ADVANCES IN FOREST FIRE RESEARCH 2022

Edited by
DOMINGOS XAVIER VIEGAS
LUÍS MÁRIO RIBEIRO

Burnt area trends in the Middle-East: evidence for the importance of recent conflicts

Georgia Majdalani[1,2]; Nikos Koutsias[3], Jocelyne Adjizian-Gerard [2]; Ghaleb Faour [4]; Florent Mouillot[*5]

[1] *UMR CEFE 5175, Centre National de la Recherche Scientifique (CNRS), Université de Montpellier, Département Scientifique Biologie, Écologie, Évolution, Environnement , Sciences Terre et Eau. 1919 route de Mende, 34293 Montpellier CEDEX 5, France, {georgia.majdalani@cefe.cnrs.fr}*
[2] *CREEMO Laboratory, Geography Department, Saint-Joseph University. Beirut, Lebanon, {jocelyne.gerard@usj.edu.lb}*
[3] *Department of Environmental Engineering, University of Patras. G. Seferi 2, GR-30100, Greece, {nkoutsia@upatras.gr}*
[4] *National Center for Remote Sensing, National Council for Scientific Research. Beirut, Lebanon, {gfaour@cnrs.edu.lb}*
[5] *UMR CEFE 5175, Centre National de la Recherche Scientifique (CNRS), Université de Montpellier, Université Paul-Valéry Montpellier, École Pratique des Hautes Études (EPHE), Institut de Recherche pour le Développement. 1919 route de Mende, 34293 Montpellier CEDEX 5, France, {florent.mouillot@cefe.cnrs.fr}*

**Corresponding author*

Keywords

Middle-East, fire history, trend, climate, social conflicts.

Abstract

Fire is a major disturbance affecting Mediterranean ecosystems. Due to a lack of exhaustive fire registration, fire drivers in the Middle East have been hardly investigated. We propose here the analysis of a newly produced fire patch reconstruction from remote sensing over the 1984 – 2020 period in Lebanon and Syria, experiencing peculiar Mediterranean climate and socio-political conflicts. We identified a particular bimodal and late-season fire regimes in the two neighboring countries. Then, taking into account their different socio-political differences since the Syrian civil war in 2011 by using the ICEWS conflict database, we could highlight the dominant role of these conflicts in extreme fire years in the region.

1. Introduction

Wildfire is among the main shaping factors of Mediterranean ecosystems (Paula *et al.*, 2009), affecting yearly about 1 million hectares of Mediterranean forests worldwide (Dimitrakopoulos and Mitsopoulos, 2006). Due to the particularly fire-prone conditions of the Mediterranean climate (Le Houérou, 1973), fires are intrinsic to the functioning of Mediterranean forests. Climate forcings, changes in traditional land use, as well as population movements and lifestyle, lead forest fires to increase after the 1970' in the Mediterranean basin (MB) (Gill *et al.*, 2013; Pausas, 2004; Xanthopoulos and Nikolov, 2019), causing adverse impacts on economic, social and ecological assets (Gill *et al.*, 2013; Xanthopoulos and Nikolov, 2019).

This natural disturbance is mostly being addressed by studies focusing on the European part of the MB where fire events have been registered since the 1970s (San-Miguel-Ayanz *et al.*, 2012). Studies conducted in the Eastern and Southern parts of the basin are more limited and systematic uniform documentation of fires is still lacking (cf. Aini *et al.*, 2019; Belhadj-Khedher *et al.*, 2018; Chergui *et al.*, 2018).

On the Eastern rim of the MB and intermediate between the North ridge where fire activity is driven by summer drought promoting large fires (Turco *et al.*, 2017), and the Southern ridge where fire activity is driven by heat waves during Saharan dry winds (Belhadj-Khedher *et al.*, 2020), Lebanon and Syria lack exhaustive fire registration, an obligate prerequisite for studying fire regimes. In addition, as of 2011, Syria experienced a series of protests that quickly escalated in 2012 to a full-fledged war (ongoing). Scholars have recently described the effects of war on the fire risk by relying mostly on MODIS global remote sensing data (Schon *et al.*, 2021; Zubkova *et al.*, 2021), over a short period (Mahfoud, 2020; Mohamed *et al.*, 2020) or focusing on agricultural lands (Schon *et al.*, 2021).

In such scarcely documented areas, remote sensing offers the most effective alternative to national statistics, providing global coverage, and multispectral and multitemporal information. Since the late 20th century, satellite imagery has been used to map fires (Xiao-rui *et al.*, 2005), from coarse (Eastwood *et al.*, 1998; Justice *et al.*, 2002; Malingreau, 1990; Pereira, 1999) and medium spatial resolution sensors (Filipponi, 2018; Liew *et al.*, 1998; Wightman, 1973).

The public release of the global historical Landsat archive (1984 – present) by the United States Geological Survey (USGS) in 2008 (Loveland and Dwyer, 2012; Woodcock *et al.*, 2008) initiated the development of automated and semi-automated tools that multi-process long and complete time series of Landsat imagery, resulting in the fast reproduction of fire perimeters over long periods and large surfaces (local to global coverage).

Nevertheless, relying solely on Landsat data can't provide a complete record of past fires and prevents an accurate dating between Landsat's overpasses. Recently, semi- and fully-automated burned area (BA) mapping tools combining Landsat data and daily Moderate Resolution Imaging Spectroradiometer (MODIS) active fire-detection data (hotspots) helped to overcome these limitations (Boschetti *et al.*, 2015; Roteta *et al.*, 2021). Fires detected throughout spectral changes in Landsat data (30 m) are dated using the high temporal resolution MODIS hotspots (1 day) when the two data sets spatially and temporarily coincide, also allowing the visual validation of the burning signal to effectively eliminate commission errors (Chuvieco and Congalton, 1988) and the manual refining of the fire polygons to narrow omission errors (Koutsias and Pleniou, 2021).

Accordingly, the aims of this study were (a) to create a GIS database of wildfire events and spatial extent in Lebanon's and the coast of Syria's wildland vegetation, two neighboring countries with similar climate conditions but contrasted socio-political events, for the last 37 years based on historical satellite archives (1984 – 2020) and MODIS hot-spots data (2001 – 2020), and (b) to provide a description of the fire regime taking into consideration the impacts of the socio-political conflicts on the natural wildfire regime in Syria.

2. Material and Methods

2.1. Study area

The study area includes the wildland areas (forests, shrublands, and grasslands) over Lebanon (between latitudes 33° and 35° N and longitudes 35° and 37° E) and the Syrian coast (between latitudes 32° and 38° N, and longitudes 35° and 43° E) (Figure 1), characterized by a typical Mediterranean climate with hot and dry summers and mild, wet winters (Köppen, 1884).

