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Short Communication

Has COVID-19 halted winter-spring wildfires in the Mediterranean? Insights for wildfire science under a pandemic context

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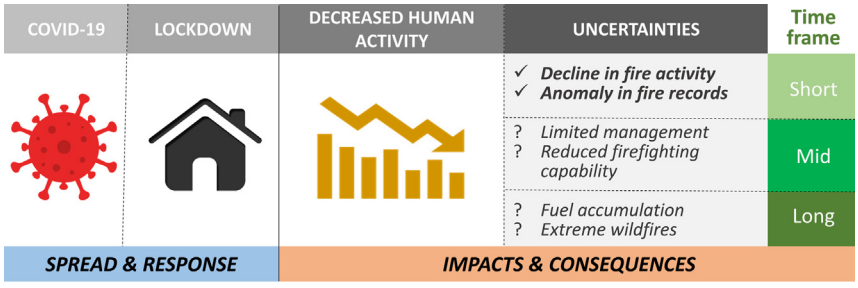
HIGHLIGHTS

- The response to COVID-19 has caused noticeable environmental impacts.
- The winter-spring season of 2020 is among the least fire-affected in the EU.
- A sustained decrease in burned area may promote fuel accumulation.
- Low fire activity, fire-prone conditions and budget limitations may foster EWEs in the future.

GRAPHICAL ABSTRACT



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ABSTRACT

Wildfires in the Mediterranean are strongly tied to human activities. Given their particular link with humans, which act as both initiators and suppressors, wildfire hazard is highly sensitive to socioeconomic changes and patterns. Many researchers have prompted the perils of sustaining the current management policy, the so-called 'total fire exclusion'. This policy, coupled to increasingly fire-prone weather conditions, may lead to more hazardous fires in the mid-long run. Under this framework, the irruption of the COVID-19 pandemic adds to the ongoing situation. Facing the lack of an effective treatment, the only alternative was the implementation of strict lockdown strategies. The virtual halt of the system undoubtedly affected economic and social behavior, triggering cascading effects such as the drop in winter-spring wildfire activity. In this work, we discuss the main impacts, challenges and consequences that wildfire science may experience due to the pandemic situation, and identify potential opportunities for wildfire management. We investigate the recent evolution of burned area (retrieved from the MCD64A1 v006 MODIS product) in the EU Mediterranean region (Portugal, Spain, France, Italy and Greece) to ascertain to what extent the 2020 winter-spring season was impacted by the public health response to COVID-19 (curfews and lockdowns). We accounted for weather conditions (characterized using the 6-month Standardized Precipitation Evapotranspiration Index; SPEI6) to disregard possible weather effects mediating fire activity. Our results suggest that, under similar drought-related circumstances (SPEI6 ≈ -0.7), the expected burned area in 2020 during the lockdown period in the EU (March–May) would lay somewhere within the range of 38,800 ha $\pm$ 18,379 ha. Instead, the affected area stands one order of magnitude below average (3325 ha). This stresses the need of considering the social dimension in the analysis of current and future wildfire impacts in the Mediterranean region.

1. Introduction

The COVID-19 pandemic is on its way to become, if it has not already, a 'one-in-a-lifetime' event, leaving an indelible footprint in an entire generation of people. Its economic and social impact over the entire planet is

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considered the largest since the Second World War, and it is undoubtedly the most relevant of the 21st century. The COVID-19 is triggering a variety of cascading effects fostering different kinds of impacts. During its most virulent stage, most European countries advocated for a reactive response implemented in terms of social distancing and national/regional lockdowns. The response immediately froze entire countries, completely halting the system into virtually neither economic activity nor population mobility allowed during a significant amount of time, at least several weeks. The strength and duration of such measures varied from one region to another, yet the European Mediterranean Region (EUMed, e.g., Portugal, Spain, France, Italy and Greece) remained under countrywide lockdowns spanning from March to May 2020 (Thomas et al., 2020). Despite the positive epidemiological effect, the post-lockdown economic scenario is looking grim and countries are experiencing large GDP drops, which will intensify in the near future.

