broadleaf and conifer stands were set to 80-110% for the live fuel moisture and to 8%-14% for the dead fine fuel moisture. For these scenarios, we used the wind field map obtained by WindNinja considering wind intensity of 30 km h-1 and wind direction 290°.

B) WIND SPEED SCENARIOS. Effects of different wind speed (10, 15, 25, 30 km h-1) on fire behaviour. These scenarios were tested using moderate fuel moisture conditions (Table 1).

C) FIRE SEVERITY. The fire severity was calculated for the whole Sardinia combining the raster maps obtained by FlamMap simulations for rate of spread, flame length and fireline intensity. These operations were done using GIS and combining, for each simulation, the associated fire behaviour values, and evaluating the cells where the fire behaviour parameters overtake hazardous threshold values (Andrews and Rothermel, 1982).

## 3. RESULTS

A) FUEL MOISTURE SCENARIOS. Figures 5,6,7 show the importance of fuel moisture conditions on fire behaviour, for all parameters considered. As expected, the fuel moisture reduction implies the increase on both maximum and average fire spread rate, flame length and fireline intensity. It is also important to highlight that the lower are the fuel moisture conditions the higher is the variability of all fire behaviour parameters.

B) WIND SPEED SCENARIOS. Figures 8,9,10 show the effects of wind intensity on fire behaviour, for all parameters considered. The increase of wind intensity causes a remarkable growth on both maximum and average fire spread rate, flame length and fireline intensity. Also these simulations confirm that there is an increment of the variability of all fire behaviour parameters moving to higher wind speed conditions.

C) FIRE SEVERITY. The potential fire behaviour and severity maps represent an important tool in order to generate useful information for decision makers, given defined environmental conditions. The fire severity was calculated combining the raster maps of FlamMap simulations, for each scenario. In order to evaluate the cells with hazardous threshold values of fire behaviour, we used the charts for interpreting wildfire behaviour characteristics proposed by Andrews and Rothermel (1982). The resulting maps of fire severity show the areas characterised by higher values of potential fire severity due to the associated hazardous combinations of fuels, topography and weather-wind conditions (Figure 4).

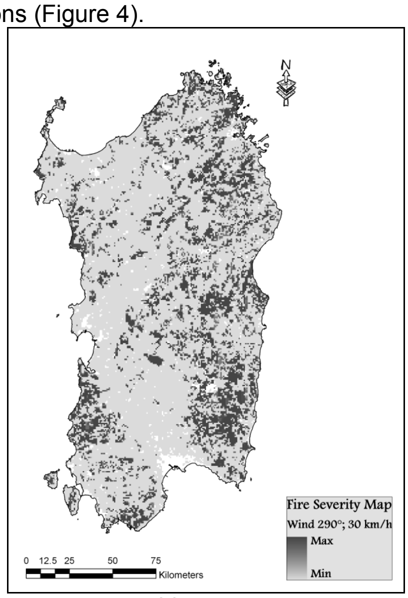
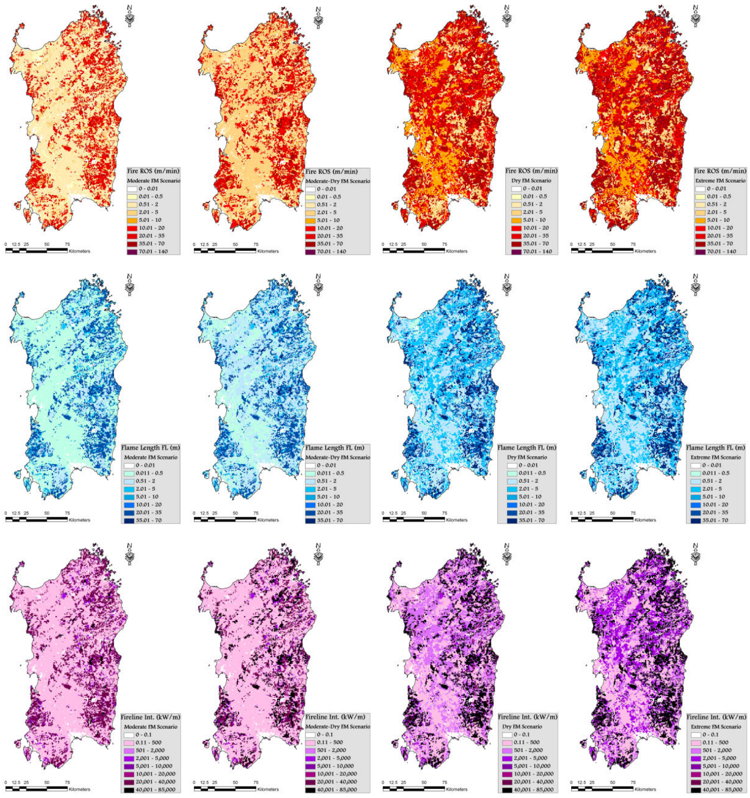