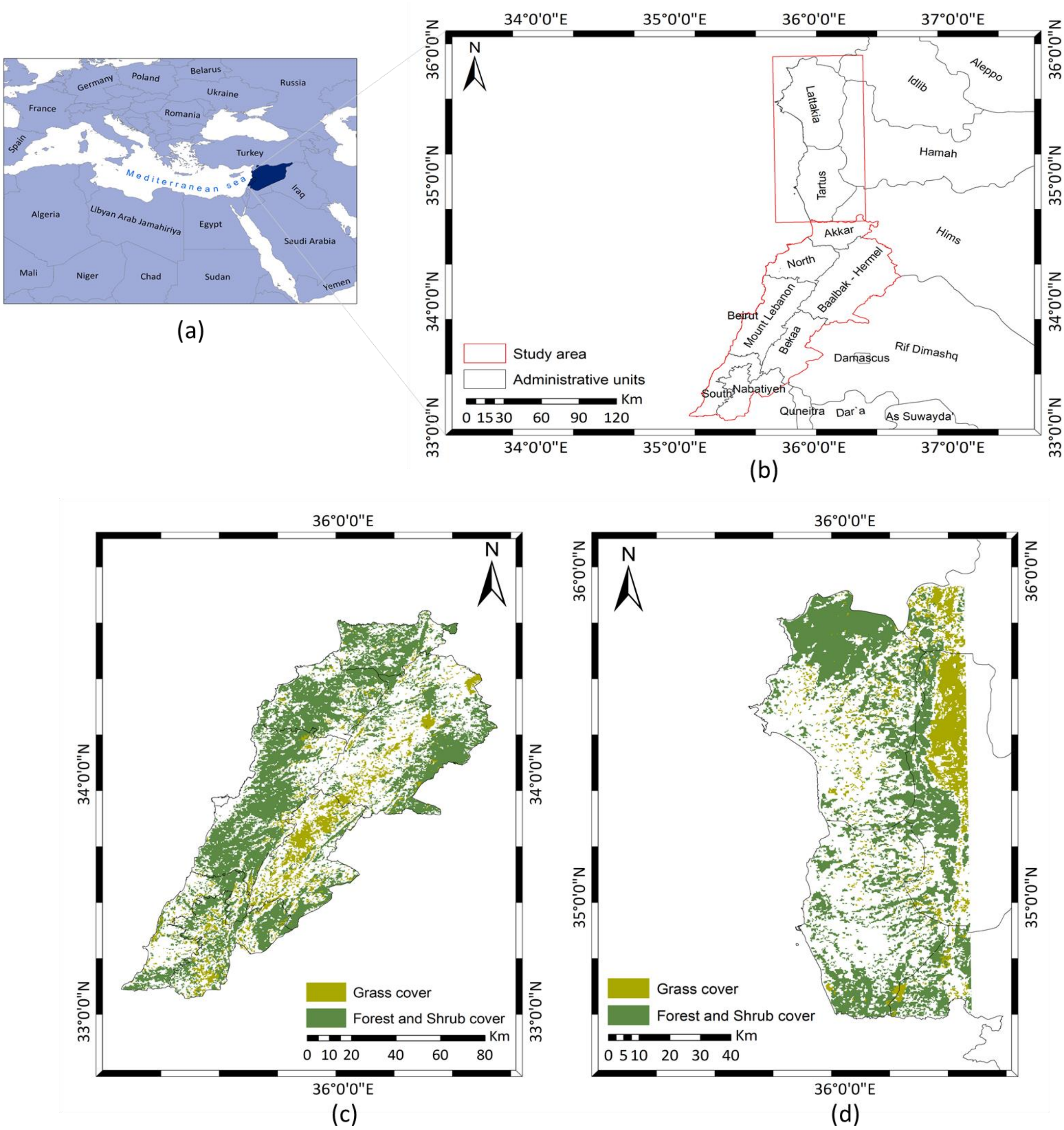

Figure 1- Location of Lebanon and Syria within the Mediterranean basin (a) and administrative units (b) overlayed with the forests/shrub cover (Deep green) and grass cover (light green) in Lebanon (c) and Coastal Syria (d).

The study area is delimited in red.

2.2. Data

2.2.1. Fire data

For the period 2001 – 2020, fire contours were generated over wildlands using the Burned Area Mapping Tools (BAMTs). BAMTs is a semi-automated tool, available on the Google Earth Engine platform (https://github.com/ekhiroteta/BAMT) whereas common spectral indices, used to characterize burnt pixels, are calculated for a pair of Landsat or Sentinel scenes and a random forest classifier algorithm is trained to identify burnt vegetation patches (Roteta *et al.*, 2021).

Fire events were first located and dated based on MODIS MCD14ML hotspots (2001 – 2011) and VIIRS hotspots (2012 – 2020) (available at https://firms.modaps.eosdis.nasa.gov/download/).

Based on the timing and location of each fire hotspot, their contours could be amped by pre and post-fire Landsat time series using BAMTS and visually checked for accuracy.

Due to the lack of hotspots for the period 1984 – 2000 to tackle the location and timing of fire events in BAMTs, a second semi-automated tool relying solely on Landsat data was used to produce the fire contours of 1984 – 2020. The tool, described in Koutsias and Pleniou (2021), is based on a set of valid rules applied to Landsat scene pairs (pre-and post-fire) to identify burnt areas. Fires produced were only yearly dated due to the coarse temporal resolution of Landsat scenes (~ 16 days). Over the period 2001 – 2020, small fires undetected by BAMTs could be identified and added to the database while fires identified from both methods were compared and merged.

Due to the lack of reliable local fire records to filter out commission errors (Faour, 2004; Faour et al., 2006), the accuracy assessment was a visual checking filtering out all detected fires occurring in croplands or with no visual changes in reflectances. Within the red–green–blue (RGB) display, BAs have a very strong spectral signal appearing as a deep red coloring in post-fire scenes (Figure 2), allowing a high accuracy visual assessment (Koutsias and Karteris 2000; Roteta *et al.,* 2019).

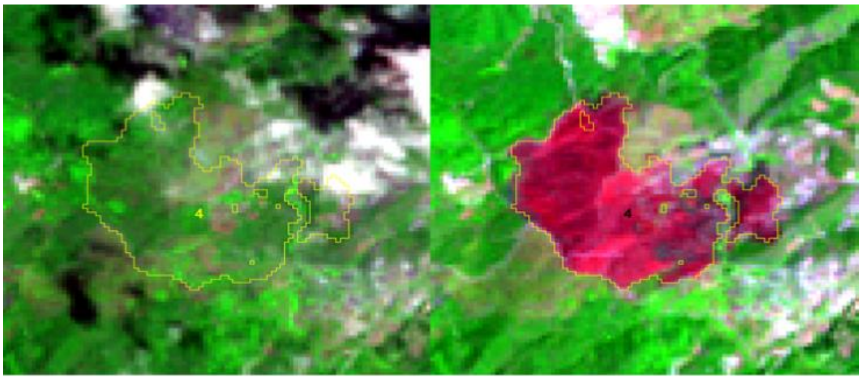

Figure 2 - Pre- (left) and post-fire (right) images showing the burnt signal (red).

