



EUFIRELAB
EVR1-CT-2002-40028

D-04-05

<http://eufirelab.org>



EUFIRELAB:
Euro-Mediterranean Wildland Fire Laboratory,
a “wall-less” Laboratory
for Wildland Fire Sciences and Technologies
in the Euro-Mediterranean Region

Deliverable D-04-05

Common methodologies and tools
for monitoring vegetation dynamics

Coordinated by Margarita ARIANOUTSOU and Dimitris KAZANIS (P021)

with contributions from partners

P09, P034, P037

January 2005

CONTENT LIST

1	General introduction	1
1.1	Planned activities during the contract.....	1
1.2	Performed Activities	1
2	Vegetation monitoring: introduction	2
3	Population level	3
4	Community level	4
5	Landscape level	5
6	Bibliographical references.....	6

SUMMARY

This document presents an exhaustive literature review of the various tools and methodologies that have been applied in the countries of the Mediterranean Basin for the post-fire monitoring of vegetation in forested and non-forested ecosystems.

In addition, reports on relevant monitoring procedures from other parts of the world have been included in order to produce a state of the art on the subject and proceed towards the evaluation of the present status and the elaboration of common procedures and approaches.

After an introductory chapter where the importance of vegetation monitoring is described, there are three chapters dedicated to the different levels of vegetation monitoring.

For each level, the monitored variables and the relevant methodology are described.

Furthermore, different tools for data analysis are briefly mentioned.

- ✂✂ Population level: Usually, the monitored variables are related to species abundance, i.e. density, cover, frequency and to individual growth and biomass development. Less frequent is the monitoring of species spatial pattern and demography. Plots and transects are the commonest sampling techniques. For data analysis several tools are available from classical statistics to multiple regression and correspondence analysis.
- ✂✂ Community level: Vegetation analysis and monitoring can be either structural or floristical. In the former case vegetation cover, layering (profil) and/or biomass development are usually recorded. In the latter case, the monitored variables include species composition and richness, species abundance and community diversity. Apart from the plot and transect sampling techniques, the point intercept quadrat method has also been frequently applied. Apart from following the temporal pattern of the monitored variables, data processing includes the production of qualitative and quantitative spectra (life forms, functional groups), the calculation of diversity indices, the evaluation of community stability and the interpretation of the monitored variables with other abiotic or biotic factors (canonical correspondence analysis).
- ✂✂ Landscape level: The studies performed at this level show great variability in the approaches followed. This variability is seen both in their way of treating both the spatial and the temporal component. Remote sensing of post-fire recovery is usually based on the proportion of the green vegetation component in the signal. In general, the NDVI is used, although some studies have investigated other applications such as Spectral Mixture Analysis (SMA). In terms of time scale, some studies report on short-term (immediately effects or less than 5 years after fire) whereas others extend on long-term scale, more than 10 years.

The last chapter gathers 122 bibliographical references that were reviewed for the production of the current deliverable.

GLOSSARY

None

ASSOCIATED FILES

None

1 GENERAL INTRODUCTION

Unit 04, was originally moderated by MARGARITA ARIANOUTSOU P021, JOSÉ MORÉNO P020, ROGER PRODON P019 and RAMON VALLEJO P009, has been in charge the activities related to WP04.

The current leader is RAMON VALLEJO, and JULI PAUSAS P009 administrates the section within the EUFIRELAB web site.

1.1 PLANNED ACTIVITIES DURING THE CONTRACT

The participants:

- evaluate and elaborate common methodologies and procedures to monitor the recovery of the burned areas, with an emphasis on the long term monitoring of a network of reference study sites (natural observatories) in forested and non-forested areas.

1.2 PERFORMED ACTIVITIES

An exhaustive literature review has been carried out covering mainly the Mediterranean Basin.

The specific objective of this task is to concentrate on methodological tools related to the issue of vegetation monitoring and to suggest the most appropriate ones in relation to the working task.

2 VEGETATION MONITORING: INTRODUCTION

There is a great deal of studies related to post-fire vegetation monitoring across the Mediterranean basin, covering a variety of forested and non-forested ecosystems.

The vast majority of them explore the short-term patterns of various aspects of vegetation dynamics and relate them to several factors such as fire characteristics, prefire vegetation structure and composition, land use and fire history, etc.

Still, it has been realised that in order to fully understand the role of fire and to evaluate the resilience of the different ecosystems towards this disturbing agent, long-term monitoring was required.

Long-term post-fire vegetation monitoring can be either direct or indirect.

In the former case, sampling units are established right after the fire event and the studied variables are monitored for several consecutive years.

This approach is also called diachronic approach.

Although this approach has been successfully applied in grasslands and shrublands, i.e. vegetation types that reach maturity within a short period of years, it becomes very difficult when forest vegetation is concerned.

To our knowledge, it is only in the United States that some reports on long-term vegetation dynamics based on the study of old (more than 50-yr-old) permanent plots has been produced.

Alternatively, given the restraints of the long-term direct vegetation monitoring, the indirect or synchronic approach has been developed.

According to this approach, a series of communities of the same vegetation type differing in the time elapsed since the disturbance, called a chronosequence, are sampled for the same variables and the results are (indirectly) plotted against time.

Although it has been argued that the synchronic approach is not always as reliable as the diachronic one, since the specific site history maybe of greater importance than assumed, it has been recognised that this "space for time substitutes" can greatly enhance our knowledge on mechanisms and patterns of vegetation dynamics and permit the testing of general hypotheses.

In a parallel effort to reduce the shortcomings and exploit the advantages of the two approaches, a combination of them has been recently applied in Greece with success.

Studies on vegetation monitoring can be classified according to the hierarchical level they address to.

