SEEFOR SOUTH-EAST EUROPEAN FORESTRY

OPEN ACCESS
ISSN 1847-6481
eISSN 1849-0891

REVIEW PAPER

DOI: https://doi.org/10.15177/seefor.22-11

Analysis of the Fire Season of 2020 in the Mediterranean Bioclimatic Zone of Croatian Adriatic

Damir Barčić[1], Tomislav Dubravac[2,*], Mario Ančić[3], Roman Rosavec[1]

(1) University of Zagreb, Faculty of Forestry and Wood Technology, Institute of Ecology and Silviculture, Svetošimunska 23, HR-10000 Zagreb, Croatia; **(2)** Croatian Forest Research Institute, Division for Silviculture, Cvjetno naselje 41, HR-10450 Jastrebarsko, Croatia; **(3)** University of Zagreb, Faculty of Forestry and Wood Technology, Institute of Forest Inventory and Management, Svetošimunska 23, HR-10000 Zagreb, Croatia

*** Correspondence:** e-mail: dbarcic@sumfak.hr

Citation: Barčić D, Dubravac T, Ančić M, Rosavec R, 2022. Analysis of the Fire Season of 2020 in the Mediterranean Bioclimatic Zone of Croatian Adriatic. *South-east Eur for* 13(2): 115-125. https://doi.org/10.15177/seefor.22-11.
Received: 14 Jul 2022; **Revised:** 24 Oct 2022; **Accepted:** 11 Nov 2022; **Published online:** 7 Dec 2022

ABSTRACT

Fire season in the Mediterranean bioclimatic area is most associated with the period from June to late October. Despite this, a large number of fires occur in February and March due to the intentional burning of agricultural lands. A characteristic of the Mediterranean region is the strong adaptation of vegetation to fire, though this adaptation also depends on the frequency and intensity of fires. This frequency is shown on satellite images via MODIS. This paper provides an overview of indicators of vegetation fires in the Croatian coast and karst coastal belt in the 2020 fire season. The 2020 fire season was above average in comparison with the period 2010 to 2019, with more fires than average and more burnt area. A specificity of the 2020 season is seen in the large number of fires in February and March. Fire protection in Croatia is facilitated by the use of new remote sensing technologies, in combination with the existing surveillance and monitoring methods, and organised protection systems to prevent open fires.

Keywords: open space fire; fire activity; distribution; mapping of burnt areas; prevention

INTRODUCTION

Wildfires significantly disturb terrestrial ecosystems. Large-scale fires inflict immeasurable ecological damage and commercial loss in forestry, agriculture and to the infrastructure. Direct consequences of wildfires are related with polluted air; smoke and soot in the atmosphere, residue from burning contaminates the soil and groundwater (Delač et al. 2021, 2022) destroys biomass, affecting, in ecological sense, both aboveground and belowground biotic communities (Bond and Keeley 2005, Dove and Hart 2017). Fire is more common in certain parts of the globe due to the local climatic factors. One such region is the Mediterranean basin, which is specific since most of the vegetation is partly adapted to fire, which is also partly due to the frequency and intensity of fires. Some authors claim that fire is a natural element in Mediterranean ecosystems (Keeley et al. 2011, Moreira et al. 2020), which needs to be considered when analysing the impacts of fire on vegetation. In Southern European Mediterranean countries, change in the fire regime are land abandonment and afforestation of former agricultural land, leading to fuel accumulation and landscape-level connectivity of flammable patches (Moreira et al. 2012). Pausas et al. (2008) state that fire is both an integral part of many terrestrial biomes including Mediterranean ones, and a major factor of disturbance. In that sense, it is necessary to list very specific and important information about the scale and causes of open fires. Approximately 80-86% of the global burnt area occurs in grassland and savannas, primarily in Africa and Australia (Mouillot and Field 2005, van der Werf et al. 2006), while the remainder occurs in forested regions of the world (Flannigan et al. 2009). Most open fires are caused by humans, intentionally or unintentionally, with less than 4% caused naturally, i.e., by lighting (Martinez et al. 2009). The number of naturally caused fires is also very low due to the development of fire prevention and protection technology in recent decades (Viegas 1998, Koo et al. 2010), and more intensive surveillance and monitoring of meteorological parameters. According to some research in the western Mediterranean, increased negative ecological impacts of fires on habitat, in the sense of diminished biodiversity and increased erosion, are due to pine plantations (Gomez-Gonzalez et al. 2018, Ojeda 2020). However, fire occurrence is most highly correlated with climate factors (temperature and drought).