2.3. Climatic data

To investigate the climatic control on the seasonal and interannual fire activity, we tested the Fire Weather Index (FWI) (Van Wagner, 1974), previously used in Mediterranean ecosystems (Chelli *et al.*, 2015; Dimitrakopoulos *et al.*, 2011; Moriondo *et al.*, 2006). We computed FWI with the R-cran "*cffdrs*" package and "*fwi*" function based on midday values of temperature (C), wind speed (km.hr^{-1}), precipitation (mm), and relative humidity (%) from the ERA5 Land climate database (https://confluence.ecmwf.int/display/CKB/ERA5-Land?src=contextnavpagetreemode) over the cities of Beirut (Lebanon) (33.68°E, 35.5°N) and Lattakia (Syria) (36.0°E, 36.05°N) for the period 1984 – 2020.

2.3.1. Conflict Data

To investigate our hypothesis of the potential impact of conflicts on the wildfire activity in Syria, we used the Integrated Crisis Early Warning System database (ICEWS) (Boschee *et al.*, 2020), previously used in studies about protests, fire, and conflicts driving forces in Syria (Ash and Obradovich, 2020; Linke and Ruether, 2021; Zubkova *et al.*, 2021). ICEWS consists of socio-political conflict and mediation global events identified and extracted automatically from news articles, available from January 1995 until April 2020. For our study, 1,607 violent events taking place in Syria between 1995 and April 2020 (29 out of 290 event types) were retained.

3. Results and Discussion

3.1. General information and Burnt Area database for the period 1984 – 2020

An exhaustive GIS fire database was produced for Lebanon and Mediterranean Syria for the period 1984 – 2020 with a spatial resolution ranging between 20 m (2016 – 2020) and 30 m (1984 – 2015). Each of the fire polygons is associated with a unique identification number, a surface area (ha), and minimum and maximum fire dates based on MCD64ML and VIIRS hotspots.

In Lebanon, a total of 3,232 fires were mapped, affecting a total area of 83,437 ha for the period 1984 – 2020. 0.42% of the wildland was burnt each year (2,255 $ha.year^{-1}$) with the highest fire years being 2007, 1998, and 1985. The majority of the fires (66.3%) occurred in forests and shrublands. 33.7% of the fires occurred in grasslands (Figure 3).

In Syria, a total of 1,544 fires were mapped, affecting a total area of 106,766 ha for the period 1984 – 2020, 1% of the wildland was burnt each year (2,885 $ha.year^{-1}$), with the highest fire years being 2020, 2012, and 2015. The majority of the fires (80.6%) occurred in forests and shrublands. 19.4% of the fires occurred in grasslands. (Figure 4).

3.2 Bimodal fire seasonality

In both countries, we observed a particular bimodal distribution of BA over the fire season with a reduced fire activity in August and peaks in the early and late fire seasons (Figure 5). Both the late end of the fire season (October/November) and the reduced fire activity in August are rarely seen in the MB where the fire season usually ends in September (Belhajd Khedher *et al.,* 2018; Ruffault *et al.,* 2020) and the largest BA is observed in August (Aini *et al.*, 2019; Belhadj-Khedher *et al.*, 2018; Chergui *et al.*, 2018; Im *et al.*, 2006). The dry season actually extends from June to early November, quite a long period for the region. During this dry period, we found that air relative humidity (RH) in August doesn't reach the low values observed in the late fire season (October-November in Lebanon; September-October in Syria). In addition, wind speed tends to decline in summer, while the highest temperatures (95% percentile) are stable from May to October leading to higher FWI events in June and September to November (Figure 6).

3.3 Non-climatic abrupt fire regime change in Syria since 2011

While no significant temporal trend of BA is observed for the two countries (Lebanon: p= 0.21, Syria: p= 0.06), contrasting with the general decreasing trends in the European Mediterranean region (Turco *et al.*, 2016), one breakpoint occurs for the year 2011 in Syria with significantly higher BA observed during the period 2012 – 2020 (81,492.5 ha) compared to the whole time series (25,273.5 ha during 1984 - 2011). This abrupt change in the fire regime, usually due to non-climatic factors (Pausas and Keeley, 2017; Syphard *et al.,* 2017), was not observed in neighboring Lebanon (Figure 7).

A higher, yet not significant, correlation was found between the BA and maximum FWI values for Lebanon (r= 0.29) and Syria (r=0.44) than with mean FWI values (Lebanon: r=0.1, Syria: r=0.24). During the pre-conflict period, maximum FWI could detect high fire years in 2010, 2007, 2002, 1994, and 1998 in Lebanon, as well as in 2007, 1986, and 1985 in Syria. We observed that during the conflict period since 2011, the years with high fire activity in Syria (2020, 2012, 2015, and 2013) still experience the highest FWI with the breaking record of 2020, as well as Lebanon for the years 2010, 2013, and 2019 (Figure 8). However, no significant temporal trend of FWI (Lebanon: p = 0.42, Syria: p = 0.09) nor breakpoints were significant in both countries, confirming the poor impact of climate on the BA trend.

When finally considering the ICEWS database, we could find a significant increasing temporal trend in the number of conflict events (p=0.049, slope=4.53) and two breakpoints (2010 and 2016) matching the breakpoint and increase of BA observed during the conflict period in Syria (Figure 9). A highly significant positive correlation between the number of conflict events and BA within each Syrian governorate was also found (p=0.04) (Figure 10).

The poor trend correlation between FWI and BA in Syria, the decorrelation in BA between Lebanon and Syria after 2011 with similar climate while the number of conflicts appeared as a significantly correlated variable suggest that the wildfire trend in Syria has socio-political drivers stronger than climate. Still, extreme fire years, as 2020, remain related to climate with 2020 being the most extreme fire weather since 1984 observed in Syria. The combined effect of climate and social troubles lead to the most extreme fire year observed in the region. In neighboring Lebanon, the social troubles (mostly urban) during the civil war ending in 1990 did not lead to major fire events. However, the political troubles in 2006 might have significantly contributed to the high BA during this year with no extreme fire weather.