Figure 4. Example of fire severity map, using wind 290°-30 km $h^{-1}$ and moderate fuel moisture conditions.

Table 1. Description of the fuel models used for FlamMap simulations, considering summer moderate fuel moisture conditions.

| **Fuel Models** | **FM1** | **FM2*** | **CM PAST** | **TU1** | **TU4** | **TU4*** | **CM GARR** | **CM MAQ** | **NB** |
|---|---|---|---|---|---|---|---|---|---|
| Land Use | grass | tree crops | pastures | broadleaf | coniferous | mixed stands | garrigue | med. maquis | not burnable |
| DF Load (Mg $ha^{-1}$) | 1.83 | 2.50 | 2.00 | 6.42 | 11.11 | 9.00 | 5.5 | 15.0 | 0 |
| LF Load (Mg $ha^{-1}$) | 0 | 2.00 | 0.00 | 2.71 | 4.94 | 3.50 | 4.0 | 12.5 | 0 |
| Fuelbed Depth (cm) | 33 | 33 | 35 | 33 | 33 | 33 | 45 | 135 | 0 |
| Moisture of Ext. (%) | 12 | 15 | 12 | 30 | 12 | 25 | 25 | 25 | 0 |
| DF & LF Heat Cont. (kJ $kg^{-1}$) | 18620 | 18620 | 18620 | 18620 | 18620 | 18620 | 18620 | 18620 | 0 |
| Dead 1-hr (%) | 10 | 10 | 10 | 11 | 11 | 11 | 10 | 10 | 0 |
| Dead 10-hr (%) | 12 | 12 | 12 | 13 | 13 | 13 | 12 | 12 | 0 |
| Dead 100-hr (%) | 13 | 13 | 13 | 14 | 14 | 14 | 13 | 13 | 0 |
| Live Herbaceous (%) | 0 | 0 | 0 | 100 | 100 | 100 | 80 | 80 | 0 |
| Live Woody (%) | 0 | 0 | 0 | 110 | 110 | 110 | 80 | 90 | 0 |

Dead and live fuel moisture are representative of Sardinian summer moderate conditions
FM1, FM2 (Anderson, 1982); TU1, TU4 (Scott and Burgan, 2005); * = adapted

