Original Research

Statistical Analysis of the Fire Environment of Large Forest Fires (>1000 ha) in Greece

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Abstract

This study analyzed the fire (pyric) environment (vegetation or fuels, meteorology, topography, suppression time) of the large forest fires (greater than 1,000 ha) that occurred in Greece during this period 1990-2003. Statistical analysis of 84 large fires (representing 0.37% of total number of fires) revealed that they usually spread under moderately to low relative humidity (21-40%) in the presence of strong to moderate winds of northern direction. Approximately one-fourth of all large fires occur during heat waves (i.e. air temperature higher than 30ºC and air relative humidity 21-40%). Large fires occur as both surface and crown fires and usually spread in dense vegetation with a continuous duff layer. Successful containment requires a combination of both ground and aerial fire suppression forces. Although large forest fires usually have short initial attack time (less than 30 minutes), the suppression time is quite variable. The main differences of the large fires from all the others lie in the prevailing wind speed (strong for large fires, moderate for smaller fires) and the mode of propagation (mixed surface and crown spread for large fires, only surface spread for smaller fires). However, no unique characteristics of large fires were found that would distinguish them from smaller fires. This supports the hypothesis that any fire may become large under certain circumstances. The results of this study could be useful in forest fire danger rating and presuppression alertness in the context of judicial fire prevention and suppression planning.

Keywords: large forest fires, mega-fires, fire environment, burning conditions, forest fuels, cluster analysis, discriminant analysis, Greece

Introduction

Forest fires constitute a global phenomenon. During the last decades both the numbers of fires and area burned have significantly increased worldwide [1, 2]. Areas with Mediterranean-type climate, due to the combination of dry and warm climate, flammable vegetation and increased human activities, are extremely fire prone [3, 4]. Specifically, the countries of Southern Europe (i.e. Italy, France, Spain, Portugal, and Greece) have suffered major catastrophes from forest fires during the last ten years [5].

However, it seems that the essence of the problem is not necessarily the increased number of fires and areas burned, but the correspondence between these two measures of fire activity. Comparing the number of forest fires with the respective area burned, it becomes obvious that a small number of fires burn disproportionately large areas, and that these fires account for the majority of the total area burned [6-10]. This is especially true for all the Southern European countries where, during the period 1989-93, the fires that exceeded 1,000 ha in size accounted for only ~0.1% of the total number of fires and yet they were responsible for around 27% of the total area burned [11]. Greece although does not represent a large part of the total number of fires

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in relation to the rest of the Southern Europe, yet it has a disproportionally high number of large fires. During the period 1986-95 in Greece, large fires (greater than 1,000 ha) represented approximately 6% of the total fires and yet they destroyed 2/3 (66%) of the total burned area [12]. In the year 2000, over 50% of the total burned area (approximately 162,000 ha) in Greece was the result of only seven large fires that occurred during the summer [13].

In USA and Australia, about 95% of all wildfires are suppressed at initial attack, while 4% exceed initial attack efforts, require extended attack operations and are often controlled within one or two burning periods [40]. Only approximately 1% of all wildfires make the transition to large and require the management and oversight of an organized Incident Command System [40]. This system brings the planning, logistical, and operational leadership necessary to deal with a complex wildland fire incident. 0.1% of all forest fires become 'mega-fires', accounting for 95% of the total area burned by wildfires and 85% of the total fire suppression costs [41]. 'Mega-fires' are extraordinary, in terms of their size, complexity, and resistance to control. These few wildfires, often burning under extreme fire weather conditions and exhibiting extreme fire behavior characteristics, exceed all efforts at conventional control, until relief in weather or a break in fuel occurs [40]. Recently, during August 2007, multiple 'mega-fires' in the region of Peloponese, Greece, burned over 150,000 ha and cost the lives of 68 people, thus setting an unprecedented negative record for Europe [14].

The research regarding large forest fires is mainly oriented towards their forecast with the use of meteorological fire risk indexes [18-22], their detection and mapping with the use of remote sensing techniques [23], the development and validation of large fire simulation models [24, 25], and the, *post-factum*, case-study analysis of certain large forest fires that occurred in the past [7, 22]. Although numerous modeling approaches exist for simulating potential fire behavior at the stand [26] and landscape scale level [27], no theoretical and/or empirical models have been developed to describe the burning conditions associated with large fire occurrence.