In that sense, fire regimes can be analysed, and some studies have highlighted the variations in the relationship between climate and fire among regions, primarily based on the differences in the effects of human and biophysical drivers on fire initiation and behaviour (Littell et al. 2009, Keeley and Syphard 2017, Syphard et al. 2017). In Croatia, fire severity has been monitored for many years, and in some cases also the connection with vegetation from a bioclimatic point of view (Barčić et al. 2020). A key issue in the Mediterranean climate conditions in Croatia is whether new technologies in fire protection offer an opportunity to reduce the number of fires and burnt areas. The cumulative impact of burnt areas in the European Mediterranean region (Ayanz et al. 2012), as mapped in the European Forest Fire Information System (EFFIS) from 2000 to 2009, is presented in Figure 1.

In the context of climate change projections, the poten-tial for wildfires will only increase in southern Europe, which can significantly reduce the resilience of Mediterranean ecosystems to fire (Vallejo et al. 2012).

MATERIALS AND METHODS

The most common index, the Canadian Fire Weather Index (FWI), was used to assess fire severity and to assess fire risk based on meteorological conditions. This index is a numerical assessment of the potential intensity of fire for a standard fuel type and is a relative measure of the expected fire behaviour and a daily requirement for fire supervision (van Wagner and Pickett 1985, van Wagner 1987, 1993). The mean seasonal FWI can successfully explain most of the year-to-year variation in burnt areas in European countries. Burnt area index (BAI) was used for the interpretation of wildfires (BAI = area affected by fire / number of fires).

Maps were developed using MODIS (Moderate Resolution Imaging Spectroradiometer) on board the Terra and Aqua satellites over a 10-day period. Each coloured dot indicates a location where MODIS detected at least one fire during the compositing period. Colours range from red where the fire count is low to yellow where number of fires is high.

The temporal resolution of MODIS is one to two days, and the radiometric resolution is 12 bits per pixel. Various channels of MODIS have various purposes, of which the most interesting to us are channels 17-19 (monitoring of vapor in the atmosphere), channels 20-23 (determining the temperature of the Earth's surface and clouds), channels 24 and 25 (determining the temperature of the atmosphere) and finally channels 31 and 32 (determining the temperature of the Earth's surface and clouds).

RESULTS

According to the data collected and kept by the Operational Fire Centre of the Croatian Firefighting Association, a total of 3906 vegetation fires were recorded in the coastal belt and coastal areas of the Mediterranean karst in 2020. This figure is 20.78% higher than the previous five-year average (Tables 1 and 3). In these fires, the total burnt area (according to field estimates and georeferencing calculations based on maps) was 35,168 ha, or 14.72% more than in the previous five-year period (Tables 2 and 3), thereby resulting in a 5.02% reduction in the burnt area index (BAI).

The distribution of the number of fires by burnt area size during the main fire season and for the whole fire season in 2020 in shown in Table 4. The size of the burnt area in most wildfires during the fire season (June – October) was less than 5 ha, while only one fire had a burnt area of over 100 ha, accounting for just 0.09% of the number of fires in that period. The number of fires that had burnt an area between 10 and 100 ha (24 fires) was nearly the same number of fires that burnt an area between