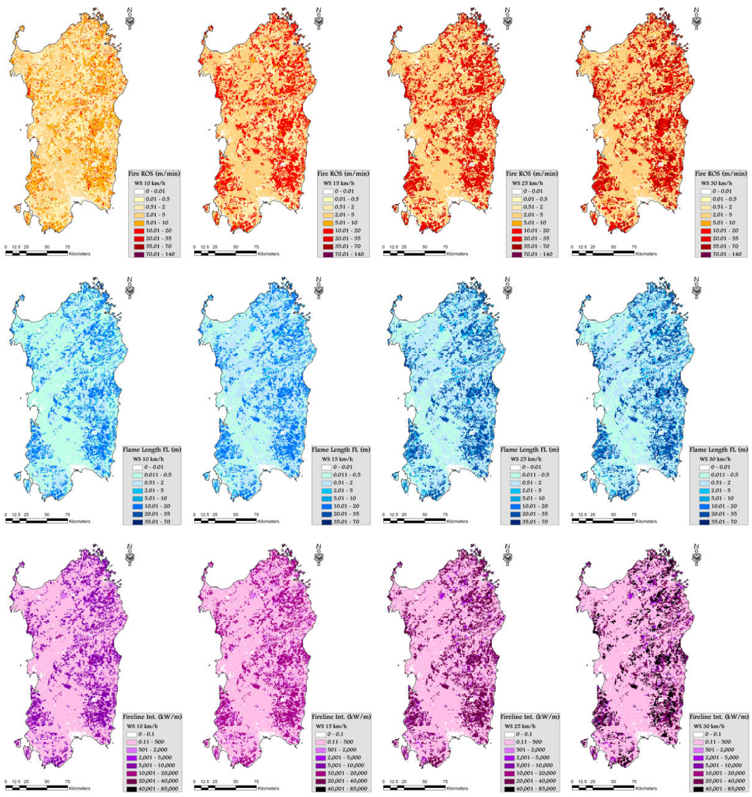


| ROS (m min$^{-1}$) | | | |
|---|---|---|---|
| **Scenario** | **max** | **avg** | **stdev** |
| *Moderate* | 60.99 | 4.62 | 10.72 |
| *Moderate-Dry* | 71.19 | 6.25 | 12.39 |
| *Dry* | 86.28 | 10.13 | 15.68 |
| *Extreme* | 102.04 | 12.22 | 18.4 |

| FL (m) | | | |
|---|---|---|---|
| **Scenario** | **max** | **avg** | **stdev** |
| *Moderate* | 36.04 | 3.18 | 8.38 |
| *Moderate-Dry* | 39.93 | 3.63 | 9.32 |
| *Dry* | 45.03 | 4.34 | 10.55 |
| *Extreme* | 49.99 | 4.89 | 11.77 |

| FLI (kW m$^{-1}$) | | | |
|---|---|---|---|
| **Scenario** | **max** | **avg** | **stdev** |
| *Moderate* | 49766 | 4082 | 10837 |
| *Moderate-Dry* | 58020 | 4839 | 12769 |
| *Dry* | 69479 | 6113 | 15454 |
| *Extreme* | 81278 | 7336 | 18336 |

Figures 5,6,7. Effects of different fuel moisture conditions (from moderate to extreme) on fire ROS (Figure 5), FL (Figure 6) and FLI (Figure 7) (wind 290°-30 kmh$^{-1}$).



| ROS (m min$^{-1}$) | | | |
|---|---|---|---|
| **Scenario** | **max** | **avg** | **stdev** |
| *10 km h$^{-1}$* | 21.31 | 2.01 | 3.37 |
| *15 km h$^{-1}$* | 33.19 | 3.06 | 5.35 |
| *25 km h$^{-1}$* | 58.53 | 5.16 | 9.8 |
| *30 km h$^{-1}$* | 71.19 | 6.25 | 12.39 |

| FL (m) | | | |
|---|---|---|---|
| **Scenario** | **max** | **avg** | **stdev** |
| *10 km h$^{-1}$* | 16.43 | 1.36 | 3.21 |
| *15 km h$^{-1}$* | 21.99 | 1.9 | 4.65 |
| *25 km h$^{-1}$* | 33.52 | 3.06 | 7.8 |
| *30 km h$^{-1}$* | 39.93 | 3.63 | 9.32 |

| FLI (kW m$^{-1}$) | | | |
|---|---|---|---|
| **Scenario** | **max** | **avg** | **stdev** |
| *10 km h$^{-1}$* | 15317 | 1035 | 2769 |
| *15 km h$^{-1}$* | 23718 | 1768 | 4724 |
| *25 km h$^{-1}$* | 44638 | 3729 | 9872 |
| *30 km h$^{-1}$* | 58020 | 4839 | 12769 |

Figures 8,9,10. Effects of different wind speed conditions (10, 15, 25, 30 km h$^{-1}$) on fire ROS (Figure 8), FL (Figure 9) and FLI (Figure 10) (moderate fuel moisture conditions).