From an environmental perspective, the response to COVID-19 has caused noticeable impacts such as the unparalleled drop in air pollution over some of the largest metropolitan areas in the world (Saadat et al., 2020; Zambrano-Monserrate et al., 2020). Nevertheless, the sustained cessation/reduction of human activities poses unforeseen implications over anthropogenic dominated landscapes, and has set an open and ongoing debate between those who see the pandemic as an opportunity to demonstrate environmental restoration potential options and those who advocate about potential negative impacts in the future (Chakraborty and Maity, 2020). In the particular case of wildfires, the cessation of human activity may reduce their incidence in the very short-term, especially during the winter-spring season, known to be the most associated with human-related fire occurrence (Rodrigues et al., 2018). However, researchers, managers and firefighters are already warning about the potential subsequent impacts on and of wildfires. For example, the lack of activity may lead to a significant reduction in forest management especially of interventions without immediateeconomic return such as fuel reduction treatments-, fuel accumulation, and limited or impaired firefighting capability (social distancing), which coupled to fire-prone conditions and budget limitations, may foster extreme wildfires (EWEs) in the mid-to-long run. Furthermore, given the increased severity of the disease in people with previous pathologies, especially respiratory ones, smoke from EWEs may boost the vulnerability to the virus (Emami et al., 2020). So far, the pandemic raised more questions than answers, though the entire society and especially the scientific community, is working towards solving the most pressing ones. What is going to happen under a scenario of budgetary constraints and likely subsequent infection waves is yet to be seen, but surely merits further research efforts.

In this work, we present a preliminary and concise analysis of the potential impacts in wildfires of the societal and public health response to COVID-19. We analyzed wildfire activity during the lockdown period in the EUMed countries –March to May– focusing on the progression of burned area during the most recent decades (2003−2020). We paid special attention to weather conditions (characterized using the 6-month Standardized Precipitation Evapotranspiration Index; SPEI6) so that we could better isolate the actual effect of curfews and lockdowns. The SPEI is a well-known indicator of water balance and drought conditions that has been previously used to predict fire activity (Marcos et al., 2015) or in the analysis of some of the most recent extreme wildfire episodes in Portugal (Turco et al., 2019) and Australia (Nolan et al., 2020). Our main goal was to determine to what extent the response to COVID-19 has affected wildfires under the hypothesis that the cessation of human activity would prompt a drop in wildfire incidence. Within this framework, we discuss possible implications and opportunities for wildfire science.

2. Materials and methods

2.1. Burned area and SPEI data

Data on burned areas were obtained for the most fire-affected countries in the EUMed region -Portugal, Spain, Italy, France and Greece- all of them experiencing strict lockdowns and mobility restrictions. We retrieved the burned area extent during the lockdown period –March to May– on a yearly basis since 2003, using the MODIS product MCD64A1 version 6 (Giglio et al., 2018). The MCD64A1 product provides reliable, homogeneous and up-to-date data since 2003 (Boschetti et al., 2019), distributed in monthly raster files at 500 × 500 meter resolution. Values of burned area were summarized into yearly time series by country, expressing them as *Z*-Scores (subtracting the mean and dividing by its standard deviation) to enable direct comparisons between countries while also enabling their interaction with SPEI.

Additionally, we also characterized the thermo-pluviometric conditions using the 6 months SPEI (SPEI6) based on May (thus covering the period December–May). SPEI6 was retrieved on a yearly basis as calculated in the Global Drought Monitor (Beguería, 2017), which provides SPEI values at 1 × 1 degree spatial resolution in *netcdf* format, calibrated in the period 1950–2010 (Beguería et al., 2014; Vicente-Serrano et al., 2009). The SPEI is a widespread indicator of drought that has been extensively used in wildfire science to infer vegetation and fuel conditions (Cardil et al., 2019; Rodrigues et al., 2018; Turco et al., 2016, 2019).

