Developments in Environmental Science, Volume 8

A. Bytnerowicz, M. Arbaugh, A. Riebau and C. Andersen (Editors)

ISSN: 1474-8177/DOI:10.1016/S1474-8177(08)00008-9

Chapter 8

Assessment of Forest Fire Impacts and Emissions in the European Union Based on the European Forest Fire Information System

Paulo Barbosa, Andrea Camia, Jan Kucera, Giorgio Libertà, Ilaria Palumbo, Jesus San-Miguel-Ayanz and Guido Schmuck*

Abstract

An analysis on the number of forest fires and burned area distribution as retrieved by the European Forest Fire Information System (EFFIS) database is presented. On average, from 2000 to 2005 about 95,000 fires occurred annually in 23 European countries, burning almost 600,000 ha of forest land every year. Of these about two-thirds or 65,000 fires occurred in 5 European Union (EU) Mediterranean countries (France, Greece, Italy, Portugal, and Spain) where on average half a million hectares of forest land were burned every year. In addition, out of the 23 European countries, the total burned area was 86% within those 5 countries alone during the 6-year study period, and out of the 19 EU countries the total for the 5 countries was 96%. Estimates of atmospheric emissions of carbon dioxide (CO_2) and other trace gases were done for the 2000–2005 period in which burned area maps were retrieved using remote sensing imagery, and then combined with fuel load and burning efficiency figures, to estimate the quantity of burned biomass. Emission factors were further used to estimate trace gas and aerosol emissions produced by vegetation fires. Fuel load was estimated based on values found in the literature and from existing land cover maps of Europe. Average burning efficiency and emission factors were retrieved from the literature. The results obtained show that the forest fires atmospheric emissions of the 23 European countries considered in this study ranged from 8.4 to 20.4 Tg of CO_2/year.

*Corresponding author: E-mail: Paulo.BARBOSA@ec.europa.eu

8.1. Forest fires in Europe

Wildfires, often referred to as forest fires in Europe, have coexisted with human activities and have shaped the Mediterranean landscapes. Although fire has always existed as a natural phenomenon—inducing species regeneration and landscaped biodiversity—the use of fire for a number of activities such as grazing, agriculture, and hunting has significantly modified fire regimes, primarily in the Mediterranean region. More recently the increase of population density in Europe and the extensive use of natural and forest regions for recreation has increased the number of human-caused fires. In addition, the decrease of rural population and the abandonment of agricultural regions mainly in southern Europe have led to the build up of fire fuels on these areas and the consequent increase in fire risk. Nevertheless, although the number of fires has steadily increased in the last decades, on average the total area consumed has not increased. This is mostly due to the active fire suppression policy and the large economic investment in firefighting techniques of the European countries as well as the fire prevention measures. Lately, however, extreme fire danger meteorological conditions in 2003, 2005, and 2007 have contributed to an increased number of fires and burned area in Europe.

The European Commission Joint Research Centre (JRC) started a research activity in 1999 aimed at the development and implementation of advanced methods for the evaluation of forest fire risk and mapping of burnt areas at the European scale. The outcome was the development of the European Forest Fire Information System (EFFIS). In addition to producing daily meteorological fire danger forecast maps, and coordinating the harmonization of a European fire database, EFFIS has produced a number of burned area maps for the 2000–2005 period in five European Union (EU) Mediterranean countries: France, Greece, Italy, Portugal, and Spain (European Commission, 2001; European Commission, 2002; European Commission, 2003; European Commission, 2004; European Commission, 2005; European Commission, 2006). Since 2006 the burned areas of other European countries such as Croatia, Cyprus, and Turkey have also been mapped, and in 2007 due to the extreme fire season in the Balkans, the burned areas of the following additional countries were also mapped: Albania, Bosnia-Herzegovina, Bulgaria, Former Yugoslav Republic of Macedonia, Montenegro, and Serbia.