## 4. CONCLUSIONS

The analysis of the information on fire behaviour and severity provided by FlamMap can be useful to identify the areas with high level of danger, and therefore, high potential risk due to different weather and fuel condition scenarios. Considering the assumptions and limitations of all fire simulation systems and the methodology presented in this work, the fire severity maps can assist decision makers in identifying areas of concern for extreme fire behaviours, planning prevention activities, and aid in the prioritization of these locations for fuel treatments and for strategical firefighting resources allocations. Fire severity maps can be useful to evaluate prescribed or natural fires and to support tactical and strategic decisions related to the mitigation of fire severity and risk and to fire attack. The fire behaviour simulations and calculations can also be compared with expected behaviours for defined fire environment at each cell (considering fuel, weather, topography) of the landscape. Furthermore, our analysis suggests that the future fire regimes determined by global change will result in fires with higher spread rate, flame length and fireline intensity, due to the predicted increase of severe weather conditions frequency.

Furthermore, our analysis suggests that future global change, due to the predicted increase of severe weather conditions frequency, will affect fire regime and behaviour, promoting fires with higher spread rate, flame length and fireline intensity.

## 5. REFERENCES


Ager A.A., Finney M.A., Kerns B.K., Maffei H., 2007. “Modeling wildfire risk to northern spotted owl (Strix occidentalis caurina) habitat in Central Oregon, USA”. Forest Ecology and Management 246 (2007) 45–56.

Ager A.A., Finney M., 2009. “Application of wildfire simulation models for risk analysis”. Geophysical Research Abstracts, Vol. 11, EGU2009-5489, EGU General Assembly, Vienna, April 2009.

Anderson H.E., 1982. “Aids to determining fuel models for estimating fire behavior”. USDA For. Service General Technical Report INT-122. (Ogden, UT).

Andrews P.L., Rothermel, R.C., 1982. “Charts for interpreting wildland fire behavior characteristics”. USDA For. Service General Technical Report INT-131. (Ogden, UT).

Arca B., Bacciu V., Duce P., Pellizzaro G., Salis M., Spano D., 2007. “Use of FARSITE Simulator to Produce Fire Probability Maps in a Mediterranean Area”. 7th Symposium on Fire and Forest Meteorology, Bar Harbor, Maine, USA, 23-25 October 2007.

Baeza M.J., De Luis M., Raventos J., Escarré A., 2002. “Factors influencing fire behaviour in shrublands of different stand ages and the implications for using prescribed burning to reduce wildfire risk”. Journal of Environmental Management 65, 199-208.

Chessa P.A., Delitala A., 1997. “Il Clima della Sardegna”. Servizio Agrometeorologico Regionale (SAR) per la Sardegna, nota tecnica n° 2. http://www.sar.sardegna.it/pubblicazioni/notetecniche/nota2/index.asp.

Chuvieco E., Giglio L., Justice C., 2008. “Global characterization of fire activity: toward defining fire regimes from Earth observation data”. Global Change Biology 14, 1488-1502.

De Luis M., Baeza M.J., Raventós J., Gonzáles-Hidalgo J.C., 2004. “Fuel characteristics and fire behaviour in mature Mediterranean gorse shrublands”. International Journal of Wildland Fire 13, 79-87.

EEA-ETC/TE, 2002. “CORINE Land Cover update. I&CLC2000 project”. Technical Guidelines.

Farris C.A., Pezeshki C., Neuenschwander L.F., 2000. “A comparison of fire probability maps derived from GIS modeling and direct simulation technique”. In Neuenschwander L.F., Ryan K.C., Gollberg G.E., Greer J.D. (Eds.), Proc. of Joint Fire Science Conference and Workshop: “Crossing the Millennium Integrating Spatial Technologies and Ecological Principles for a New Age in Fire Management”, Boise Idaho, June 15-17, 1999, University of Idaho, pp. 130-137.