2.2. Assessing COVID-19 impacts on wildfire activity

The impact of COVID-19 responses on wildfires was addressed by investigating yearly burned area anomalies (*Z*-scores) at country level. To isolate the influence of lockdowns and curfews we accounted for previous weather conditions by means of SPEI6 values. By doing so, we could disregard potential effects of weather on fire incidence. In short, drier (SPEI<0) or moister (SPEI>0) than average conditions (SPEI = 0) were expected to trigger higher and lower burned area, respectively. We used SPEI6 to better frame the actual influence of COVID-19. For example, if a given year shows higher than usual burned area (Z-Score > 0) under a moist condition (SPEI6 > 0) we can assume that human activity is behind fire incidence. Likewise, unusually low burned area under dry conditions (SPEI6 < 0) may point towards a disruption in human-related ignitions.

3. Results and discussion

3.1. Effects of COVID-19 curfews on fire incidence in the Mediterranean

The winter-spring season of 2020 is among the least fire-affected in recent decades (Fig. 1). All EUMed countries (except Greece, which undergo a regular season) experienced below average burned area totals, especially in Spain (−1.63 sd), which was among the first and foremost impacted countries by the COVID-19 in Europe. Only 2007, 2013 and 2018 portrayed a similar behavior, i.e., a generalized burned area response below the mean figures. However, seasons 2013 and 2018 constitute anomalies along the observed record of increasing drought conditions, depicting rather moist conditions all over Europe (SPEI6 = 0.99 ± 0.89 and 0.58 ± 0.99, respectively). Unlike the 2013 and 2018 episodes, 2020 has undergone drier than usual conditions, with a 6-month SPEI often below the −0.84 threshold that signals moderate dry conditions (mean SPEI6 = −0.44).

Overall, the temporal dynamic of burned areas usually follows a somewhat erratic profile, with strong variability between years and countries. Only a few cases broke the pattern and showed a consistent behavior across countries; the aforementioned 2013, 2018 and 2020; and 2005, which experienced warm and dry situations (SPEI6 = −0.77 ± 0.60) conducive to a generalized increase in burned area. Likewise, 2012 and 2017 were also related to increased fire activity possibly linked to drought spells, though affecting more intensively a particular country (Spain in 2012 and Portugal in 2017). Nonetheless, the link between weather and fires is clear from the data.

Burned areas in the winter-spring season of 2020 differ in an order of magnitude from weather-based expectations. Under the under the