Although estimates of biomass burning emissions exist at the global and regional scales, no studies have ever been performed to specifically estimate the contribution of forest fires in the EU. This chapter presents the most current statistics for number of forest fires and burned area in

the EU as well as estimates of biomass burning emissions for the 2000–2005 period. The burned area maps for each year were combined with fuel loads and burning efficiency figures, to estimate the quantity of burned biomass. Emission factors were further used to estimate the trace gas and aerosol emissions produced by vegetation fires.

8.2. Data sets

The burned area maps were produced using two different remote sensing images: the Indian Remote Sensing (IRS)–Satellite Wide Field Sensor (WiFS) for the 2000–2003 period and the TERRA/AQUA–MODerate-resolution Imaging Spectroradiometer (MODIS) images for the 2003–2005 period. A map of fuel types was used in order to obtain the fuel load information. The EU fire database managed by the JRC has also been used to further enhance the forest fire emissions and burned biomass estimates.

8.2.1. The EU fire database

The European Economic Community (EEC) regulation No. 804/94 (now expired) established a community system of information on forest fires for which a systematic collection of a minimum set of data on each fire, the ''common core'', had to be carried out by the member states participating in the system.

According to the current regulation (Forest Focus [EEC] No. 2152/2003) about monitoring forests and environment interactions in the community, the forest fire common core data should continue to be recorded and provided to the EC in order to collect comparable information on forest fires at community level. Within this new framework the database is being refined and an enhanced version is under development, with the support of the relevant forest services and civil protection services of the EU member states, to consolidate and implement the EU fire database in EFFIS (effis.jrc.it/EU_Fire_Database).

The forest fire data for the EU Fire Database are provided each year by individual member states, with the following primary data items recorded for each fire event

- Date and time of first alert, first intervention, and fire extinction.
- Fire location in terms of administrative units (local area units) and of geographical coordinates.

– Burned area detailed into the following four land cover categories: forest, other wooded land, other non-wooded natural land, agriculture, and other artificial vegetated land.
– Presumed fire cause as outlined in both the general EU fire causes category and the individual countries category.

At present the database covers 23 countries with information for 2000–2005 although some countries have information on a longer time period, such as Austria, Cyprus, Czech Republic, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Latvia, Lithuania, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Croatia, Switzerland, Turkey, and Norway.

The information from the EU fire database has been used to improve the estimations of forest fire emissions and burned biomass computed with the burned area maps for the five EU Mediterranean countries as well as to extend the estimations to the 23 countries currently included in the database.

8.2.2. Burned area maps

The burned area maps were obtained through the classification of two different types of satellite imagery, IRS–WiFS and MODIS. In both cases the minimum mapping unit used was set to 50 ha, meaning that only fires equal to or larger than 50 ha were mapped.

The WiFS camera is a multispectral-WiFS, whose spectral channels are optimized to determine vegetation indices. WiFS collects data in two bands that correspond to red and near infrared. The ground swath is around 810 km, and the spatial resolution is 180 m. The time of overpass is around 10:30 a.m. local time. The potential revisiting time is five days. Images were acquired at the end of the fire season, typically between middle of September to end of October, in order to map all the burned areas of the year. The burned areas were mapped using a multitemporal change-detection technique (Barbosa et al., 2002). Although no specific validation was done for the burned area maps, the maps were sent to the national Forest Services for quality assessment, which reported positive feedback.

MODIS instrument is carried both on the TERRA (morning pass) and AQUA (afternoon pass) satellites. MODIS data has two bands with spatial resolutions of 250 m (red and near-infrared bands) and five bands with spatial resolution of 500 m (blue, green, and three short-wave infrared bands). The time of overpass of TERRA is in the early morning,

while AQUA overpass is in early afternoon, allowing for two images per day. Images are acquired every day, providing continuous monitoring of fires and mapping of burned areas. Although mainly the 250-meter bands were used to map the burned areas, the MODIS bands at 500 m resolution were sometimes used for confirmation. Mapping of the burned areas was done through visual classification, and the comparison of the estimated total burned area with the official statistics from the five countries analyzed showed high correlation (Barbosa et al., 2006).