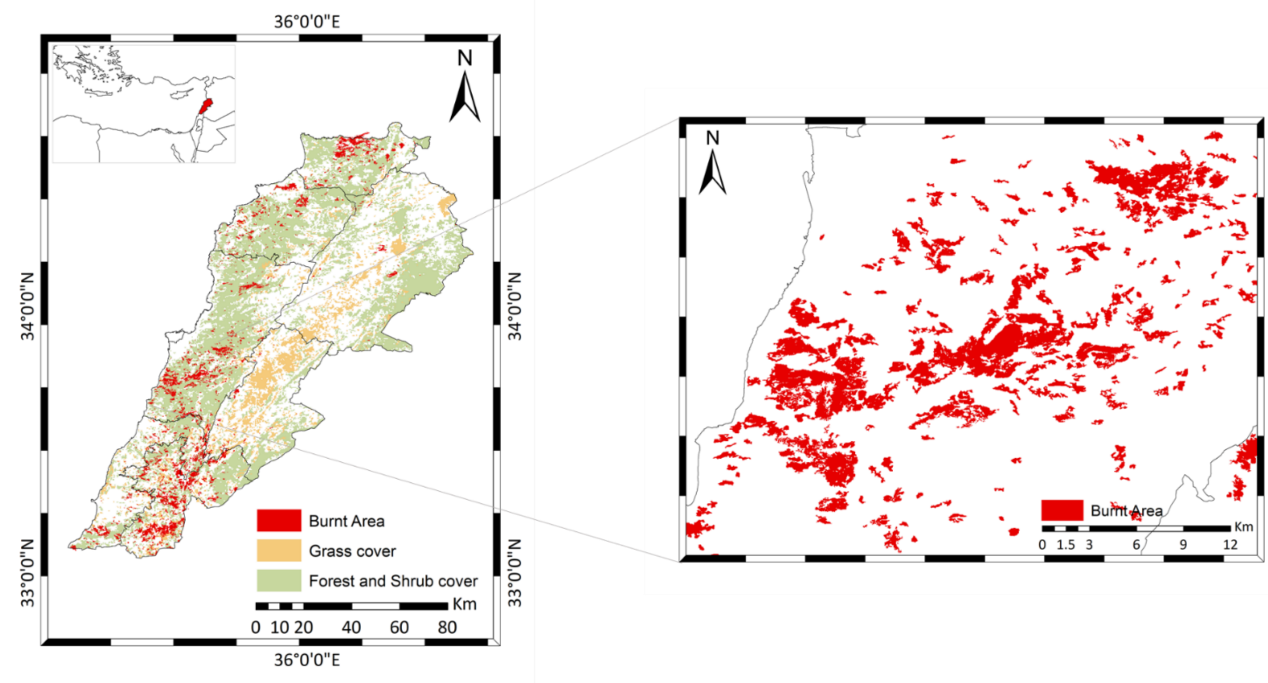

Figure 3 - Location of fire events in Lebanon for the period 1984 – 2020; fire contours (red polygons) and wildland cover (green and yellow polygons).

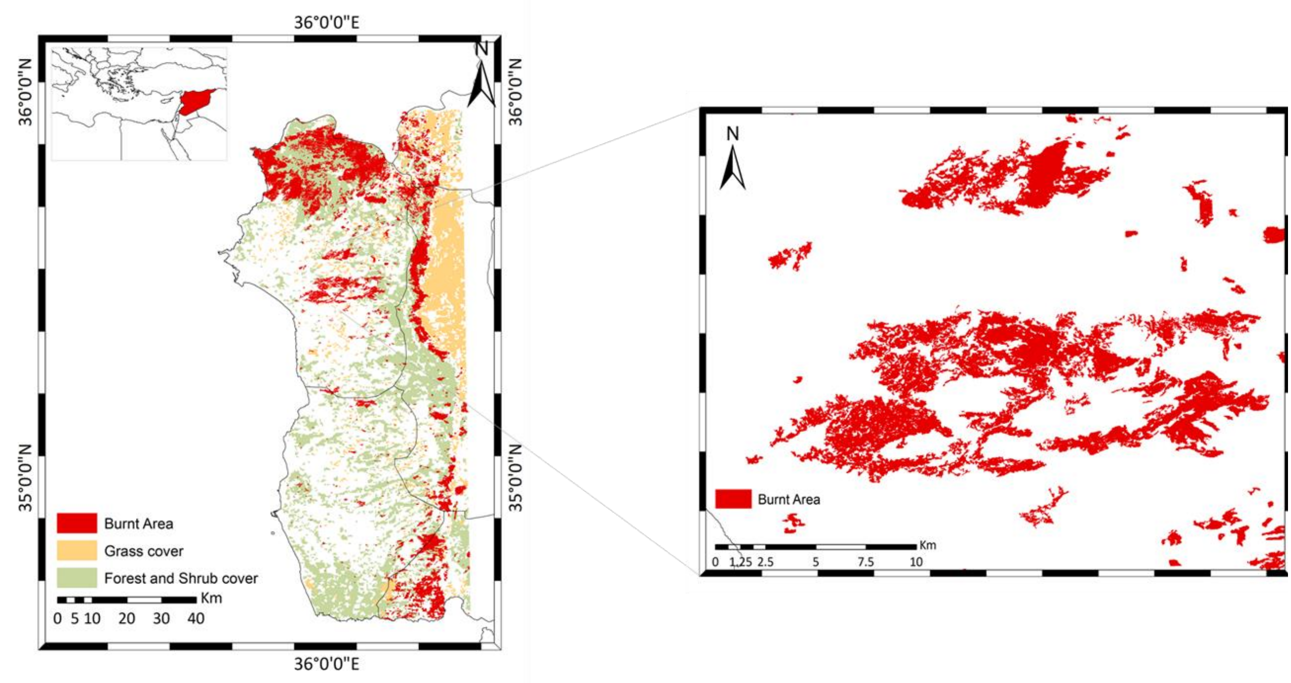

Figure 4 - Location of fire events in Syria for the period 1984 – 2020; fire contours (red polygons) and wildland cover (green and yellow polygons).

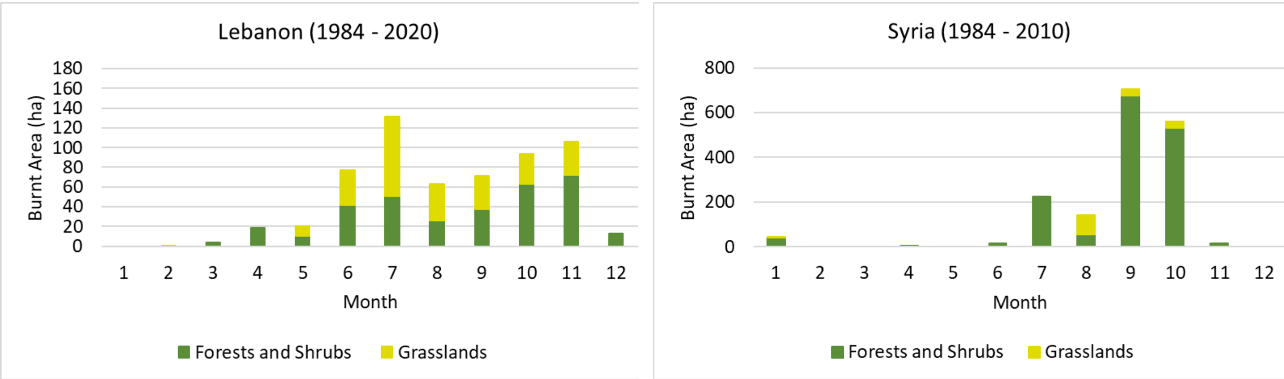

Figure 5- Seasonality of BA in Lebanon (1984 – 2020) (left) and Mediterranean Syria (1984 – 2010) (right).