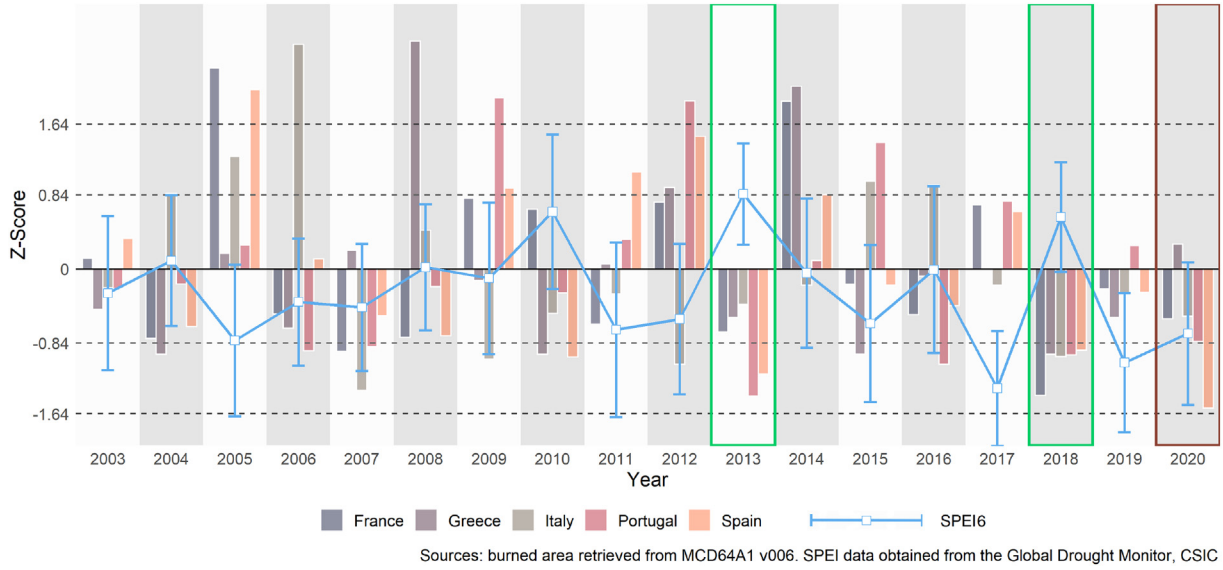

Fig. 1. Temporal evolution of burned area anomaly and SPEI6. Color bars indicate *Z*-Scores of burned area by year and country. Blue squares indicate mean SPEI6 values for the EUMed region whereas blue error bars mark the range between ±1 standard deviation. The red frame highlights the year 2020. Green frames indicate years with similar conditions of burned area, i.e., all EUMed countries arousing values below the mean.

2020 spring weather conditions, no one would have anticipated such a low impact of winter-spring fires, which supports the evidence of diminished fire incidence due to COVID-19 curfews. Since wildfires are triggered by the combination of human ignition sources and environmental factors, the observed reduction in burned areas this season is likely to be primarily explained by the reduction in human activity. Even though other factors might be mediating, in a scenario of normal/usual human activity, drought (crucial in fuel moisture) is the most temporally variable driver with human ignition rates, and it was accounted for through SPEI6. The observed SPEI6 values would lead us to expect burned areas in the range of 36,800 ha (± 18,389 ha), i.e. the March–May average under equivalent weather conditions (e.g., 2005, 2011, 2012 and 2015), instead of the current 3325 ha in 2020 (Table 1). It has long been recognized that ignition probabilities are determined by human activities but most of previous scientific work has modelled ignitions from weather and geographical variables eluding the link with human-related drivers (Costafreda-Aumedes et al., 2017; Rodrigues et al., 2018). Therefore, direct impacts of changing socio-economic activities in fire incidence remained unquantified until now (François-Nicolas et al., 2018).

3.2. Future challenges and uncertainties in wildfire science and management

Under strict limitations on human activities, winter-spring 2020 fires have experienced a measurable and significant decrease in all EUMed countries, becoming an outlier in fire statistics. Wildfire records for 2020 clearly separate from previous trends so far, posing a challenge for data management and interpretation in future analyses. It remains to be determined how lastly the effects of the pandemic will affect fire incidence (the 2020 summer season, longer?), but implications for future wildfire research are evident, if only to measure how fire activity would respond to cessation of human activity in the Mediterranean. In the event of upcoming waves conducive to further mobility/activity restrictions, we may experience decreased fires for an undetermined period. Quantitative assessments like ours may be conducted elsewhere, or even globally, allowing identifying disruptions in fire activity and possibly preparing for exacerbated fires in the future, since sustaining this situation in time or subsequent lockdowns may well promote fuel built-up due to decreased vegetation management. Once budget and personnel constraints due to the likely economic recession reach fire governance structures and combine with the expected increased frequency of droughts and fire weather danger (Jolly et al., 2015; Turco et al., 2017), a perfect-storm confluence of conditions may trigger amplified wildfire disasters. On the other hand, certain COVID-related responses may exert a direct influence on firefighting capability. To the expected decline in means and resources due to budgetary constraints, specific measures like individual quarantines may add to the existing limitations in personnel. In the same line, social distancing strategies may also hinder firefighting or prescribed burning training operations and volunteer activities (i.e. Forest Defense Associations, ADF in Spain)

Table 1
Summary of fire-weather data March–May in the EUMed region (2003–2020). Green shadowing indicates years similar to 2020 in terms of SPEI6 (±0.1 difference). Blue shadowing identifies years similar to 2020 in terms of burned area (most countries showing below average burned area; *Z*-Score < 0). Red shadowed cells mark the year 2020.