Consequently, there are studies focusing on the monitoring of plant population dynamics, studies that focus on the whole plant community and studies that monitor vegetation at the landscape level, where different patches or types of vegetation maybe included.

This hierarchical approach to vegetation monitoring has been followed to the tables that were prepared in order to facilitate the reviewing of the available literature and is also maintained in the present report.

These tables (together with two examples of data introduction) are downloadable from the site under Ecology /Directories/ T3a_monitoring, page http://www.eufirelab.org/prive/directory_list.php?genre_id=4&rep_id=333.

3 POPULATION LEVEL

There are three main cases where population monitoring is required.

The first case refers to those species that were dominant before the fire event and, consequently, their regeneration is of primary importance for the ecosystem resilience.

Studies focusing on population monitoring of pines in the Mediterranean-climate pine forests or of *Cistus* spp. in shrublands characterized by *Cistus* dominance are examples of this first case.

Second is the case of species or group of species that are important for the ecosystem resilience not by forming a dominant component of the vegetation but by playing an important role in one or more of the system functions.

This is the case of studies on members of Cistaceae and Leguminosae families in Mediterranean-climate pine forests, where the species in question may not be dominant before the fire but are quite abundant right after the fire event, playing a crucial role to the ecosystem recovery.

Finally, there is the case of rare, threatened or endangered species, where the monitoring of their populations is important for their conservation.

From the available studies, it seems that the most common sampling technique for monitoring plant populations is the use of permanent plots.

The choice of size, the shape and the number of different plots is related both to species characteristics (growth form, abundance, spatial distribution within the community) and to area that has to be included in the study.

Accordingly, there is a wide variety of sampling protocols.

Usually the minimum plot area varies from 1/4 m² or even less, in the case of seedlings, to 10 m² or more (up to 0.1ha, when trees are involved).

Consequently, it is common, whenever a demographic analysis is included, to use different plot dimensions per different age class (seedlings, juveniles, matures), in terms of plots and subplots within the plots.

In the vast majority of studies, the shape of the plots is square or rectangle, but there are some researchers who prefer circular plots (defined by its radius).

The number of the plots is extremely variable.

The range varies usually between 10-50, but it can be as high as several hundreds.

As far as the arrangement of the plots is concerned, there are studies where the distribution of the plots is random, while according to other protocols, plots are established following a certain pattern along a transect.

Still, no matter the sampling protocol, the commonest parameters recorded are species cover and species density.

Species cover is usually recorded for species that regenerate vegetatively after fire.

For many resprouters (e.g. *Quercus coccifera* or *Brachypodium retusum*) it is impossible to decide whether two different resprouts belong to the same or different individuals.

In order to avoid over- or under-estimating the species population, cover is selected as the recorded variable.

In some reports, the growth of individual plants, or the biomass accumulation is recorded.

If these variables are recorded together with species abundance, then the plot sampling technique is applied.

Otherwise, if only the temporal pattern of plant growth and biomass development is studied, then it is possible not to follow the plot sampling protocol but to randomly select individuals in the community for monitoring.

A very interesting tool of monitoring at the population level is the demographic monitoring, according to which not only the species abundance is recorded, but also the abundance of different age classes.

In such a way, the fate of the newly established individuals can be followed for successive years and be related to factors such as microsite characteristics, intra- and interspecies competition, etc.

Additionally, other aspects of demography such as age to maturity or life span and senescence are being approached.

Demographic monitoring is very important for species of conservation priority.

Although there is a great deal of data on plant population monitoring after fire from a variety of Mediterranean-climate ecosystems across the Mediterranean Basin, most of them are restricted to 3 - 5 consecutive years.

There are few long-term studies, where permanent plots are being revisited and the same variables are being recorded.

Usually, this is the case of studies where the plots had been frequently sampled during the first postfire years (on an annual basis or even more frequently) and then resampled after 3 or 5 years, etc.

Even fewer are the long-term population monitoring studies with the synchronic approach.

Non-linear regression analysis of individual species abundance against time has been proposed as a tool that provides the opportunity to distinguish between actual patterns and stochastic fluctuations.

Still, this analysis is advised only in the availability of long-term data.

For short-term data, tools from classical statistics have been used, e.g. to test significant difference between different years or sites, or to test normal distribution of variables.

If, apart from data on species performance, data on site characteristics have been collected, then multiple regression and correspondence analysis is usually performed to test the significance of the various environmental factors.

4 COMMUNITY LEVEL

Vegetation analysis and monitoring can be either structural or floristic or a combination of the above.

In the structural approach variables such as cover, vertical organisation (profile) and spatial heterogeneity are being monitored.

Results are afterwards plotted against time and the overall pattern is produced.

The structural analysis of vegetation has the advantage of not being time consuming – in several cases it is based on visual estimation – but nothing more than general trends can be produced.

Nowadays, structural monitoring is performed only in studies where vegetation is not the main target but just a variable that influences other ecosystem components (avifauna, soil animals) and functions (soil development, soil erodibility).

In the floristic approach, vegetation is regarded as a plant community, which consists of populations of different species.

Accordingly, the emphasis is on vegetation composition and the monitored variables are species composition and richness, species abundance and community diversity.

However, the objectives of these studies are very different and because of that they show a great methodological heterogeneity.

As already mentioned, the applied sampling techniques vary in terms of their design and arrangement (unit size, shape, replicate number and distribution in the burned community).

In general, all protocols used can be distinguished into two general categories, that of plots and that of transects.

The transect approach has the advantage of permitting the sampling of a wider part of the community in minimum time.

The main drawback is the absence of reference material in the literature, since the vast majority of studies (in particular the more classical ones) have been performed with the plot sampling.