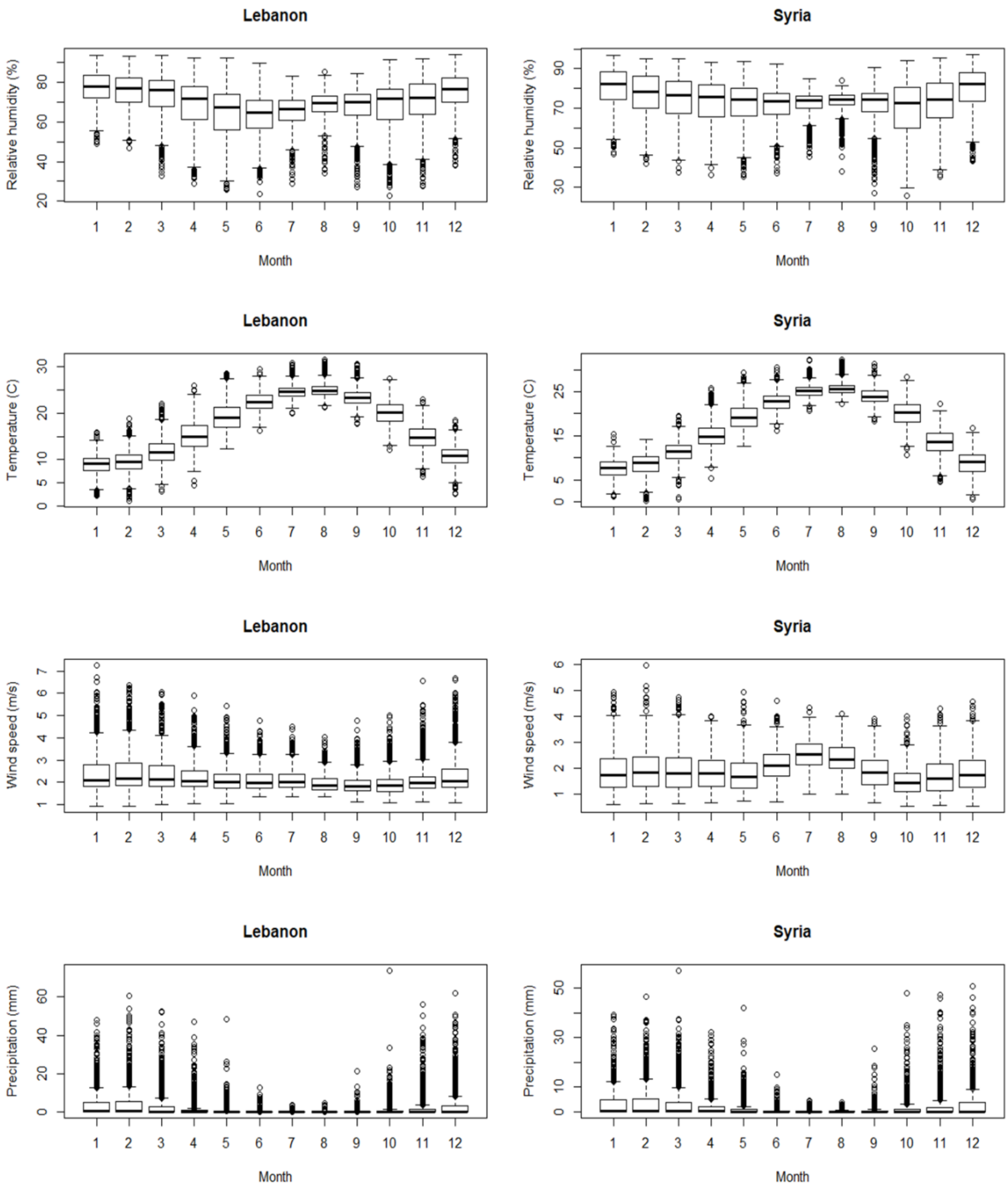

Figure 6 - Median, standard deviation, 95% confidence interval, and outliers of daily values of air Relative Humidity (RH) (%), Temperature (C), Wind Speed ($m.s^{-1}$,) and Precipitation (mm) in Lebanon (left) (1984 – 2020) and Mediterranean Syria (right) (1984 – 2010).