	SPEI6		Burned area (ha)
	Mean	sd	
2003	–0.274	0.874	17,350
2004	0.094	0.739	9,875
2005	–0.811	0.858	60,550
2006	–0.373	0.719	21,300
2007	–0.435	0.721	5,575
2008	0.020	0.714	11,750
2009	–0.105	0.858	34,425
2010	0.649	0.877	11,075
2011	–0.688	0.989	24,125
2012	–0.567	0.853	41,925
2013	0.849	0.574	3,250
2014	–0.046	0.846	38,800
2015	–0.618	0.888	20,600
2016	–0.009	0.945	10,950
2017	–1.350	0.650	26,850
2018	0.588	0.621	3000
2019	–1.060	0.787	12,175
2020	–0.731	0.807	3,325

by impeding practices requiring close teamwork at the threat of infection.

The unpredictable mid-term consequences of COVID-19 on fire regime dynamics add uncertainty on top of an already controversial clash of current and proposed management frameworks, i.e., '*fire exclusion*' versus '*fire smart*' (Doerr and Santín, 2016; Otero et al., 2018). Many authors recommend reconsidering the 'business as usual' approach to wildfires in EUMed countries (Rodrigues et al., 2020), rebalancing suppression and mitigation. As Moreira et al. (2020) suggest in their a recent work, this requires a paradigm shift to face new and unknown concerns about fires in the future: policy and management effectiveness should not be primarily measured as a function of area burned, which is the usual practice, but rather as a function of avoided socioecological damage and loss.

From a research perspective, we believe that social dimensions must unavoidably be considered when analyzing the actual impact of COVID-19, and in truth, all future fires in the Mediterranean. This means strengthening the assessment of causal inference between human activities and fire occurrence but also unraveling the specific interactions between people and wildlands. Wildfire risk has been described as a "socioecological pathology: a set of interrelated social and ecological conditions and processes that deviate from what is considered healthy or desirable" (Fischer et al., 2016). To face fire in the Mediterranean we need to deepen our focus on the human drivers of fires, as demonstrated by this study. Considering the dynamic character of fire risk, a very promising line of research would be integrating mobility tracking (via GPS mobile phone tracking or social media) into fire risk assessments. Likewise, the use of remote sensing products to monitor fire incidence (i.e. active fire products) will soon enable detecting and monitoring impacts at multiple scales almost in real time.

4. Conclusions

The socioeconomic consequences of the COVID-19 pandemic are being dramatic, with millions of people already affected by the disease, hundreds of thousands dying, and a global economic recession incoming. The cessation of human activity has caused a variety of environmental impacts as well.

Due to the strong link between fires and human activities in Mediterranean-type ecosystems, wildfire hazard is highly sensitive to socioeconomic changes. In this brief report, we investigate the effects on wildfire activity of countrywide lockdowns in Europe. Our research highlights the sudden drop in wildfire incidence in all EUMed countries during the 2020 winter-spring season. The average burned area in this period stands one order of magnitude below the expected figures under similar water availability conditions (SPEI6). This situation opens new questions, uncertainties and challenges at different temporal frames. For instance, post-COVID budgetary constraints may lead to a significant reduction in forest management and limited firefighting capability, which coupled to fire-prone weather conditions, may foster extreme wildfires in the mid-to-long run. In the meantime, wildfire records for 2020 clearly separate from the observed trends, already becoming an 'outlier record' that wildfire scientists and managers will have to face in the future.