8.2.3. Fuel map

Fuel types were classified using two databases: the COoRdinate Information on the Environment (CORINE) Land Cover 2000 (CLC2000; European Environment Agency, 2002) and the Map of Natural Vegetation of Europe (MNVE; Bohn & Neuhäusl, 2003). CLC2000 is an update for the reference year 2000 of the first CORINE Land Cover database that was finalized in the early 1990s as part of the European Commission CORINE program (European Commission, 1994). CLC2000 is based on the photo-interpretation of Landsat satellite images and has a fairly good spatial resolution, with a mapping scale of 1:100,000 and minimum mapping unit of 25 ha. However, thematically the CLC can be considered relatively poor, since only 44 classes are distinguished. On the other hand, the MNVE has a lower spatial resolution (mapping scale of 1:3,000,000) but depicts more than 100 vegetation associations. The CLC classes were stratified into subregions according to phytosociological criteria, which accounted for the floristic composition and other factors governing the distribution of the vegetation. These subregions were then linked to the U.S. National Fire Danger Rating System (NFDRS) fuel model map (Burgan, 1988; Sebastian et al., 2002) in order to assign a fuel type to each of the subregions. The NFDRS fuel load corresponding to each of the fuel model classes was then assigned to the European Fuel Model Map (Table 8.1).

8.3. Computation of burned biomass and atmospheric emissions

The NFDRS model divides each of the fuel classes into dead fuel (fine, small, and large) and live fuel (woody and herbaceous). Each of the components of the fuel classes are attributed a specific burning efficiency and emission factor for gas-phase or aerosol compounds, depending on if the fire is flaming or smoldering, which is related with the diameter of the fuel type (Leenhouts, 1998). The general equation for computing emission

Table 8.1. NFDRS fuel model corresponding to the fuel model classes assigned to the European fuel model map

NFDRS model	European fuel model model description
A	Grassland vegetated by annual grasses and forbs
C	Open pine stands with perennial grasses and forbs
D	Shrubland understory and pine overstory
F	Sclerophylous oakwood vegetation
H	Short-needled conifers with sparse undergrowth and thin layer of ground fuels
L	Grassland vegetated by perennial grasses
N	Inland and coastland marshes
O	Broadleaved forests of *Quercus ilex*, rotundifolia, and suber
P	Coniferous forest with Iberian-Atlantic oak-ash woods and Cantabrian beechwoods
R	Broadleaved forest
S	Sparsely vegetated areas
T	Transitional woodland shrub
X	Non forest class

(e.g., CO_2) from forest fires is the following:

$$CO_2 = \sum_f A_f \times B_f \times C \times E_f$$

A_f burned area (m^2)
B_f fuel load ($g\,m^{-2}$)
C burning efficiency ($g\,g^{-1}$)
E_f emission coefficient for CO_2
f fuel class

8.4. Results and discussion

According to the EU Fire Database, during the 2000–2005 period on average about 95,000 fires occurred annually in the 23 European countries (Fig. 8.1), burning almost 600,000 ha of forest land every year (Fig. 8.2).

Of these fires about two-thirds or 65,000 occurred in five EU Mediterranean countries (France, Greece, Italy, Portugal, and Spain) where on average half a million hectares of forest land were burned every year. In addition, out of the 23 European countries, the total burned area was 86% within those 5 countries alone during the 6-year study period, and out of the 19 EU countries the total for the 5 countries was 96%. Figure 8.3 shows the average burned area per year in the 23 European