Another drawback of transects is that it is difficult to compare with the literature, because of the different length, and different inter-point distances (point intercept).

This drawback is especially important when studying species richness patterns; changes in species richness may be very sensitive to length, and to inter-point distances in the transects and cannot be compared with area-based species richness.

Another sampling technique applied in case where many different communities have to be included and time is a restraining factor, is the point intercept sampling technique, according to which measurements refer neither to within plots nor across transects but only at certain points across a transect.

In few studies, a spatial explicit sampling scheme has been applied, which allows to study spatial heterogeneity of plant distribution and the post-fire changes in spatial pattern.

Finally, there are a few studies where vegetation monitoring is performed by applying phytosociological protocols (BRAUN-BLAQUET OR ELLENBERG).

The commonest analysis of data includes plotting of species richness against time, either as a whole (total richness) or after grouping species into different categories, according to their life form, regeneration mode or a combination of vital attributes that permit the classification into functional groups.

Furthermore, abundance of species or group of species is plotted against time in the cases where quantitative data are available.

In order to combine qualitative with quantitative data, several indices have been proposed, providing information on the diversity of the community and its change over time.

Additionally, in some cases indices on the stability of the community over time have been proposed (e.g. fugacity index), while in other cases cluster analysis or indirect ordination methods are been applied for the same reason.

Direct correspondence analysis is a very important tool that has been developed during the last years and has been used very effectively in chronosequence studies in order to clarify which other factors, apart from post-fire age, determine species composition and abundance, and, consequently, evaluate whether the included and sampled communities/stands form a true chronosequence (i.e. a seral of communities with similar characteristics) or not.

5 LANDSCAPE LEVEL

The studies about the fire effects on landscape structure show great diversity of approaches due to the different way to treat the spatial and temporal component.

Some studies analyse fire effects at short-term (immediately effects or less than 5 years after fire) whereas others focus on long-term scale considering the effects over more than 10 years.

The usual means used are aerial photographs and satellite images.

Continuous data by NDVI values, texture indices or semivariograms and nominal data by land cover classes have been the main landscape variables used to infer the effects of fire on landscapes and, in all the cases, spatially explicit fire perimeters were considered to carry out the analysis.

In general, changes in FRAGSTATS landscape metrics have been used as surrogates of the effects of fire on landscape structure.

The regeneration process has been analysed at landscape scale considering continuous data (NDVI) for multiple burned areas to characterise the pathway of recovery using regression models at middle-term (not more than 10 years after fire).

The remote sensing of post-fire recovery is usually based on the proportion of the green vegetation component in the signal.

In general, the NDVI is used, although some studies have investigated other applications such as Spectral Mixture Analysis (SMA).

LANDSAT MSS and TM imagery is most widely used because they can provide time series since 1975, but the application of SAR imagery seems to be very promising in post-fire recovery mapping.

The usefulness of hyperspectral remote sensing data, such as AVIRIS, in characterising the regeneration process has been assessed as useful for estimating post-fire recovery.

SWIR reflectance measured by LANDSAT TM has been found to be sensitive to burned area and biomass.

Artificial Neural Network (ANN) models performed better than multiple regression models in predicting the regeneration age because the former are highly effective in mapping non-linear relationships between reflectance and regeneration age.

Single-channel density slices of band 7 of LANDSAT MSS has been used to report the first-year recovery of vegetation.

Burn severity has been mapped using a band ratio of MSS7/MSS5, and performing an unsupervised classification to detect vegetation change.

Synthetic Aperture Radar (SAR) can estimate volumes of vegetation, and therefore is able to map parameters related to forest biomass, namely, stem volume, total growing stock, or above ground net primary productivity.

SAR has been used in several regeneration studies carried out after disturbances other than fire.

SAR proved to be highly reliable in areas with small biomass, such as burned or harvested areas.

It seems that the technique offers unique possibilities to update existing inventory data and to characterize (1) the level of disturbances and their consequences, (2) succession regularities, (3) restoration processes in forests, and (4) the current state of forests.

The change in spatial patterns among multi-resolution images is a new source of information for diagnosing surface characteristics.

Maps of post-fire recovery, in combination with GIS databases, may be used, to show the relationship between post-fire recovery and spatial and temporal patterns in the environment (topography, weather, management), to indicate areas in need of protective measures, and to monitor fire-induced land use changes.

Fire impact mapping is strongly dependent on field validation in order to link spectral classes on the image with the visible classes of fire severity in the field.

Normally, fire impact is mapped after a single fire, preferably some weeks after the fire.

Post-fire recovery is less dependent on field validation because the most important aspect of post-fire recovery is the temporal change over several images, in comparison with unburned sites or pre-fire conditions.

One of the advantages of using Remote Sensing techniques is that it is possible to get RS imagery from pre-fire conditions and relate then to post-fire regeneration.

Also it allows to related spatial features (topography) with fire severity

Finally, the temporal and spatial analysis capacities of GIS enable a better understanding of the relationships between fire impact and/or post-fire recovery and between landscape characteristics and fire regime.