CRediT authorship contribution statement

Marcos Rodrigues is the main author, responsible for the research design, analyses and writing of the manuscript.

Pere Gelabert retrieved and organized the necessary data, also participating in data visualization and manuscript drafting.

Aitor Ameztegui and **Lluis Coll** contributed to writing and proofreading.

Cristina Vega-García was co-responsible for the research line (together with Marcos Rodrigues) and contributed to concept development and writing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Beguería, S., 2017. Sbegueria/{Speibase}: {Version} 2.5.1. https://doi.org/10.5281/ZENODO.834461.

Beguería, S., Vicente-Serrano, S., Reig, F., Latorre, B., 2014. Standardized precipitation evapotranspiration index (SPEI) revisited: parameter fitting, evapotranspiration models, tools, datasets and drought monitoring. Int. J. Climatol. 34, 3001–3023. https://doi.org/10.1002/joc.3887.

Boschetti, L., Roy, D.P., Giglio, L., Huang, H., Zubkova, M., Humber, M.L., 2019. Global validation of the collection 6 MODIS burned area product. Remote Sens. Environ. 235, 111490. https://doi.org/10.1016/j.rse.2019.111490.

Cardil, A., Vega-García, C., Ascoli, D., Molina-Terrén, D.M., Silva, C.A., Rodrigues, M., 2019. How does drought impact burned area in Mediterranean vegetation communities? Sci. Total Environ. 693, 133603. https://doi.org/10.1016/j.scitotenv.2019.133603.

Chakraborty, I., Maity, P., 2020. COVID-19 outbreak: migration, effects on society, global environment and prevention. Sci. Total Environ. 728, 138882. https://doi.org/10.1016/j.scitotenv.2020.138882.

Costafreda-Aumedes, S., Comas, C., Vega-Garcia, C., 2017. Human-caused fire occurrence modelling in perspective: a review. Int. J. Wildl. Fire 26, 983–998. https://doi.org/10.1071/WF17026.

Doerr, S.H., Santín, C., 2016. Global trends in wildfire and its impacts: perceptions versus realities in a changing world. Philos. Trans. R. Soc. B Biol. Sci. 371, 20150345. https://doi.org/10.1098/rstb.2015.0345.

Emami, A., Javanmardi, F., Pirbonyeh, N., Akbari, A., 2020. Prevalence of underlying diseases in hospitalized patients with COVID-19: a systematic review and meta-analysis. Arch. Acad. Emerg. Med. 8, e35. 32232218.

Fischer, A.P., Spies, T.A., Steelman, T.A., Moseley, C., Johnson, B.R., Bailey, J.D., Ager, A.A., Bourgeron, P., Charnley, S., Collins, B.M., Kline, J.D., Leahy, J.E., Littell, J.S., Millington, J.D.A., Nielsen-Pincus, M., Olsen, C.S., Paveglio, T.B., Roos, C.I., Steen-Adams, M.M., Stevens, F.R., Vukomanovic, J., White, E.M., Bowman, D.M.J.S., 2016. Wildfire risk as a socioecological pathology. Front. Ecol. Environ. 14, 276–284. https://doi.org/10.1002/fee.1283.

François-Nicolas, R., Janice, B., Promode, K., Mike, D.F., Michael, K., Bill, De G., Mike, D.W., 2018. Summary Note of a Global Expert Workshop on Fire and Climate Change (ISBN: 9783903258136).

Giglio, L., Boschetti, L., Roy, D.P., Humber, M.L., Justice, C.O., 2018. The Collection 6 MODIS burned area mapping algorithm and product. Remote Sens. Environ. 217, 72–85. https://doi.org/10.1016/j.rse.2018.08.005.

Jolly, W.M., Cochrane, M.A., Freeborn, P.H., Holden, Z.A., Brown, T.J., Williamson, G.J., Bowman, D.M.J.S., 2015. Climate-induced variations in global wildfire danger from 1979 to 2013. Nat. Commun. 6, 7537. https://doi.org/10.1038/ncomms8537.