The prevailing burning conditions under which a wildland fire occurs constitute the fire (or 'pyric') environment [10, 42, 43]. The fire environment is comprised of three sets of parameters that influence fire behavior and, thus, suppression tactics: vegetation (fuel), weather and topography [42, 43]. The physical and chemical properties of the forest fuels and, especially, their moisture content affect their flammability and combustibility during fire spread [10]. The weather conditions (i.e. wind speed and direction, air temperature, and relative humidity) greatly influence the propagation rate and the intensity of the fire, while topography (slope steepness and aspect, elevation) influences both the fire parameters and the suppression options [43]. While some researchers have investigated different aspects of large forest fires, very little research on the fire environment of large forest fires (greater than 1,000 ha) in the Mediterranean basin has been published to date [21-23, 35].

The purpose of this study was to analyze the fire environment associated with very large forest fires (>1,000 ha) that occurred in Greece during the period 1990-2003. The central focus was to isolate the prevailing burning conditions that favor large fire occurrence.

Materials and Methods

The data set used in this study concerning the fire environment of very large forest fires (>1,000 ha) that occurred in Greece, was obtained from the official fire records of the Ministry of Agriculture of Greece during the period 1990-2003. An electronic version of the official fire records of the Ministry of Agriculture of Greece was obtained from the PYROSTAT data base [31]. The fire records are documented by trained foresters immediately after every fire event and they represent the 'prevailing (average) burning conditions' of the fire. However, in essence, they reflect the peak burning conditions of the fire. During the 14-year study period, 84 very large forest fires (>1,000 ha) occurred in a total of 22,806 wildland fires. Fig. 1 presents a histogram of the very large fire size distribution.

The fire (pyric) environment for the purpose of this study was distinguished into four categories:
1) meteorology (air temperature, relative humidity, wind strength, and wind direction),
2) topography (elevation, slope exposure, slope steepness),
3) suppression times (initial attack time, suppression time), and
4) fuels (vegetation density, duff cover).

The weather data were obtained from the meteorological station located nearest to the fire and they represent the 'average' weather conditions during the fire. The topographical data were obtained by *in situ* examination of the burned area. The suppression times were recorded during the fire. The vegetation (fuel) data was examined by inspection of the burned area and adjacent unburned vegetation, from local forest management plans and from vegetation maps of the burned area. All data were collected and recorded by foresters who received special training and they represent the 'prevailing' ('average', 'representative') conditions during the fire.

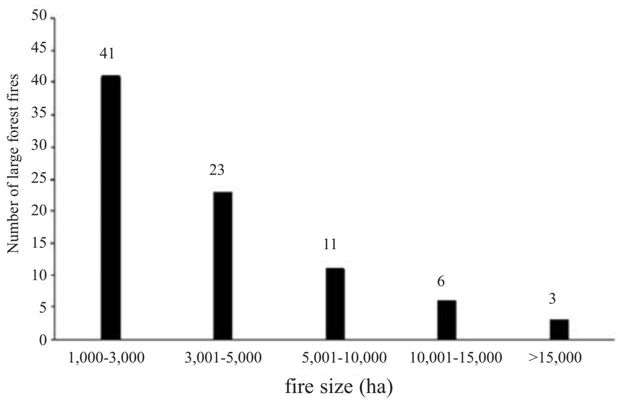

Fig. 1. Size distribution of large forest fires in Greece during the period 1990-2003.

Two multivariate statistical methods were applied in order to find the common characteristics of large forest fires: hierarchical cluster analysis and discriminant analysis.

Hierarchical Cluster Analysis is a statistical method that analyzes a data set containing information about a sample of observations and reorganizes these observations into relatively homogeneous groups (clusters) according to a preset criterion [28]. In this study, the Ward method was applied in order to form the clusters. The Ward method combines clusters with the smallest increase in the overall sum of the squared within-cluster distances [29].

Consequently, discriminant analysis was performed on the groups (clusters) that resulted from the cluster analysis. The purpose of discriminant analysis is the creation of canonical components that describe a sum of observations that are separated into groups and, subsequently, the classification of new observations to these groups [30].