6 BIBLIOGRAPHICAL REFERENCES

- AHLGREN IF, and AHLGREN CE, 1960.- Ecological effects of forest fires. *Bot.Rev.*26,483-533
- AHLGREN IF, and AHLGREN CE, 1965.- Effect of prescribed burning on soil micro-organisms in a Minnesota jack pine forest *Ecol.* 46,306-310
- ALONSO I, LUIS E and TARREGA R, 1992.- First phases of regeneration of *Cistus laurifolius* and *Cistus ladanifer* after burning and cutting in experimental plots. *Int. J. Wildland Fire* 2(1): 7-14
- ARIANOUTSOU M, 1979.- Biological activity after fire in a phryganic ecosystem. Ph.D Thesis. University of Thessaloniki, (in Greek with an English Summary)
- ARIANOUTSOU M, 1984.- Post-fire successional recovery of a phryganic (East Mediterranean) ecosystem. *Acta Oecologica (Oecologica Plantarum)* 5(19):287-394
- ARIANOUTSOU M, 1998.- Aspects of demography in post-fire plant communities of Greece. In: RUNDEL, P.W, MONTENEGRO G. and JAKSIC F (eds). *Landscape Degradation and Biodiversity in Mediterranean Type Ecosystems. Ecological Studies* 136. Springer-Verlag, Berlin, Heidelberg, pp 273-295
- ARIANOUTSOU M, 1999.- Effects of fire on vegetation demography. *International Symposium on Forest Fires: Needs and Innovations, (DELFI), Athens 1999*
- ARIANOUTSOU M, 2001.- Landscape changes in Mediterranean Ecosystems of Greece: implications for Fire and Biodiversity issues. *Journal of Mediterranean Ecology* 2: 165-178.
- ARIANOUTSOU M, and MARGARIS NS, 1981a.- Producers and the fire cycle in a phryganic ecosystem. In: Margaris N.S. and H.A. Mooney (eds). *Components of productivity in Mediterranean climate regions – basic and applied aspects.* Dr W. Junk, The Hague, pp 181-190
- ARIANOUTSOU M, and MARGARIS NS, 1981b.- Early stages of regeneration after fire in a phryganic ecosystem (East Mediterranean). I. Regeneration by seed germination. *Ecologia Mediterranea* 7: 119-128
- ARIANOUTSOU M, and NE'EMAN G, 2000.- Post-fire regeneration of natural *Pinus halepensis* forests in the East Mediterranean Basin. In: *Ecology, Biogeography and Management of Mediterranean Pine Forest.* G. NE'EMAN, and L. TRABAUD (eds), pp 269-290, Backhuys Publishers, 407p
- ARIANOUTSOU M, KAZANIS D, KOKKORIS Y, and SKOUROU P, 2002.- Land-use interactions with fire in Mediterranean *Pinus halepensis* landscapes of Greece: patterns of biodiversity. IV International Forest Fire Research Conference, Millpress, electronic edition.
- ARIANOUTSOU M, KAZANIS D, and VARELA V, 2000.- Ecological indicators of land degradation due to frequent fires: the case of Penteli Mt., Attica, Greece. *Book of Abstracts, MEDECOS 2000, Stellenbosch.*
- BASTIDA F, TALAVERA S, 2002.- Temporal and spatial patterns of seed dispersal in two *Cistus* species (Cistaceae). *Annals of Botany* 89: 427-434
- BAUTISTA S, VALLEJO VR, 2002.- Spatial variation of post-fire plant recovery in Aleppo pine forests. In TRABAUD L, PRODON R (Eds) *Fire and biological processes.* Backhuys Publishers, Leiden
- BOERNER R.E.J. 1981. Forest structure dynamics following wildfire and prescribed burning in the New Jersey Pine Barrens. *The American Midland Naturalist* 105(2): 321-333
- BRADSTOCK RA, WILLIAMS JE, and GILL AM, 2002.- *Flammable Australia. The fire regime and biodiversity of a continent.* Cambridge University Press, Cambridge, UK.
- BRIGGS K. MARK, HOWE JIM, HARRIS LISA, HALVORSON WILLIAM 1996. Using long-term monitoring to understand how adjacent land development affects natural areas: an example from Saguaro National Park, Arizona (USA). *Natural Areas Journal* 16(4): 354-361.
- BUCINI G and LAMBIN EF, 2002.- Fire impacts on vegetation in Central Africa: a remote-sensing-based statistical analysis. *Applied Geography* 22(1): 27-48
- CALLAWAY, RM, DAVIS FW. 1993. Vegetation dynamics, fire and the physical environment in coastal central California. *Ecology* 74: 1567-1578.
- CALVO L, TARREGA R and LUIS E, 1991.- Regeneration in *Quercus pyrenaica* ecosystems after surface fires. *Int. J. Wildland Fire* 1(4): 205-210
- CALVO L, TARREGA R and LUIS E, 1994.- Comparative study of post-fire successional development in two communities with different maturity stage in *Quercus pyrenaica* climax. *Proc. 2nd Int. Conf. Forest Fire Research* 2: 951-960. International Association of Wildland Fire
- CALVO L, TARREGA R and LUIS E, 1998.- Twelve years of vegetation changes after fire in an *Erica australis* community: 123-136. International Association of Wildland Fire
- CALVO L, TARREGA R and LUIS E, 1999.- Post-fire succession in two *Quercus pyrenaica* communities with different disturbance histories. *Ann. For. Sci.* 56: 441-447
- CALVO L, TARREGA R and LUIS E, 2002.- The dynamics of Mediterranean shrubs species over 12 years following perturbations. *Pl. Ecol.* 160: 25-42