Marcos, R., Turco, M., Bedía, J., Llasat, M.C., Provenzale, A., 2015. Seasonal predictability of summer fires in a Mediterranean environment. Int. J. Wildl. Fire 24, 1076. https://doi.org/10.1071/WF15079.

Moreira, F., Ascoli, D., Safford, H., Adams, M.A., Moreno, J.M., Pereira, J.M.C., Catry, F.X., Armesto, J., Bond, W., González, M.E., Curt, T., Koutsias, N., McCaw, L., Price, O., Pausas, J.G., Rigolot, E., Stephens, S., Tavsanoglu, C., Vallejo, V.R., Van Wilgen, B.W., Xanthopoulos, G., Fernandes, P.M., 2020. Wildfire management in Mediterranean-type regions: paradigm change needed. Environ. Res. Lett. 15, 11001. https://doi.org/10.1088/1748-9326/ab541e.

Nolan, R.H., Boer, M.M., Collins, L., de Dios, V., Clarke, H., Jenkins, M., Kenny, B., Bradstock, R.A., 2020. Causes and consequences of eastern Australia's 2019–20 season of mega-fires. Glob. Chang. Biol. 26, 1039–1041. https://doi.org/10.1111/gcb.14987.

Otero, I., Castellnou, M., González, I., Arilla, E., Castell, L., Castellví, J., Sánchez, F., Nielsen, J.Ø., 2018. Democratizing wildfire strategies. Do you realize what it means? Insights from a participatory process in the Montseny region (Catalonia, Spain). PLoS One 13, 1–35. https://doi.org/10.1371/journal.pone.0204806.

Rodrigues, M., Jiménez-Ruano, A., Peña-Angulo, D., de la Riva, J., 2018. A comprehensive spatial-temporal analysis of driving factors of human-caused wildfires in Spain using Geographically Weighted Logistic Regression. J. Environ. Manag. 225, 177–192. https://doi.org/10.1016/j.jenvman.2018.07.098.

Rodrigues, M., Jiménez-Ruano, A., de la Riva, J., 2020. Fire regime dynamics in mainland Spain. Part 1: drivers of change. Sci. Total Environ. 721, 135841. https://doi.org/10.1016/j.scitotenv.2019.135841.

Saadat, S., Rawtani, D., Hussain, C.M., 2020. Environmental perspective of {COVID}-19. Sci. Total Environ. 728, 138870. https://doi.org/10.1016/j.scitotenv.2020.138870.

Thomas, H., Webster, S., Petherick, A., Phillips, T., Kira, B., 2020. Oxford {COVID}-19 {Government} {Response} {Tracker}.

Turco, M., Bedia, J., Di Liberto, F., Fiorucci, P., von Hardenberg, J., Koutsias, N., Llasat, M.-C., Xystrakis, F., Provenzale, A., 2016. Decreasing fires in Mediterranean Europe. PLoS One 11, 1–19. https://doi.org/10.1371/journal.pone.0150663.

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. Sci. Rep. 7, 81. https://doi.org/10.1038/s41598-017-00116-9.

Turco, M., Jerez, S., Augusto, S., Tarín-Carrasco, P., Ratola, N., Jiménez-Guerrero, P., Trigo, R.M., 2019. Climate drivers of the 2017 devastating fires in Portugal. Sci. Rep. 9, 13886. https://doi.org/10.1038/s41598-019-50281-2.

Vicente-Serrano, S.M., Beguería, S., López-Moreno, J.I., 2009. A multiscalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index. J. Clim. 23, 1696–1718. https://doi.org/10.1175/2009JCLI2909.1.

Zambrano-Monserrate, M.A., Ruano, M.A., Sanchez-Alcalde, L., 2020. Indirect effects of COVID-19 on the environment. Sci. Total Environ. 728, 138813. https://doi.org/10.1016/j.scitotenv.2020.138813.