Finally, the common characteristics of large fires were compared to the characteristics of all the fires (22,806 fires) that occurred in Greece during the same period, in order to detect differences. An electronic version of the official fire records of the Ministry of Agriculture of Greece for all the studied fires was obtained from the PYROSTAT data base [31].

The statistical analysis was conducted with the SPSS 11.0 program [32].

Results and Discussion

Table 1 presents all the variables used in the statistical analysis. The cluster analysis of the meteorological parameters identified 4 clusters at rescaled distance (RDCC) 11: the first cluster is comprised of 25 fires that burned under high relative humidity (41-80%), the second (17 fires) burned under moderately low relative humidity (21-40%) and moderately strong winds, and the third cluster (20 fires) also with moderately low relative humidity (21-40%) but with strong winds. The fourth cluster is comprised of 22 fires that fused at very small distance (RDCC 7), which implies great homogeneity. The fires of this cluster are quite characteristic because they occurred under conditions of extreme heat with air temperatures over 30ºC and relative humidity between 21-40%. The cluster analysis of the topographic parameters did not identify clusters with meaningful common characteristics.

The cluster analysis of the fire suppression parameters identified 3 clusters at RDCC 11. The fires of the first cluster (45 fires) had initial attack time less than 30 minutes and suppression time between 120 and 480 hours. The fires of the second cluster (18 fires) had the same initial attack time but the suppression time was less than 120 hours. The third cluster (21 fires) had fires with initial attack time greater than 30 minutes.

The cluster analysis of the vegetation or fuels conditions under which the fires burned identified 3 clusters at RDCC 11.The first cluster (50 fires) is comprised of fires that burned in fuels with a continuous duff layer and dense vegetation, the second cluster (18 fires) presents continuous duff present but sparse vegetation, and the third cluster (16 fires) had little or no duff presence and sparse or dense vegetation.

Table 1. Description of variables used in the statistical analysis.

Variables	Type	Value
Meteorology		
Air temperature	Continuous	ºC
Relative humidity	Continuous	%
Wind speed	Categorical	No wind (0.0-1.0 BF)[a]
		Moderate (1.1-4.0 BF)
		Strong (4.1-7.0 BF)
		Very strong (7.1-9.0 BF)
		Stormy (>9.0 BF)
Wind direction	Categorical	No wind
		East
		South
		West
		North
Topography		
Elevation	Continuous	m (a.s.l.)
Slope exposure (Aspect)	Categorical	Undetermined
		East
		South
		West
		North
Slope steepness	Continuous	%
Suppression times		
Initial attack time	Continuous	min
Suppression time	Continuous	hours
Vegetation		
Density	Categorical	Dense (cover >0.4)
		Sparse (cover <0.4)
Duff cover	Categorical	No duff
		Sparse
		Dense

[a] Beaufort Scale (BF): 0-1 (0-3 km/h), 1.1-4 (4-24 km/h), 4.1-7 (25-56 km/h), 7.1-9 (57-81 km/h), >9 (>81 km/h).

Canonical discriminant analysis was applied to the clusters obtained from the cluster analysis of the meteorological parameters. Fig. 2 presents the scatter plot of the first and second canonical components, accounting for 100% of the variation. Canon 1, which accounted for 81% of the

Table 2. Differences between large (>1,000 ha) and total fires in Greece during the period 1990-2003.

Variables	Large fires (>1000 ha)	Total fires (<1,000 ha)
Wind speed	Strong winds (4.1-7.0 BF)	Moderate winds (1.1-4.0 BF)
Type of fire	Mixed mode of propagation (i.e. combination of surface and crown fire spread)	Surface fires
Suppression tactics	Mixed method of suppression (i.e. combination of ground and aerial forces)	Ground forces

variation, had strong positive correlation with the air temperature (+0.762), and strong negative correlation with the relative humidity (-0.618). Thus, along the horizontal axis of the scatter plot, air temperature is proportional and relative humidity inversely proportional to the values of Canon 1. Canon 2, which accounted only for 18.9% of the variation, had highly positive correlation with the wind direction (+0.816). Consequently, the right part of the scatter plot represents fires that burned with high air temperature and moderately low relative humidity, while the left part represents fires that burned with low air temperature and high relative humidity. The upper part of the scatter plot represents fires that spread with a northerly wind direction, while the lower part represents fires with variable wind directions.