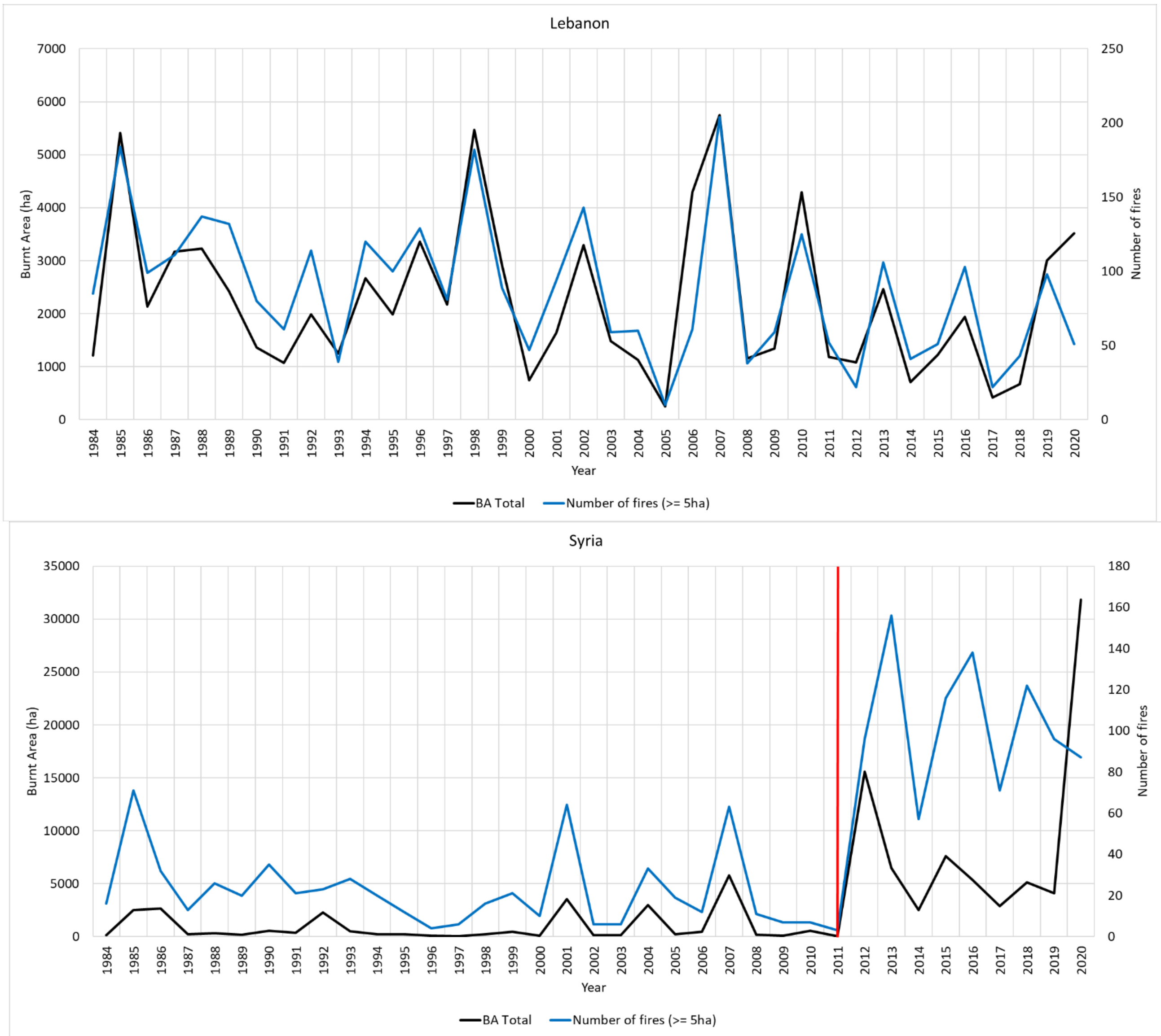

Figure 7 - Interannual variability of BA (black) and number of fires (blue) in Lebanon and Syria for the period 1984 - 2020. Breakpoint in Syria at 2011 (red).

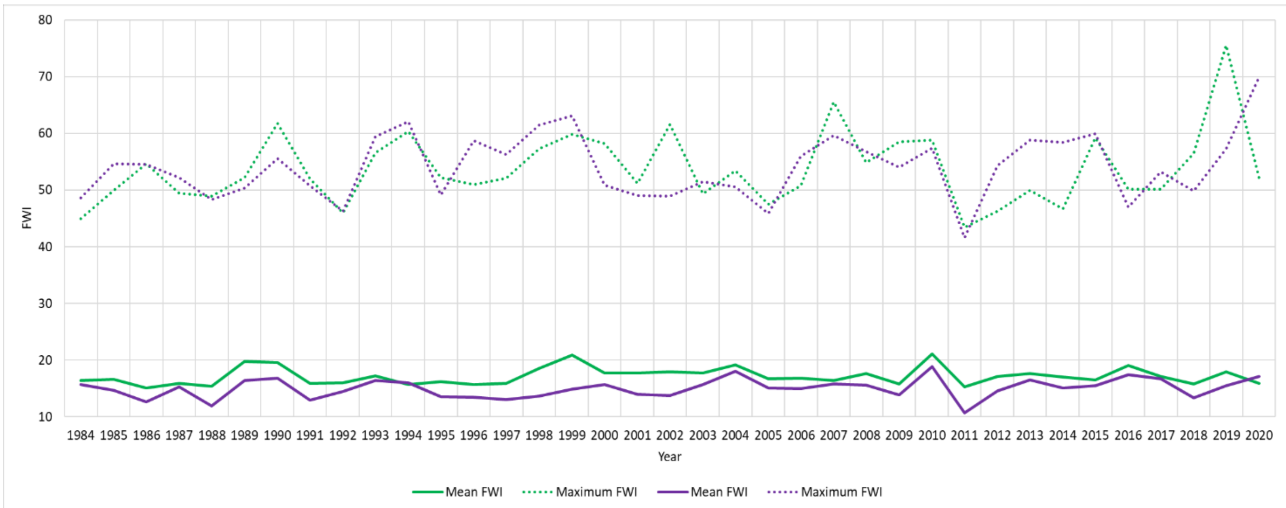

Figure 8 - Interannual variability of FWI values (line) and maximum daily FWI values (dashes) in Lebanon (green) and Syria (purple) for the period 1984 - 2020. The maximum value is the highest data point in the data set excluding outliers.

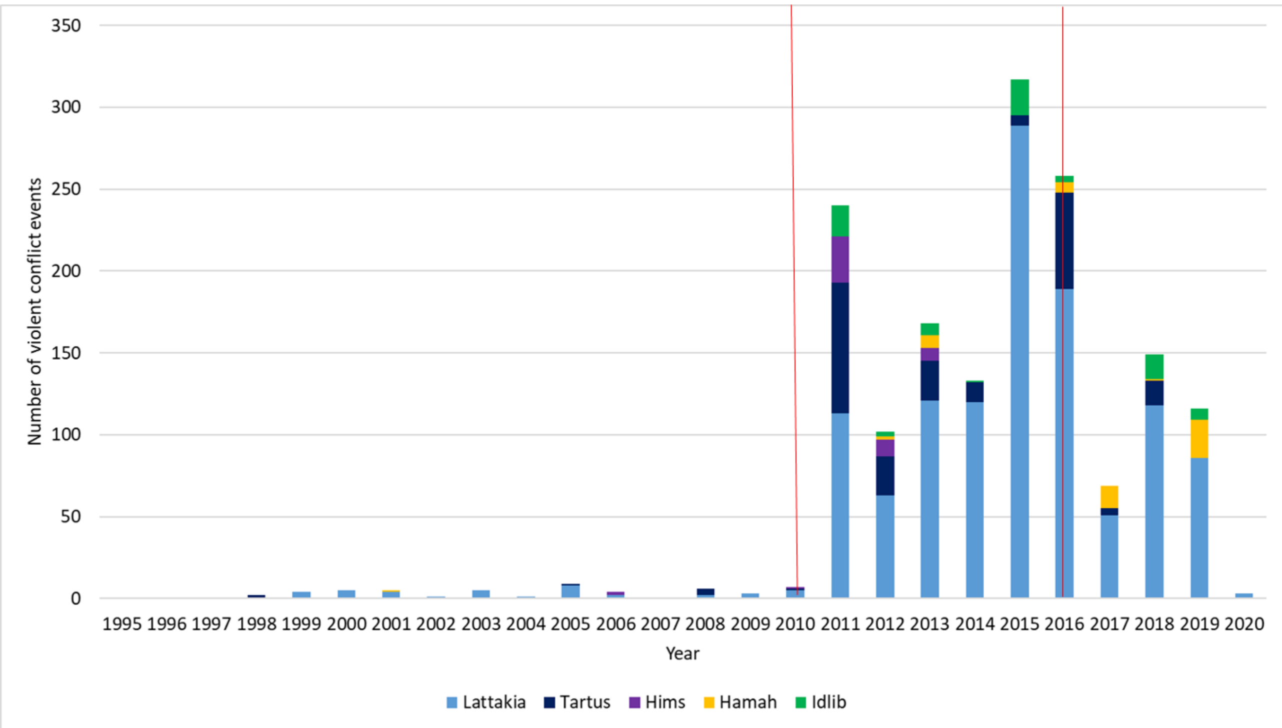

Figure 9 - Breakpoints (red) and interannual variability of the number of violent conflict events per governorate in Syria for the period 1995 - April 2020.