- CANADELL J, LLORET F, LÓPEZ-SORIA L, 1991.- Resprouting vigour of two Mediterranean shrub species after experimental fire treatments. *Vegetatio* 95: 119-126
- CATARINO F., CORREIA O.C.A. AND CORREIA A.I.V.D. 1987. Structure and dynamics of Serra da Arrabida mediterranean vegetation. *Ecologia Mediterranea* XIII(4): 25-37.
- CHUVIECO E, 1999.- Measuring changes in landscape pattern from satellite images: short-term effects of fire on spatial diversity. *International Journal of Remote Sensing* 20 (12): 2331-2346
- CLARK PJ, 2002. Habitat islands in fire-prone vegetation: do landscape features influence community composition? *Journal of Biogeography*, 29: 677-684.
- CLARK JS. 1996. Testing disturbance theory with long term data: alternative lifehistory solutions to the distribution of events. *Amer. Natur.*, 148(6): 976-996.
- CLEMENTE A, REGO F and CORREIA A, 1996.- Demographic Patterns and Productivity of Post-fire regeneration in Portuguese Mediterranean Maquis. *Int. J. of Wildland Fire* 6 (1): 5-12.
- COFFIN, D. P. LAYCOCK, W. A. LAUENROTH, W. K. 1998. Disturbance intensity and above- and belowground herbivory effects on long-term (14 y) recovery of a semiarid grassland. *Plant Ecology* 139: 221-233.
- CONRAD CE, and OECHEL WC eds, 1982.- *Dynamics and management of Mediterranean-type ecosystems*. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station.
- CORONA P, LEONE V and SARACINO A, 1998.- Plot size and shape for the early assessment of post-fire regeneration in Aleppo Pine Stands. *NEW FORESTS* 16 (3): 213-220
- CRUZ A, PÉREZ B, MORENO JM, 2003.- Resprouting of the Mediterranean-type shrub *Erica australis* with modified lignotuber carbohydrate content. *J. Ecol* 91: 348-356
- CRUZ A, PÉREZ B, VELASCO A, Moreno JM, 2003.- Variability in seed germination at the interpopulation, intrapopulation and intraindividual levels of the shrub *Erica australis* in response to fire-related cues. *Plant Ecology* 169:93-103
- DASKALAKOU EN, and THANOS CA, 1996.- Aleppo pine (*Pinus halepensis*) postfire regeneration: the role of canopy and soil seed banks. *Int. J. of Wildland Fire* 6: 59-66
- DASKALAKOU EN, and THANOS CA, 1997.- Post-fire establishment and survival of Aleppo pine seedlings. In: *Forest Fire Risk and Management. Proceedings of The Summer School of Climatology and Natural Hazards*, P. Balabanis, G. Eftichidis and R. Fantechi (eds), EUR 16719, pp 357-368.
- DAUBENMIRE, R, 1968.- The ecology of fire in grasslands. *Adv. Ecol. Res.* 5, 209-266
- DAVIS EA, (1989.- Prescribed fire in Arizona Chaparral: Effects on stream water quality. *Forest Ecol Manage* 26:189-206.
- DELARZE R., CALDELARI D. AND HAINARD P. 1992. Effects of fire on forest dynamics in southern Switzerland. *Journal of Vegetation Science* 3: 55-60.
- DE LILLIS M. and TESTI A. Fire disturbance and vegetation dynamics in a mediterranean maquis of central Italy. *Ecologia Mediterranea* XVIII: 55-68.
- DIAZ-DELGADO R and PONS X, 2001.- Spatial patterns of forest fires in Catalonia (NE of Spain) along the period 1975-1995: Analysis of vegetation recovery after fire. *Forest Ecology and Management*, 147(1): 67-74.
- DIAZ-DELGADO R, LLORET F, PONS X, and TERRADAS J, 2002.- Satellite evidence of decreasing resilience in Mediterranean plant communities after recurrent wildfires. *Ecology* 83 (8): 2293-2303
- DIAZ-VILLA MD, MARANON T, ARROYO J, GARRIDO B, 2003.- Soil seed bank and floristic diversity in a forest-grassland mosaic in southern Spain. *Journal of Vegetation Science* 14, 701-709
- ESHEL A, HENIG-SEVER N, NE'EMAN G, 2000.- Spatial variation of seedling distribution in an east Mediterranean pine woodland at the beginning of post-fire succession. *Plant Ecology* 148: 175-182
- ESPIRITO SANTO M.D. and CAPELO J. Succession dynamics in ten years of permanent plot observation after wildfire in the center of Portugal (Mediterranean region). Draft paper.
- ESPOSITO A, MAZZOLENI S, STRUMIA S, 1999.- Post-fire bryophyte dynamics in Mediterranean vegetation. *Journal of Vegetation Science* 10:261-268
- FARACO AM, FERNÁNDEZ F, MORENO JM, 1993.- Post-fire vegetation dynamics of pine woodlands and shrublands in the Sierra de Gredos, Spain. In: Trabaud L, Prodon R (eds) *fire in Mediterranean Ecosystems (Ecosystems research report 5)* EU
- FARACO AM, FERNÁNDEZ-GONZÁLEZ F and MORENO JM, 1993.- Post-fire vegetation dynamics of pine woodlands and shrublands in the Sierra de Gredos, Spain. In: TRABAUD L. and PRODON R. (Eds.), *Fire in Mediterranean Ecosystems*: 101-112. Commission of the European Communities, EUR 15089 EN, *Ecosystems Research Report 5*, F118
- FERNANDEZ-ABASCAL I, TÁRREGA R, LUIS-CALABUIG E and Marcos E, 2002.- Trends in post-fire biomass recovery in an *Erica australis* heathland. *Fire and Biological Process*: 33-42
- FERRANDIS P, DE LAS HERAS J, MARTINEZ-SANCHEZ JJ, HERRANZ JM, 2001.- Influence of a low-intensity fire on a *Pinus halepensis* Mill. forest seed bank and its consequences on the early stages of plant succession. *Israel J. Plant Sci.* 49, 105-114.