Canonical discriminant analysis was also applied to the clusters that where distinguished from the cluster analysis of the fire suppression parameters. Fig. 3 presents the scatter plot of the first and second canonical components, accounting for 100% of the variation. Canon 1 accounted for 77.7% of the total variation, while Canon 2 accounted for an additional 22.3%. Canon 1 had strong positive correlation with the initial attack time (+0.849), meaning that along the horizontal axis of the scatter plot, initial attack time is proportional to the values of Canon 1. Canon 2 had positive correlation with the suppression time (+0.598). Thus, along the vertical axis of the scatter plot, suppression time is proportional to the values of Canon 2. Consequently, the horizontal axis of the scatter plot represents the gradient in initial attack time, starting from short initial attack times at the left part and reaching fires with long initial attack times at the end of the right part of the axis. In the same manner, the upper part of the scatter plot along the vertical axis represents fires with large suppression time, and the lower part represents fires with small suppression time.

Canonical discriminant analysis of the vegetation parameters did not reveal any new information.

The comparison of total and large fires is summarized in Table 2. Three major differences were revealed:

a) Most fires (i.e. 66.9% or 16,517 fires) occur under winds of moderate intensities, while the majority of the large fires (i.e. 41.6% or 350 fires) as well as their respective burned areas (i.e. 43.1% or 170,154 ha), occurred under strong winds. There is also a significant number of large fires (i.e. 30.9% or 26 fires) and area burned (i.e. 26.8% or 105,705 ha) that occurred under moderately strongly winds.

b) The distribution of the number of fires and area burned of all fires and the large fires per type of fire (i.e. surface and crown fire) showed that only about half of total fires (i.e. 51.5% or 11,746 fires) have a mixed mode of propagation (i.e. a combination of surface and crown fire spread), while most areas burned (i.e. 64.24% or 183,497 ha) are caused by surface fires. On the other hand, most large fires (i.e. 88.1% or 74 fires) have a mixed mode of propagation that results in the largest burned area by wildfires (i.e. 95.2% or 394,686 ha).

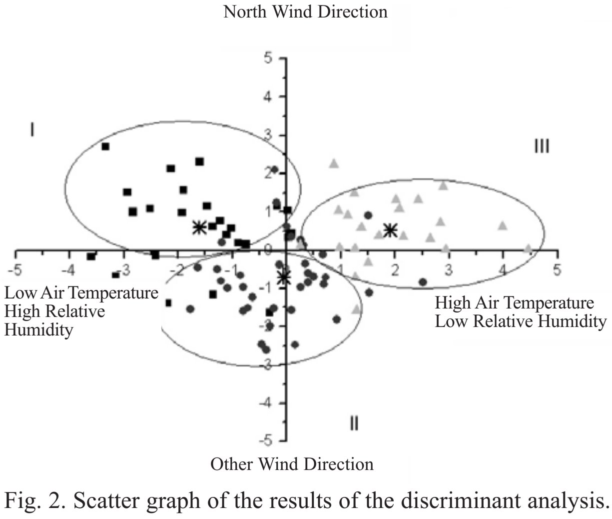

Fig. 2. Scatter graph of the results of the discriminant analysis. The groups (I, II, III) that resulted from the cluster analysis of the meteorological data, as well as the centroids of each group are noted.

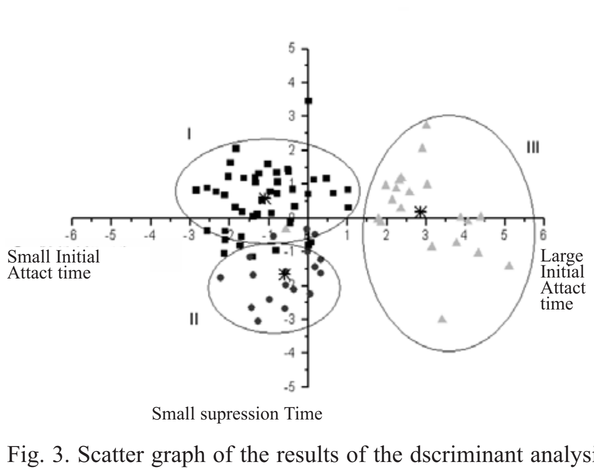

Fig. 3. Scatter graph of the results of the dscriminant analysis. The groups (I, II, III) that resulted from the cluster analysis of the suppression data as well as the centroids of each group are noted.

c) With respect to fire suppression tactics, most fires (i.e. 81.8% or 18,238 fires) are controlled by ground forces. As for large fires, the vast majority (i.e. 89.3% or 75 fires) of them required a mixed method of suppression involving the use of both ground and aerial forces. No other differences between large and other fires were found.