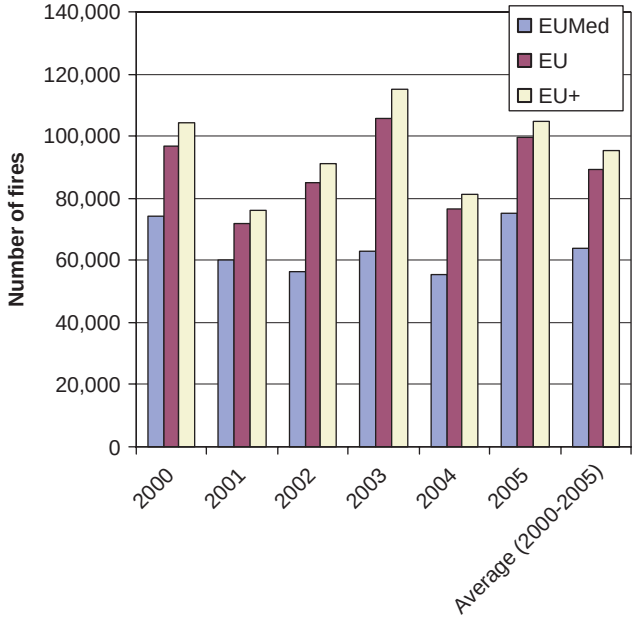

Figure 8.1. Number of fires in the 5 EU Mediterranean countries (EU Med: France, Greece, Italy, Portugal, and Spain) compared with the 19 countries for which data is currently available in the database of EU (Austria, Cyprus, Czech Republic, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Latvia, Lithuania, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, and Sweden) and with EU+ (19 EU countries + Croatia, Switzerland, Turkey, and Norway).

countries covered by the EU Fire Database for the period 2002–2005. (Note that possible discrepancies between the values in this chapter and in Szczygieł et al. (2009) in this book are due to the fact that the EU Fire Database does not include fires outside forest or shrubland (e.g., agriculture fires) except if these areas are part of a forest fire.)

The total area burned mapped from 2000 to 2005 for fires larger than 50 ha in the five EU Mediterranean countries was 1,828,663 ha. However, the burned area retrieved from the EU Fire Database, that includes also the fires smaller than 50 ha, was 2,942,924 ha. This means only 62% of the burned areas were mapped which is due to the fact that only fires larger than 50 ha can be detected with the satellite imagery used.

Taking into account this information and assuming that the relative distribution of fuel types remains the same in the burned areas that were not mapped, the total biomass burned annually for these five countries

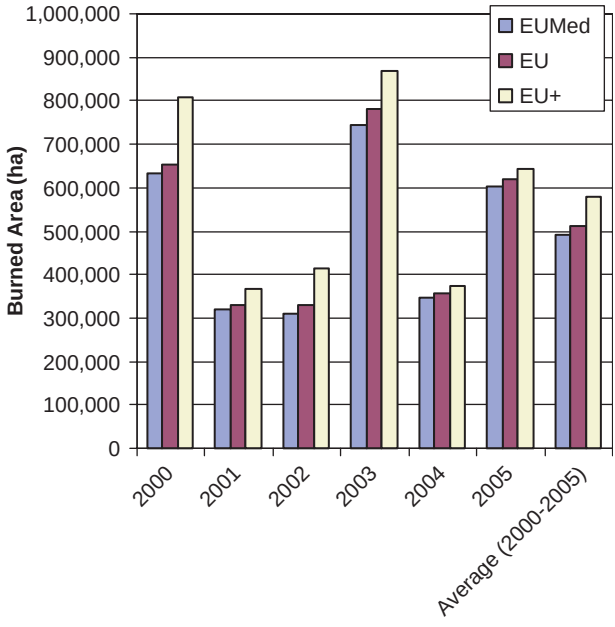

Figure 8.2. Burned area in the 5 EU Mediterranean countries (EU Med: France, Greece, Italy, Portugal, and Spain) compared with the 19 countries for which data is currently available in the database of EU (Austria, Cyprus, Czech Republic, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Latvia, Lithuania, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, and Sweden) and with EU+ (19 EU countries+Croatia, Switzerland, Turkey, and Norway).

was estimated between 4.0 and 10.5 Tg, while the CO_2 emitted was estimated between 6.6 and 17.5 Tg (Table 8.2).

Assuming that the relative distribution of fuel types remains invariable when including the remaining EU countries that did not have the burned area mapped, and considering that the total area burned increases to 3,023,293 ha, then the annual burned biomass for this 6-year period varied between 4.2 and 11.0 Tg, and the CO_2 between 7.1 and 18.4 Tg (Table 8.3). If all 23 countries covered by the EU Fire Database are included, further increases are found in the burned biomass values: from a minimum of 5.1 to a maximum of 12.2 Tg and from a minimum of 8.4 to a maximum of 20.4 Tg for CO_2 (Table 8.4).