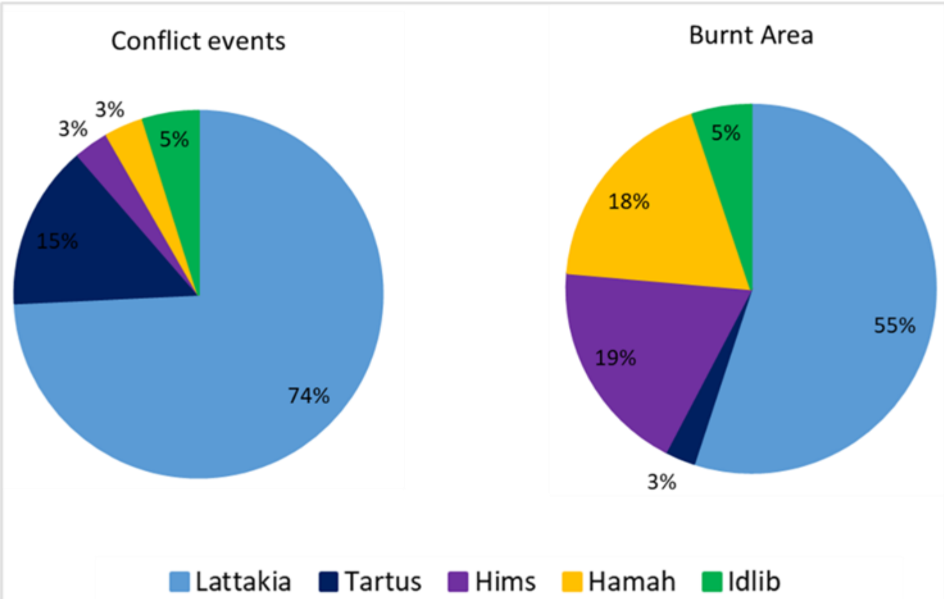

Figure 10 - Conflict events (%) (left) and BA (%) (right) per governorate in Syria for the period 1984 - 2020.

4. Funding

The authors would like to acknowledge the National Council for Scientific Research of Lebanon (CNRS-L) and the University of Montpellier (UM) for granting a doctoral fellowship to Georgia Majdalani.

5. Bibliography

Aini, A., Curt, T., & Bekdouche, F. (2019). Modelling fire hazard in the southern Mediterranean fire rim (Bejaia region, northern Algeria). *Environmental monitoring and assessment*, *191*(12), 1-19.

Ash, K., & Obradovich, N. (2020). Climatic stress, internal migration, and Syrian civil war onset. *Journal of Conflict Resolution*, *64*(1), 3-31.

Belhadj-Khedher, C., El-Melki, T., & Mouillot, F. (2020). Saharan hot and dry Sirocco winds drive extreme fire events in Mediterranean Tunisia (North Africa). *Atmosphere*, 11(6), 590.

Belhadj-Khedher, C., Koutsias, N., Karamitsou, A., EI-Melki, T., Ouelhazi, B., Hamdi, A., ... & Mouillot, F. (2018). A revised historical fire regime analysis in Tunisia (1985–2010) from a critical analysis of the national fire database and remote sensing. *Forests*, *9*(2), 59.

Boschee, E. Lautenschlager, J., O'Brien, S., Shellman, S., Starz, J., Ward, M. (2015). ICEWS Coded Event Data.

Boschetti, L., Roy, D. P., Justice, C. O., & Humber, M. L. (2015). MODIS–Landsat fusion for large area 30 m burned area mapping. *Remote Sensing of Environment*, *161*, 27-42.

Chelli, S., Maponi, P., Campetella, G., Monteverde, P., Foglia, M., Paris, E., ... & Panagopoulos, T. (2015). Adaptation of the Canadian fire weather index to Mediterranean forests. *Natural Hazards*, 75(2), 1795-1810.

Chergui, B., Fahd, S., Santos, X., & Pausas, J. G. (2018). Socioeconomic factors drive fire-regime variability in the Mediterranean Basin. *Ecosystems*, *21*(4), 619-628.

Chuvieco, E., & Congalton, R. G. (1988). Mapping and inventory of forest fires from digital processing of TM data. *Geocarto International*, *3*(4), 41-53.

Dimitrakopoulos, A. P., & Mitsopoulos, I. D. (2006). Global forest resources assessment 2005-report on fires in the Mediterranean region. *Fire Management Working Papers (FAO)*.

Dimitrakopoulos, A. P., Bemmerzouk, A. M., & Mitsopoulos, I. D. (2011). Evaluation of the Canadian fire weather index system in an eastern Mediterranean environment. *Meteorological Applications*, 18(1), 83-93.

Eastwood, J. A., Plummer, S. E., Wyatt, B. K., & Stocks, B. J. (1998). The potential of SPOT-Vegetation data for fire scar detection in boreal forests. *International Journal of Remote Sensing*, *19*(18), 3681-3687.

Faour, G. (2004). Forest fire fighting in Lebanon using remote sensing and GIS.

Faour, G., Kheir, R. B., & Verdeil, E. (2006). Caractérisation sous système d'information géographique des incendies de forêts: l'exemple du Liban. *Forêt méditerranéenne*, 27(4), 339-352.

Filipponi, F. (2018). BAIS2: Burned area index for Sentinel-2. *Multidisciplinary digital publishing institute proceedings*, *2*(7), 364.

Gill, A. M., Stephens, S. L., & Cary, G. J. (2013). The worldwide “wildfire” problem. *Ecological applications*, *23*(2), 438-454.

Im, U., Onay, T., Yeniguin, O., Anteplioglu, U., Incecik, S., Toppu, S., ... & Papadopoulos, A. (2006, July). An overview of forest fires and meteorology in Turkey and Greece. In 2006 *First International Symposium on Environment Identities and Mediterranean Area* (pp. 62-67). IEEE.