The fact that a small number of forest fires is responsible for the largest percentage of the area burned has been observed by several other researchers worldwide [33-37]. Assuming that any wildfire can become large if the environmental factors are favorable, using the analysis of the present study, some deductions can be made regarding the favorable burning conditions of large forest fires. According to other research studies, large forest fires occur under the influence of strong winds, with high air temperatures and low relative humidity [7, 4, 22, 34]. The results of this study confirm these conclusions. From the 84 large forest fires that exceeded 1,000 ha and occurred in Greece during the period 1990-2003, approximately 2/3 occurred under high air temperatures and moderately low relative humidity. Furthermore, about a quarter of the large fires occurred under conditions of extreme heat.

About the three quarters of the large fires had short initial attack time (<30 minutes) while the remaining had long initial attack times (i.e. >30 minutes). However, half of the fires with short initial attack time had long suppression time (i.e. >120 hours). This supports the assertion that short initial attack time is often not sufficient to control a potentially large fire when the burning conditions are favorable [19]. Pyne [10] suggests that during large fire suppression, action should be attempted by the parallel attack. Alvarado [38] claims that the use of airtankers would be preferred because it renders the suppression less expensive. Finally, Stocks et al. [34] notes that suppression is not even attempted in some cases due to inaccessible topography (e.g. remote areas of Canada). Large wildfires, due to the combined mode of propagation (i.e. surface and crown fire spread) and extreme fire behavior, demand special fire suppression planning (i.e. deployment of the incident command system, fire management headquarters, combined suppression methods, shared resources, logistics, and finance). They also entail very high suppression costs (i.e. long suppression time, costly aerial firefighting means, extensive use of ground forces) in comparison to other fires [15, 16]. Furthermore, due to the fact that almost every forest fire has the possibility to become large under favorable burning conditions, a policy or procedure involving immediate action on all fires has been proposed [17].

The main characteristic that distinguishes most large fires from the other smaller fires seems to be the presence of strong winds. This should be expected since wind is the single most influential weather factor affecting fire spread and, consequently, area burned. Millán et al. [4] mention that the most devastating wildfires that occur along the east coast of Spain are accompanied with strong winds. The presence of strong winds also causes the mixed propagation mode of surface and crown fire spread [39].

Conclusion

Very large fires generally occur in Greece under moderately low relative humidity with strong prevailing winds. Many large fires also occur during heat waves (i.e. a combination of high air temperatures, low relative humidity and dry spells). They propagate as a combination of surface and crown fire spread. Although the initial attack time of very large fires is generally short, their suppression time is quite variable (more than 120 hours on average). No vegetation or topography parameters could discriminate large fires from others. Overall, no unique characteristics of large fires were found that distinguish them from smaller fires. This supports the hypothesis that large fires are the result of a combination of factors that may coincide at any given time. Thus, any fire may become large under certain conditions.