Comparison of these results with average estimations for wildland fires in the conterminous United States (U.S.) show that although European forest fire emissions are normally smaller than those in the U.S., they can in some cases be larger than the average minimum in the U.S. (Table 8.5).

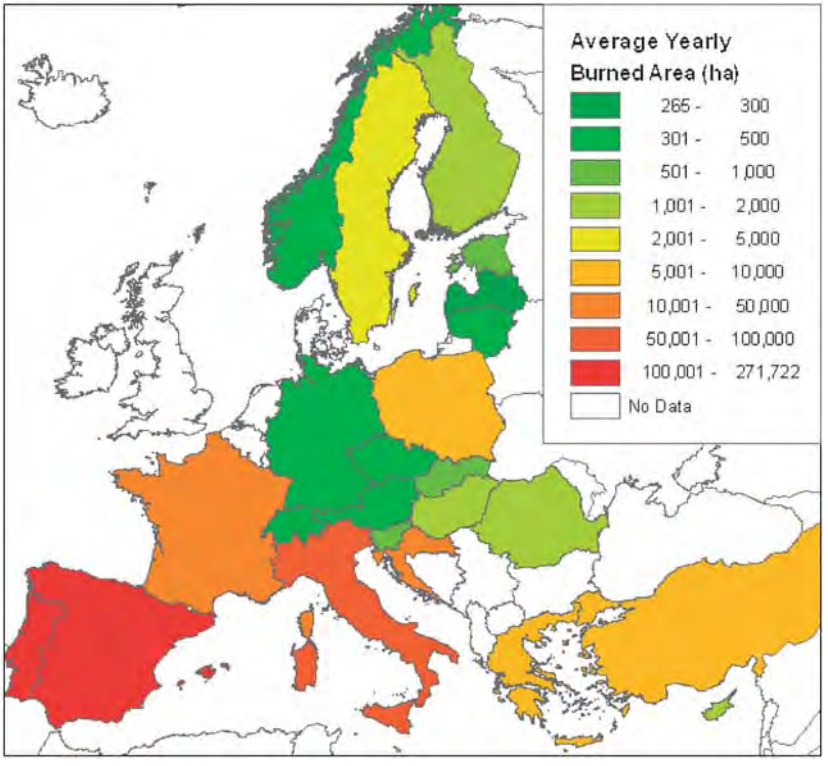

Figure 8.3. Average burned area per year in the European countries for the period 2000–2005, derived from the EU Fire Database.

Table 8.2. Burned biomass and emission estimates from forest fires in the five EU Mediterranean countries between 2000 and 2005. Values are given in Tg

	2000	2001	2002	2003	2004	2005	Average
Burned biomass	6.4	4.4	4.0	10.5	4.8	7.9	6.3
CO_2	10.7	7.4	6.6	17.5	8.0	13.2	10.6
CO	0.434	0.292	0.266	0.680	0.319	0.541	0.422
CH_4	0.023	0.015	0.014	0.036	0.017	0.028	0.022
PM2.5	0.043	0.029	0.027	0.069	0.032	0.054	0.042
PM10	0.051	0.035	0.031	0.081	0.038	0.063	0.050
NMHC	0.071	0.049	0.044	0.114	0.053	0.089	0.070
VOC	0.019	0.013	0.011	0.030	0.014	0.023	0.018
NO_X	0.022	0.015	0.014	0.036	0.017	0.028	0.022
OC	0.030	0.020	0.019	0.047	0.022	0.038	0.029
EC	0.026	0.017	0.016	0.041	0.019	0.032	0.025

Table 8.3. Burned biomass and emission estimates from forest fires in the 19 countries for which data is currently available in the database of EU (Austria, Cyprus, Czech Republic, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Latvia, Lithuania, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, and Sweden) between 2000 and 2005. Values are given in Tg