- FRIEDEL MH and SHAW K. 1986. Evaluation of methods for monitoring sparse patterned vegetation in arid rangelands. II. Trees and shrubs. *Journal of Environmental Management* 25: 309-318.
- FRIEDEL MH and SHAW K. 1987. Evaluation of methods for monitoring sparse patterned vegetation in arid rangelands. II. Herbage. *Journal of Environmental Management*, 25: 297-308.
- FRIEDEL MH. 1990. Some key concepts for monitoring Australia's arid and semi-arid rangelands. *Australian Rangelands Journal* 12: 21-24.
- GIOVANNINI G, LUCCHESI S, and CIOMPI S, 1998.- Post-fire vegetation dynamic and its effect on soil erosion processes. In: *Fire management and landscape ecology*. TRABAUD L. Ed. International Association of Wildland Fire. Fairfield, Washington. pp.69-74
- GRANSTROM A, 2001.- Fire management for biodiversity in the European boreal forest. *Scandinavian Journal of Forest Research*. 62-69.
- HOBBS R.J. and ATKINS L. 1990. Fire-related dynamics of a *Banksia* woodland in South-Western Australia. *Australian Journal of Botany* 38: 97-110.
- HOLT R.D., ROBINSON G.R. AND GAINES M.S. 1995. Vegetation dynamics in an experimentally fragmented landscape. *Ecology*, 76(5): 1610-1624.
- JUHREN MC and MONTGOMERY KR. 1977. Long-term responses of *Cistus* and certain other introduced shrubs on disturbed wildland sites in Southern California. *Ecology* 58: 129-138.
- KAZANIS D, and ARIANOUTSOU M, 1996.- Vegetation composition in a post-fire successional gradient of *Pinus halepensis* forest in Attica, Greece. *Int. J. Wildland Fire* 6(2): 83-91
- KAZANIS D. and ARIANOUTSOU M, 2002.- Long term post-fire dynamics of *Pinus halepensis* forests of Central Greece: plant community patterns. In: VIEGAS D.X. (ed). *Proceedings of the IV International Forest Fire Research Conference*, Millpress, The Netherlands, Electronic edition.
- ?AZANIS D. and ARIANOUTSOU M, 2004.- Long-term post-fire vegetation dynamics in *Pinus halepensis* forests of central Greece: a functional-group approach, *Plant Ecology*.
- KAZANIS D, and ARIANOUTSOU M, 2004.- Factors determining low Mediterranean ecosystems resilience to fire: the case of *Pinus halepensis* forests. In: ARIANOUTSOU M and PAPANASTASIS VP (eds). *Ecology, Conservation and Management of Mediterranean Climate Ecosystems of the World*. *Proceedings of the MEDECOS 10th International Conference*, Rhodes, Greece. Millpress, The Netherlands, Electronic Edition.
- KOSLOWSKI TT, and AHLGREN CE, 1974.- *Fire and ecosystems*. Academic Press, New York.
- KRUGER F.J. 1983. Plant community diversity and dynamics in relation to fire. 446-472.
- KUTIEL P., LAVEE H. and SHOSHANY M. 1995. Influence of a climatic gradient upon vegetation dynamics along a Mediterranean arid transect. *Journal of Biogeography* 22: 1065-1071.
- LLORET F, CALVO E, PONS X and DÍAZ-DELGADO R, 2002.- Wildfires and landscape patterns in the Eastern Iberian Peninsula. *Landscape Ecology* 17: 745-759.
- LLORET F and LÓPEZ-SORIA L, 1993.- Resprouting of *Erica multiflora* after experimental fire treatments. *J Veg Sci* 4: 367-374
- LUIS-CALABUIG E, TÁRREGA R and ALONSO I, 1996.- Seedling regeneration of two *Cistus* species after experimental disturbances. *Int. J. Wildland Fire* 6(1): 13-19
- MARCOS E, VALBUENA L, LUIS-CALABUIG E and TÁRREGA R, 1994.- First stages of post-fire regeneration in *Pinus radiata* plantations. *Proc. 2nd. Int. Conf. Forest Fire Research* 2: 969-978. International Association of Wildland Fire,
- MATEU J, USO JL, and MONTES F. 1998.- A marked bivariate spatial model to detect interactions between Mediterranean shrubs. *Ecosystems and sustainable development* 1: 447-455
- MENGES, E. and KIMMICH J. 1996. – Microhabitat and time since fire: effects on demography on *Eryngium cuneifolium* (Apiaceae), a Florida scrub endemic plant. *American Journal of Botany* 83(2): 185-191.
- MORAVEC J, 1990.- Regeneration of N.W. African *Pinus halepensis* forest following fire. *Vegetatio* 87: 29-36
- MOREIRA F, REGO FC and FERREIRA PC, 2001.- Temporal (1958-1995) pattern of change in a cultural landscape of northwestern Portugal: implication for fire occurrence. *Landscape Ecology* 16: 557-567.
- MOUILLOT F, RATTE JP, JOFFRE R, MORENO JM and RAMBAL S, 2003.- Some determinants of the spatio-temporal fire cycle in a Mediterranean landscape (Corsica, France). *Landscape Ecology* 18: 665-674.
- NE'EMAN G, 1997.- Regeneration of Natural Pine forest- Review of work done after the 1989 fire in Mount Carmel, Israel. *Int. J. Wildland Fire* 7(4): 295-306
- NE'EMAN G, LAHAV H, and IZHAKI I, 1992.- Spatial pattern of seedlings 1 year after fire in a Mediterranean pine forest. *Oecologia* 91: 365-370.
- NE'EMAN G, and IZHAKI I, 1998.- Stability of pre- and post-fire spatial structure of pine trees in Aleppo pine forest. *Ecography* 21: 535-542
- NISHITA H, and HAUG RM, 1972.- Some physical and chemical characteristics of heated soils. *Soil Sci.* 113, 422-430.
- OJEDA F, MARAÑÓN T, and ARROYO J, 1996.- Postfire regeneration of a mediterranean heathland in southern Spain. *International Journal of Wildland Fire* 6(4):191-198