References

1. NEVES M., PEREIRA J., NATARIO R.M. A statistical analysis of Wildfire size data. In: 2nd International Conference on Forest Fire Research, Coimbra Portugal 21/24 November 1994, C.13: pp. 1-10, **1994**.
2. PAUSAS J. Changes in fire and climate in the Eastern Iberian Peninsula (Mediterranean Basin). Climatic Change **63**, 337, **2004**.
3. DAVIS G. Landscapes and biodiversity in Mediterranean-type ecosystems: The role of changing fire regimes. In: Moreno JM (Ed) Large Forest Fires, Backhuys Publishers, Leiden, pp. 109-131, **1998**.
4. MILLAN M.M., ESTRELA M.J., BADENAS C. Synoptic analysis of meteorological processes relevant to forest fire dynamics on the Spanish Mediterranean coast. In: Moreno JM (Ed.) Large Forest Fires, Backhuys Publishers, Leiden, pp. 1-30, **1998**.
5. DIMITRAKOPOULOS A.P., MITSOPOULOS I.D. Global Forest Resources Assessment 2005 – Report on fires in the Mediterranean Region. Fire Management Working Paper 8. FAO, pp. 43, **2006**.
6. DIMITRAKOPOULOS A.P. Descriptive analysis of forest fires and area burned in Greece during the period 1955-1999. Proceedings of the 9th Panhellenic Forestry Conference, Hellenic Forestry Society, Kozani October 17-20 2000, Thessaloniki, pp. 85-90, **2001** [In Greek].
7. GILL A.M., MOORE P. Big versus small fires: the bushfires of greater Sydney January 1994. In: Moreno JM (Ed.) Large Forest Fires, Backhuys Publishers, Leiden, pp. 49-68, **1998**.
8. DIMITRAKOPOULOS A.P. Analysis of the pyric environment and fire suppression parameters of the large forest fires in Greece, during the period 1990-1994. Scientific Annals of the Department of Forestry and Natural Environment 39/2: pp. 533-544, **1996** [In Greek].
9. STRAUSS BEDNAR D.L., MEES R. Do one percent of forest fires cause ninety – nine percent of the damage? For. Sci. **35**, 319, **1989**.
10. PYNE S.J. Introduction to Wildland Fire, Fire Managements in the United States. John Wiley & Sons, Inc., pp. 455, **1984**.
11. EUROPEAN COMMISSION. Forest Fires in the South of the European Union 1989-1993, Pilot Project in preparation for setting up the Community forest-fire information system. Directorate General for Agriculture, Office for Official