Fernandes P.M., 2001. “Fire spread prediction in shrub fuels in Portugal”. Forest Ecology and Management 144, 67-74.

Finney M.A., Britten S., Seli R., 2003. “FlamMap2 Beta Version 3.0.1”. Fire Sciences Lab and Systems for Environmental Management, Missoula, Montana.

Finney M.A., 2005. “The challenge of quantitative risk assessment for wildland fire”. Forest Ecology and Management 211:97-108.

Finney M.A., 2006. “An overview of FlamMap modeling capabilities”. In Proc. of Conf. on fuels management - How to measure success, Andrews P.L., and Butler B.W. (eds.). pp. 213-220. USDA Forest Service, RMRS-P41.

Finney M.A., Seli R.C., McHugh C.W., Ager A.A., Bahro B., Agee J.K., 2007. “Simulation of long-term landscape-level fuel treatment effects on large wildfires”. International Journal of Wildland Fire. 16:712-727.

Flannigan M.D., Harrington J.B., 1988. “A study of the relation of meteorological variables to monthly provincial area burned by wildfire in Canada”. 1953-80. Journal of Applied Meteorology 27:441-452.

Flannigan M.D., Wotton B.M., 2001. “Climate, weather and area burned”. In: Johnson E.A., Miyanishi K. (eds.), Forest Fires-Behaviour and Ecological Effects. Academic Press, San Diego, CA, pp 335-357.

Forthofer J.M., 2007. “Modeling wind in complex terrain for use in fire spread prediction”. (thesis). Colorado State University.

JRC – IES (Joint Research Centre – Institute for Environment and Sustainability), 2009. “Forest Fires in Europe 2008”. Luxembourg: Office for Official Publications of the European Communities. 83 pp. EUR – Scientific and Technical Research Series – ISSN 1018-5593.

Noonan E.K., 2007. “A coupled model approach for assessing fire hazard at Point Reyes National Seashore: Flammap and GIS”. 7th Symposium on Fire and Forest Meteorology, Bar Harbor, Maine, USA, 23-25 October 2007.

Pausas J.G., 2004. “Changes in fire and climate in the Eastern Iberian Peninsula (Mediterranean Basin)”. Climate Change 63: 337-350.

Pellizzaro G., Duce P., Ventura A., Zara P., 2007. “Seasonal variations of live moisture content and ignitability in shrubs of the Mediterranean Basin”. International Journal of Wildland Fire 16, pp. 633–641.

Pyne S.J., 1984. “Introduction to Wildland Fire”, John Wiley & Sons: New York, 455 pp..

Rothermel R.C., 1972. “A mathematical model for predicting fire spread in wildland fuels”. USDA Forest Service, Research Paper INT-115.

Rothermel R.C., 1991. “Predicting behavior and size of crown fires in the northern Rocky Mountains”. USDA Forest Service, Research Paper INT-438.

Scott J.H., Burgan R.E., 2005. “Standard fire behavior fuel models: a comprehensive set for use with Rothermel's surface fire spread model”. Gen. Tech. Rep. RMRS-GTR-153. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station; 72 pp..

Stratton R.D., Long D., Mislivets M., 2003. “Greenville Bench case study analysis”. http://jfsp.nifc.gov/documents/Greenville_Case_Study.pdf.

Stratton R.D., 2004. “Assessing the effectiveness of landscape fuel treatments on fire growth and behavior”. Journal of Forestry 102:32-40.

Van Wagner C.E., 1977. “Conditions for the start and spread of crownfire”. Can. J. For. Res. 7:23-24.

Viegas D.X., Viegas M.T., 1994. “A relationship between rainfall and burned area for Portugal”. International Journal of Wildland Fire 4:11-16.