- ORDOÑEZ JL, and RETANA J, 2004.- Early reduction of post-fire recruitment of a seeder tree species by post-dispersal seed predation in different time-since-fire habitats. *Ecography* (in press).
- PAPANASTASIS VP, 1977.- Fire ecology and management of phrygana communities in Greece: H.A. Mooney and C.E. Conrad (techn. coord.). Proc. of the Symposium on the environmental consequences of fire and fuel management in mediterranean ecosystems. USDA Forest Service, General Technical Report WO 3, pp 476-482.
- PAPAVASSILIOU S, 2001.- The role of legumes in post-fire regeneration of Mediterranean forest ecosystems. Ph.D Thesis. University of Athens.
- PAPAVASSILIOU S, and ARIANOUTSOU M, 1997.- Natural post-fire regeneration of Leguminosae in a *Pinus halepensis* forest of Attica. In: Book of Proceedings of the European School on "Forest Fire Risk and Management", P. Balabanis, G. Eftichidis and R. Fantechi (Eds), pp 411-419. European Commission, 443p.
- PAPAVASSILIOU S, ARIANOUTSOU M. and Thanos CA, 1994.- Aspects of the reproductive biology of fire following species of Leguminosae in a *Pinus halepensis* Mill. forest. In: Viegas D.X. (ed). Proceedings of the 2nd International Conference on Forest Fire Research. Suppl. D.24.
- PAUSAS J, CARBÓ E, CATURLA RN, GIL JM, and VALLEJO R, 1999.- Post-fire regeneration patterns in the eastern Iberian Peninsula. *Acta Oecologica* 20(5): 499-508
- PAUSAS JG, OUADAH N, FERRAN A, GIMENO T, and VALLEJO R, 2003.- Fire severity and seedling establishment in *Pinus halepensis* woodlands, Eastern Iberian peninsula. *Plant Ecology* 169: 205-213.
- PAUSAS, J.G., RIBEIRO, E. and VALLEJO, R. in press. Post-fire regeneration variability of *Pinus halepensis* in the eastern Iberian Peninsula. *For. Ecol. Manage.* in press
- PEREZ B, CRUZ A, FERNANDEZ-GONZALEZ F, and MORENO JM, 2003.- Effects of the recent land-use history on the post-fire vegetation of uplands in Central Spain. *Forest Ecol. Manag.* 182: 273-283.
- PÉREZ B and MORENO JM, 1998.- Fire-type and forestry management effects on the early postfire vegetation dynamics of a *Pinus pinaster* woodland. *Plant Ecology* 134: 27-41
- PÉREZ B, SÁNCHEZ-MATA D, and MORENO JM, 1995.- Effects of past and current land-use on post-fire vegetation recovery in Sierra de Gredos, Spain. In: Balabanis P. (Ed.) *Forest fire risk and management*. Commission of the European Communities, EUR Report Series.
- RIBA M, RODRIGO A, COLAS B, and RETANA J, 2002.- Fire and species range in Mediterranean landscapes: an experimental comparison of seed and seedling performance among *Centaurea taxa*. *Journal of Biogeography* 29:135-146
- RICOTTA C, AVENA GC, OLSEN ER, RAMSEY RD and Winn DS, 1998.- Monitoring the landscape stability of Mediterranean vegetation in relation to fire with a fractal algorithm. *International Journal of Remote Sensing* 19 (5): 871-881.
- ROMERO-CALCERRADA R, and PERRY GLW, 2002.- Landscape change pattern (1984-1999) and implications for fire incidence in the SPA Encinares del rio Alberche y Cofio (Central Spain). In: D.X. VIEGAS (Editor), *Forest Fire Research and Wildland Fire Safety*. Millpress, Rotterdam.
- ROMERO-CALCERRADA R, and PERRY GLW, 2004.- The role of land abandonment in landscape dynamics in the SPA 'Encinares del rio Alberche y Cofio, Central Spain, 1984-1999. *Landscape and Urban Planning*, 66(4): 217-232.
- ROY J, and SONIÉ L, 1992.- Germination and population dynamics of *Cistus species* in relation to fire. *Journal of Applied Ecology* 29:647-655
- SANTALLA S, MARCOS E, VALBUENA L, CALVO L, TÁRREGA R. and LUIS E, 2002.- First years of regeneration in *Quercus pyrenaica* forest and *Pinus pinaster* stand after wildland fire. In: Viegas X. (Ed.) *Forest fire research and wildland fire safety: 1-7*. Millpress, Rotterdam.
- SARACINO A, and LEONE V, 1993.- Natural regeneration 2 and 4 years after fire of *Pinus halepensis* Miller in dunal environment. In: TRABAUD L and PRODON R, eds. *Fire in Mediterranean ecosystems*. Brussels-Luxembourg: ECSC-EEC-EAEC. 141-159.
- SCHILLER G., NE'EMAN G., and KOROL L. 1997. Post-fire vegetation dynamics in a native *Pinus halepensis* Mill. forest on MT. Carmel, Israel. *Israel Journal of Plant Sciences* 45: 297-308.
- SKOUROU P, 2003.- Population dynamics of *Cistus* spp. in post-fire successional stages of *Pinus halepensis* forests in Attica. Ph.D Thesis, University of Athens, (in Greek with an English summary).
- SKOUROU P, and ARIANOUTSOU M, 1998.- Population dynamics of *Cistus creticus* along a post-fire chronosequence of Aleppo pine forests of Attica. In: Proceedings of the 7th Conference of the Hellenic Botanical Society, pp 219-223. (in Greek with an English summary).
- SKOUROU P, and ARIANOUTSOU M, 2004.- Patterns of seed dispersal in three co-occurring *Cistus* species in *Pinus halepensis* forests of Central Greece. In: ARIANOUTSOU M and PAPANASTASIS VP (eds). *Ecology, Conservation and Management of Mediterranean Climate Ecosystems of the World*. Proceedings of the MEDECOS 10th International Conference, Millpress, the Netherlands, Electronic Edition.