Publications of the European Communities, ISBN 92-827-5369-7, pp. 61, **1996**.
12. DIMITRAKOPOULOS A.P. Preliminary distribution of forest fires and burned area according to initial attack time in Greece, during the decade 1986-1995. Forest Research **13**, 26, **2000** [In Greek].
13. EUROPEAN COMMISSION. Forest Fires in Europe, 2001 fire campaign. Report No 2, Official Publication of the European Communities, S.P.I.02.72 EN, pp. 27, **2002**.
14. XANTHOPOULOS G. Forest fire related deaths in Greece: confirming what we already know. In: Proceedings of "Wildfire 2007," Sevilla, Spain. pp. 1-12, **2007**.
15. MINNICH R.A. Landscapes, land-use and fire policy: Where do large fires come from? In: Moreno JM (Ed.) Large Forest Fires, Backhuys Publishers, Leiden, pp. 133-158, **1998**.
16. GORTE R.W. Forest Fires and Forest Health. CRS Report for Congress, National Library for the Environment, ENR 95-511, **1995**.
17. VELEZ R., MERIDA J.C. Forest fire management in Spain: Some examples of systematic analysis of comprehensive database to improve effectiveness and efficiency. In: Viegas DX (Ed) Forest Fire Research & Wildland Fire Safety, Millpress, Rotterdam, **2002**.
18. DORIA F., PINOL A.T. Hourly meteorology and large forest fires. In: Viegas DX (Ed) Forest Fire Research & Wildland Fire Safety, Millpress, Rotterdam, **2002**.
19. EUROPEAN COMMISSION. European Information System on Forest Fires. Report 1985-1999, DG AGRI FI, Official Publication of the European Communities, pp. 68, **2000**.
20. ROMERO M. Multivariate analysis techniques applied to cluster regions according to initiation parameters of forest fires. In: Viegas DX (Ed) Forest Fire Research & Wildland Fire Safety, Millpress, Rotterdam, **2002**.
21. CAMIA A., BOVIO G., AGUADO I., STACH N. Meteorological fire danger indices and Remote Sensing. In: Chuvieco E. (Ed) Remote Sensing of Large Wilfires in the European Mediterranean Basin, Springer, Berlin, pp. 39-59, **1999**.
22. VIEGAS D.X. Weather, fuel status and fire occurence: Predicting large fires. In: Moreno JM (Ed) Large Forest Fires, Backhuys Publishers, Leiden, pp. 31-48, **1998**.
23. CHUVIECO E. Remote Sensing of Large Wilfires in the European Mediterranean Basin, Springer, Berlin. pp. 210, **1999**.
24. DIMITRAKOPOULOS A.P., OMI P.N. Evaluation of the Fire Simulation Processes of the National Fire Management System's Initial Attack Analysis Processor. Environmental Management **31**, 147, **2003**.
25. KOSTOUSOV A. Application of parallel computing to simulation of chaotic dynamics. Proceedings of the VIII International Workshop on Advanced Computing and Analysis Techniques in Physics Research, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment **502**, 733, **2003**.
26. ANDREWS P.L., BEVINS C.D., SELI R.C. BehavePlus fire modeling system, version 4.0: User's Guide. General Technical Report RMRS-GTR-106 Revised. Ogden, UT: Department of Agriculture, Forest Service. Rocky Mountain Research Station. pp. 107, **2008**.
27. FINNEY M.A. FARSITE: Fire area simulator-model development and evaluation. USDA, Forest Service, Rocky Mountain Research Station, Research Paper RMRS-RP-4, Ogden, Utah. pp. 47, **2004**.
28. ALDENDERFER M.S., BLASHFIELD R.K. Cluster Analysis, Series: Quantitative Applications in the Social Sciences. SAGE Publications, Newburry Park, California, pp. 88, **1984**.
29. ROMESBURG H.C. Cluster Analysis For Researchers. Krieger Publishing Company, Malabar Florida, pp. 344, **1984**.
30. KLECKA, W.R. Discriminant Analysis, Series: Quantitative Applications in the Social Sciences. SAGE Publications, Newburry Park, California, pp. 71, **1980**.
31. DIMITRAKOPOULOS A.P. PYROSTAT – a computer program for forest fire data inventory and analysis in Mediterranean countries. Environ. Modell. Softw. **16**, 351, **2001**.
32. NORUSIS M.J. SPSS professional statistics. SPSS Inc: Chicago pp. 376, **1997**.
33. LEFORT P., GAUTHIER S., BERGERON Y. The Influence of Fire Weather and Land Use on the Fire Activity of the Lake Abititi Area, Eastern Canada. For. Sci. **49**, 509, **2003**.
34. STOCKS B.J., MASON J.A., TODD J.B., BOSCH E.M., WOTTON B.M., AMIRO B.D., FLANNIGAN M.D., HIRSCH K.G., LOGAN K.A., MARTELL D.L., SKINNER W.R. Large forest fires in Canada, 1959-1997. J. Geophys. Res. **108**, 1, **2003**.
35. BADIA A., SAURI D., CERDAN R., LLURDES J.C. Causality and management of forest fires in Mediterranean environments: an example from Catalonia. Global Environmental Change Part B: Environmental Hazards **4**, (1), 23, **2002**.
36. CANADIAN COUNCIL OF FOREST MINISTERS (CCFM) Compendium of Canadian forestry statistics, National Forestry Database Program. Available from http://nfdp.ccfm.org/cp95/image_e/fig8ae.htm, **2002**.
37. MORENO J.M., VASQUEZ A., VELEZ R. Recent history of forest fire in Spain. In: Moreno J.M. (Ed) Large Forest Fires, Backhuys Publishers, Leiden, pp 159-185, **1998**.
38. ALVARADO E., SANDBERG D.V., BARE B.B. Analysis of area burned by wildfires through the partitioning of a probability model. USDA Forest Service, Gen. Tech. Rep. PSW-GTR-173, pp. 59-68, **1999**.
39. CRUZ M., ALEXANDER M., WAKIMOTO R. Development and testing of models for predicting crown fire rate of spread in conifer forest stands. Can. J. For. Res. **35**, 1626, **2005**.
40. THE BROOKINGS INSTITUTION. The Mega-Fire Phenomenon: Toward a More Effective Management Model. Concept Paper Presented to the U.S. National Fire and Aviation Board, 20th September, 2005. The Brookings Institution Centre for Public Policy Education, Washington, D.C. pp. 15, **2005**.
41. BARTLETT T., LEONARD M., MORGAN G. The megafire phenomenon: some Australian perspectives. In: The 2007 Institute of Foresters of Australia and New Zealand Institute of Forestry Conference: Programme, Abstracts and Papers, Institute of Foresters of Australia, Canberra. **2007**.