	2000	2001	2002	2003	2004	2005	Average
Burned biomass	6.6	4.6	4.2	11.0	5.0	8.1	6.6
CO_2	11.1	7.6	7.1	18.4	8.3	13.5	11.0
CO	0.448	0.302	0.286	0.717	0.329	0.555	0.439
CH_4	0.023	0.016	0.015	0.037	0.017	0.029	0.023
PM2.5	0.045	0.030	0.028	0.072	0.033	0.055	0.044
PM10	0.053	0.036	0.034	0.085	0.039	0.065	0.052
NMHC	0.074	0.050	0.047	0.120	0.055	0.091	0.073
VOC	0.019	0.013	0.012	0.031	0.014	0.024	0.019
NO_X	0.023	0.016	0.015	0.038	0.017	0.029	0.023
OC	0.031	0.021	0.020	0.050	0.023	0.039	0.031
EC	0.027	0.018	0.017	0.043	0.020	0.033	0.026

Table 8.4. Burned biomass and emission estimates from forest fires in EU+ (19 EU countries+Croatia, Switzerland, Turkey, and Norway) between 2000 and 2005. Values are given in Tg

	2000	2001	2002	2003	2004	2005	Average
Burned Biomass	8.2	5.1	5.3	12.2	5.2	8.5	7.4
CO_2	13.7	8.4	8.8	20.4	8.6	14.1	12.3
CO	0.555	0.333	0.358	0.795	0.342	0.577	0.493
CH_4	0.029	0.017	0.019	0.041	0.018	0.030	0.026
PM2.5	0.055	0.033	0.036	0.080	0.034	0.057	0.049
PM10	0.065	0.039	0.042	0.095	0.040	0.068	0.058
NMHC	0.091	0.055	0.059	0.133	0.057	0.094	0.082
VOC	0.024	0.014	0.015	0.034	0.015	0.025	0.021
NO_X	0.029	0.017	0.019	0.042	0.018	0.030	0.026
OC	0.039	0.023	0.025	0.055	0.024	0.040	0.034
EC	0.033	0.020	0.021	0.048	0.020	0.034	0.029

Table 8.5. Burned biomass (Tg) comparison between European union countries and USA with estimated maximum and minimum values in brackets

Regions	Tg
EU+	[5.1, 12.2]
EU 19 countries (2000–2005)	[4.2, 11.0]
EU Med (2000–2005)	[4.0, 10.5]
USA	[9, 59]

Analyzing forest fire emissions from the European countries in a wider context shows only a small contribution to the estimated emissions found in the literature. Estimates from Levine (1994) for burned biomass for savannas (3690 Tg/year), temperate and boreal forest (280 Tg/year), and tropical forest (1260 Tg/year) are in fact much higher than the results presented in this chapter. This is confirmed by more recent figures that estimate a total of 8903 Tg of CO_2/year at a global level (van der Werf et al., 2006).

8.5. Conclusions

The results of our study present an initial comprehensive and comparative picture of forest fire emissions in most of the EU countries. We found that the vast majority of the current emissions come from five EU Mediterranean countries (France, Greece, Italy, Portugal, and Spain). The relative importance of European forest fire emissions in a global context show that although their contribution is relatively small at the global scale, these emissions can have important implications for international commitments, such as the Kyoto protocol that has the objective of reducing greenhouse gases that cause climate change.

The most important uncertainties are mainly related to fuel load, since no specific fuel load or biomass maps exist at the European level. Burning efficiency is another factor that has to be studied in order to reduce uncertainties about forest fire emissions. Since the fuel map used was built using surface fire fuel models of the U.S. NFDRS model (Burgan, 1988), the estimates should be regarded as conservative because they do not include the emission contribution from tree-crown consumption in the case of crown-fire. In order to have more precise values of area burned, mainly for the fires smaller than 50 ha, higher spatial resolution satellite images should be used, depending on their availability. Efforts should also be made to develop a specific fuel map model for Europe, and specific studies should be conducted to quantify burning efficiency in different fuel types and in different fire-severity conditions.

REFERENCES

Barbosa, P., San-Miguel-Ayanz, J., Martinez, B., and Schmuck, G. 2002. Burned area mapping in southern Europe using IRS-WiFS. In: Viegas, X., ed. Forest fire research & wildland fire safety, 2002. Millpress, Rotterdam, ISBN 90-77017-72-0.