- TATONI T, and ROCHE P. 1994. Comparison of old-field and forest revegetation dynamics in Provence. *Journal of Vegetation Science* 5: 295-302.
- TARREGA R, and LUIS E, 1987.- Effect of fire on structure, dynamics and regeneration of *Quercus pyrenaica* ecosystems. *Ecol. Medit. (Marseille)* 13(4): 79-86.
- TARREGA R, LUIS-CALABUIG E, and ALONSO I, 1995.- Comparison of the regeneration after burning, cutting and ploughing in a *Cistus ladanifer* shrubland. *Vegetatio* 120: 59-67.
- TARREGA R, LUIS-CALABUIG E, and ALONSO I, 1997.- Space-time heterogeneity in the recovery after experimental burning and cutting in a *Cistus laurifolius* shrubland. *Pl. Ecol.* 129: 179-187.
- TARREGA R, LUIS-CALABUIG E, and VALBUENA L, 2001.- Eleven years of recovery dynamic after experimental burning and cutting in two *Cistus* communities. *Acta Oecol.* 22: 277-283.
- THANOS CA, 1999.- Fire effects on forest vegetation, the case of Mediterranean pine forests in Greece. In: *Wildfire management*, pp. 323-336, Eftichidis G, Balabanis P, Ghazi A. (eds), Algosystems and European Commission DGXII, Athens.
- THANOS CA, DASKALAKOU E, and SKORDILIS A, 1998.- Reproductive biology of Mediterranean pines – the duration of the juvenile period. In: *Proceedings of the 7th Conference of the Hellenic Botanical Society*, pp.155-158 (in Greek with an English summary).
- TINNER W, HUBSCHMID P, WEHRLI M, AMMANN B, and CONEDERA M. 1999. Long-term forest fire ecology and dynamics in southern Switzerland. *Journal of Ecology* 87: 273-289.
- TRABAUD L, 1991.- Fire regimenes and phytomass growth dynamics in a *Quercus coccifera* garrigue. *Journal of Vegetation Science* 2:307-314
- TRABAUD L, 1994.- The effect of fire on nutrient losses and cycling in a *Quercus coccifera* garrigue(southern France).*Oecologia* 99:379-386
- TRABAUD L, and GALTIE JF, 1996.- Effects of fire frequency on plant communities and landscape pattern in the Massif des Aspres (southern France). *Landscape Ecology* 11: 215-224.
- TRABAUD L, and CASAL M, 1989.- Réponses des semences de *Rosmarinus officinalis* à différents traitements simulant une action de feu. *Acta Oecologica* 10(4):355-363
- TRABAUD L, and CHANTERAC B, 1985.- The influence of fire on the phenological behaviour of Mediterranean plant species in Bas-Languedoc (southern France). *Vegetatio* 60:119-130
- TRABAUD L, and LEPART J, 1980.- Diversity and stability in Garrigue ecosystems after fire. *Vegetatio* 43: 49-57
- TRABAUD L, MARTINEZ SANCHEZ JJ, and FERRANDIS P, 1997.- Above-ground vegetation and soil seed bank: The contribution to the cyclical stability of a mixed pine forest of *Pinus halepensis* and *P. pinaster*. *Can. J. Bot.*75: 1012-1021.
- VAN HULST S. 1978. On the dynamics of vegetation: patterns of environmental and vegetation change. *Vegetatio* 38: 65-75.
- VARELA V, EFTICHIDIS G, MAROUDI E, and ARIANOUTSOU M, 1999.- Land use changes in an area heavily affected by fire: the case of Mountain Penteli. *International Symposium on Forest Fires: Needs and Innovations, (DELFI)*, Athens.
- VÁZQUEZ A, and MORENO JM, 2001.- Spatial distribution of forest fires in Sierra de Gredos Central Spain. *Forest Ecology and Management* 147: 55-65.
- VIEDMA O, and MELIÁ J, 1996.- On the relationship between community patterns and topographic factors in disturbed and undisturbed Mediterranean shrublands *Proceedings of the International Workshop on Application of Remote Sensing in European Forest Monitoring*, pp.101-115 . Viena (Austria).
- VIEDMA O, MELIÁ J, and CHICA-OLMO M, 1998.- Detecting Temporal Trends in the Spatial Patterns of Mediterranean Burned Shrublands at different Scales. *Proceedings of the III International Conference on Forest Fire Research, 14th Conference on Fire and Forest Meteorology*, vol.II, pp.1593-1618. Luso (Coimbra) Portugal.
- VIEDMA O, MELIA J, SEGARRA D, and GARCIA-HARO J, 1997.- Modelling Rates of Ecosystem Recovery after Fires using Landsat TM Data. *Remote Sensing of Environment. An interdisciplinary Journal.* vol.61 (3), pp.383-398.
- WILGEN BWV, RICHARDSON DM, KRUGER FJ, and HENSGERGEN HJv, 1992.- *Fire in South African mountain fynbos. Ecosystem, community and species response at Swartboskloof*. Springer-Verlag, Berlin.