Justice, C. O., Giglio, L., Korontzi, S., Owens, J., Morisette, J. T., Roy, D., ... & Kaufman, Y. (2002). The MODIS fire products. *Remote sensing of Environment*, *83*(1-2), 244-262.

Köppen, W. (1884). Die Wärmezonen der Erde, nach der Dauer der heissen, gemässigten und kalten Zeit und nach der Wirkung der Wärme auf die organische Welt betrachtet. *Meteorologische Zeitschrift*, *1*(21), 5-226.

Koutsias, N., & Karteris, M. (2000). Burned area mapping using logistic regression modeling of a single post-fire Landsat-5 Thematic Mapper image. *International Journal of Remote Sensing*, 21(4), 673-687.

Koutsias, N., & Pleniou, M. (2021). A rule-based semi-automatic method to map burned areas in Mediterranean using Landsat images–revisited and improved. *International Journal of Digital Earth*, 14(11), 1602-1623.

Le Houérou, H. N. (1973). *Fire and vegetation in the Mediterranean basin* (pp. 237-277). FAO.

Liew, S. C., Lim, O. K., Kwoh, L. K., & Lim, H. (1998, July). A study of the 1997 forest fires in South East Asia using SPOT quicklook mosaics. In *IGARSS'98. Sensing and Managing the Environment. 1998 IEEE International Geoscience and Remote Sensing. Symposium Proceedings.(Cat. No. 98CH36174)* (Vol. 2, pp. 879-881). IEEE.

Linke, A. M., & Ruether, B. (2021). Weather, wheat, and war: Security implications of climate variability for conflict in Syria. *Journal of Peace Research*, *58*(1), 114-131.

Loveland, T. R., & Dwyer, J. L. (2012). Landsat: Building a strong future. *Remote Sensing of Environment*, *122*, 22-29.

Mahfoud, I. (2020). The Impact of Syrian Crisis on the Forestry Areas in North Latakia Governorate.

Malingreau, J. P. (1990). The contribution of remote sensing to the global monitoring of fires in tropical and subtropical ecosystems. In *Fire in the Tropical Biota* (pp. 337-370). Springer, Berlin, Heidelberg.

Mohamed, M. A., Anders, J., & Schneider, C. (2020). Monitoring of changes in land use/land cover in Syria from 2010 to 2018 using multitemporal landsat imagery and GIS. *Land*, *9*(7), 226.

Moriondo, M.; Good, P.; Durao, R.; Bindi, M.; Giannakopoulos, C.; Corte-Real, J. Potential impact of climate change on fire risk in the Mediterranean area. *Clim. Res*. 2006, 31, 85–95.

Paula, S., Arianoutsou, M., Kazanis, D., Tavsanoglu, Ç., Lloret, F., Buhk, C., ... & Pausas, J. G. (2009). Fire-related traits for plant species of the Mediterranean Basin: Ecological Archives E090-094. *Ecology*, *90*(5), 1420-1420.

Pausas, J. G. (2004). Changes in fire and climate in the eastern Iberian Peninsula (Mediterranean basin). *Climatic change*, *63*(3), 337-350.

Pausas, J. G., & Keeley, J. E. (2017). Epicormic resprouting in fire-prone ecosystems. *Trends in Plant Science*, *22*(12), 1008-1015.

Pereira, J. M. (1999). A comparative evaluation of NOAA/AVHRR vegetation indexes for burned surface detection and mapping. *IEEE transactions on geoscience and remote sensing*, *37*(1), 217-226.

Roteta, E., Bastarrika, A., Franquesa, M., & Chuvieco, E. (2021). Landsat and Sentinel-2 based burned area mapping tools in google earth engine. *Remote Sensing*, *13*(4), 816.

Roteta, E., Bastarrika, A., Padilla, M., Storm, T., & Chuvieco, E. J. R. S. O. E. (2019). Development of a Sentinel-2 burned area algorithm: Generation of a small fire database for sub-Saharan Africa. *Remote sensing of environment*, 222, 1-17.

Ruffault, J., Curt, T., Moron, V., Trigo, R. M., Mouillot, F., Koutsias, N., ... & Belhadj-Khedher, C. (2020). Increased likelihood of heat-induced large wildfires in the Mediterranean Basin. *Scientific reports*, 10(1), 1-9.

San-Miguel-Ayanz, J., Schulte, E., Schmuck, G., Camia, A., Strobl, P., Liberta, G., ... & Amatulli, G. (2012). *Comprehensive monitoring of wildfires in Europe: the European forest fire information system (EFFIS)*. IntechOpen.

Schon, J., Mezuman, K., Heslin, A., Field, R. D., & Puma, M. J. (2021). How fire patterns reveal uneven stabilization at the end of conflict: examining Syria's unusual fire year in 2019. *Environmental Research Letters*, *16*(4), 044046.

Syphard, A. D., Keeley, J. E., Pfaff, A. H., & Ferschweiler, K. (2017). Human presence diminishes the importance of climate in driving fire activity across the United States. *Proceedings of the National Academy of Sciences*, *114*(52), 13750-13755.

Turco, M., Bedia, J., Di Liberto, F., Fiorucci, P., von Hardenberg, J., Koutsias, N., ... & Provenzale, A. (2016). Decreasing fires in mediterranean Europe. *PLoS one*, *11*(3), e0150663.

Turco, M., von Hardenberg, J., AghaKouchak, A., Llasat, M. C., Provenzale, A., & Trigo, R. M. (2017). On the key role of droughts in the dynamics of summer fires in Mediterranean Europe. *Scientific reports*, *7*(1), 1-10.

Wightman, J. M. (1973, January). Detection, mapping and estimation of rate of spread of grass fires from southern african ERTS-1 imagery. In *NASA. Goddard Space Flight Center Symp. on Significant Results obtained from the ERTS-1, Vol. 1, Sect. A and B (SEE N73-28207 19-13)* (No. PAPER-E6).

Woodcock, C. E., Allen, R., Anderson, M., Belward, A., Bindschadler, R., Cohen, W., ... & WULDER, M. A. W. (2008). Free access to Landsat imagery. *SCIENCE VOL 320: 1011*.

Xanthopoulos, G., & Nikolov, N. (2019). Wildfires and fire management in the eastern mediterranean, southeastern Europe, and middle east regions.

Xiao-rui, T., Mcrae, D. J., Li-fu, S., Ming-yu, W., & Hong, L. (2005). Satellite remote-sensing technologies used in forest fire management. *Journal of Forestry Research*, *16*(1), 73-78.

Zubkova, M., Giglio, L., Humber, M. L., Hall, J. V., & Ellicott, E. (2021). Conflict and Climate: Drivers of Fire Activity in Syria in the Twenty-First Century. *Earth Interactions*, *25*(1), 119-135.