Barbosa, P., Kucera, J., Strobl, P., Vogt, P., Camia, A., and San-Miguel-Ayanz, J. 2006. European forest fire information system (EFFIS)-rapid damage assessment: Appraisal of

burned area maps in southern Europe using modis data (2003–2005), Proceedings of the 5th International Conference on Forest Fire Research. 27–30 November, Figueira da Foz, Portugal, Elsevier Pub. ISSN 0378-1127.

Bohn, U., and Neuhäusl, R. 2003. Map of the natural vegetation of Europe, scale 1:2 500 000, Münster, Landwirtschaftsverlag, 656 pp.

Burgan, R.E. 1988. 1988 revisions to the 1978 national fire-danger rating system. Research Paper SE-273. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station, 39 pp.

European Commission. 1994. CORINE land cover—Technical Guide. Publication EUR 12585 of the European Commission, EG, DG Environment, Nuclear Safety, and Civil Protection. Office for official publications of the European Communities, 144 pp.

European Commission. 2001. San-Miguel-Ayanz, J., Barbosa, P., Schmuck, G. and Schulte, E. eds. Report No. 1: Forest fires in southern Europe. Official Publication of the European Communities, SPI.01.95.EN.

European Commission. 2002. San-Miguel-Ayanz, J., Barbosa, P., Libertà, G., Schmuck, G., and Schulte, E. eds. Forest fires in Europe—2001 fire campaign. Official Publication of the European Communities, SPI.02.72.EN.

European Commission. 2003. San-Miguel-Ayanz, J., Barbosa, P., Libertà, G., Schmuck, G., and Schulte, E. eds. Forest fires in Europe—2002 fire campaign. Official Publication of the European Communities, SPI.03.83.EN.

European Commission. 2004. San-Miguel-Ayanz, J., Barbosa, P., Camia, A., Kucera, J., Libertà, G., Schmuck, G., Schulte, E., Bucella, P., Colletti, L., and Flies, R., eds. Forest fires in Europe—2003 fire campaign. Official Publication of the European Communities, SPI.04.124 EN.

European Commission. 2005. Schmuck, G., San-Miguel-Ayanz, J., Barbosa, P., Camia, A., Kucera, J., Libertà, G., Schulte, E., and Colletti, L., eds. Forest fires in Europe 2004. Official Publication of the European Communities, EUR 22 312 EN.

European Commission. 2006. Schmuck, G., San-Miguel-Ayanz, J., Barbosa, P., Camia, A., Kucera, J., Libertà, G., Schulte, E., Colletti, L., Martin, H., and Toussaint, M. eds. Forest fires in Europe 2005. Official Publication of the European Communities, EUR 22 312 EN.

European Environment Agency. 2002. CORINE Land Cover update 2000. Technical guidelines, 2002, 56 pp.

Leenhouts, B. 1998. Assessment of biomass burning in the conterminous United States. Conserv. Ecol. [online] 2(1), 1 http://www.consecol.org/vol2/iss1/art1

Levine, J.S. 1994. Biomass burning and the production of greenhouse gases. In: Righard, G.Z., ed. Climate biosphere interaction: Biogenic emissions and environmental effects of climate change. Wiley.

Sebastian, L. A., San-Miguel-Ayanz, J., and Burgan, R. 2002. Integration of satellite sensor data, fuel type maps, and meteorological observations for the evaluation of forest fire risk at the pan-European scale. Int. J. Remote Sens. 23(13), 2713–2719.

Szczygieł, R., Ubysz, B., and Zawiła-Niedźwiecki, T. 2009. Spatial and temporal trends in distribution of forest fires in central and eastern Europe (this volume).

van der Werf, G.R., Randerson, J.T., Giglio, L., Collatz, G.J., Kasibhatla, P.S., and Arellano, A.F. Jr. 2006. Interannual variability of global biomass burning emissions from 1997 to 2004. Atmos. Chem. Phys. Discuss. 6, 3175–3226.