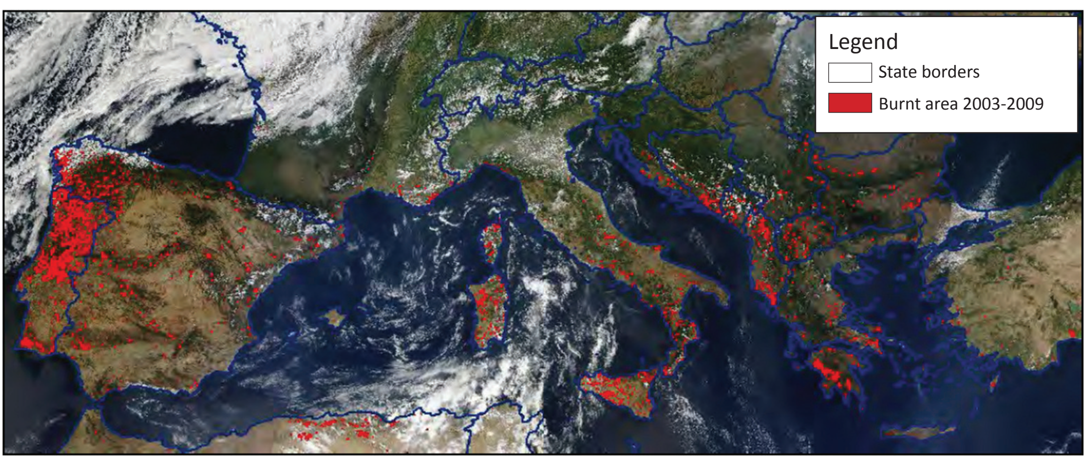

Figure 1. Cumulative impact of forest fires in the 2000-2009 period marked with red.

5 and 10 ha (25 fires). This is a characteristic recorded for the fourth year in a row (where the ratio is nearly the same or is larger), indicating that, unless controlled, fires spread very quickly to areas of over 10 ha. Taking the entire year into account (data analysed at the Croatian Operational Fire Control Centre), 25 fires spread to an area greater than 100 ha (0.67%) and 167 fires were contained within an area of 10 and 100 ha (4.28%), while 110 affected an area of 5 to 10 ha (2.82%) and the vast majority of 3604 fires (92.27%) burnt an area of less than 5 ha.

The severity of the global fire seasons in 2019, 2020 and 2021 is shown in Figures 2,3 and 4, in a ten-day period in the month of January and in the month of August. Mouillot and Field (2005) estimate that the global average burnt area decreased from 535 to 500 Mha per year during the first half of the 20th century. Meanwhile, in recent decades, certain regions have shown evidence of a strong threat of the trend towards more fires affecting a larger area, and burning with greater severity (FAO 2007).

Figure 7 shows that the 2020 fire season was above average in comparison with the period of 2010 to 2019 (Figure 5), indicating that there were more fires and more area burnt than during the ten-year average. The specificity of 2020 is seen in the larger number of fires in February and March (during cleaning weeds on agricultural area), primarily due to weather conditions (reduced precipitation and a higher number of days with strong to gale force winds), with the frequent, irresponsible burning of agricultural lands that went out of control. The deviation for the year 2020 is also clearly shown by the burnt area index (9.00 ha), which is still significantly less compared to the extremely dry and warm year of 2017, when the index was 20.86 ha per one fire.

Table 1. Number and surface of open fires in the coastal areas of Croatia.

Observed period	2015		2016		2017		2018		2019		2020	
	Number of fires	Surface (ha)	Number of fires	Surface (ha)	Number of fires	Surface (ha)	Number of fires	Surface (ha)	Number of fires	Surface (ha)	Number of fires	Surface (ha)
01/01-31/12	3382	23909	2913	19773	4150	86576	1875	3891	3850	19129	3906	35168
01/06-31/10	1317	10265	1407	7415	1574	59770	1330	3160	1090	2643	1059	1695

Table 2. Five-year average of the number of fires and their area, and the burnt area index (BAI).

Observed period	2015-2019			2020
	Number of fires	Surface (ha)	BAI (ha·fire^{-1})	BAI (ha·fire^{-1})
01/01-31/12	3234	30655,6	9.48	9.00
01/06-31/10	1343,6	16650,6	12.39	1.60

Table 3. Comparison of the 2020 fire season and the five-year average.

Observed period	Ratio of the number of fires (%)	Ratio of the burnt area (%)	Ratio of the burnt area index - BAI (%)
01/01-31/12	20.78	14.72	-5.02
01/06-31/10	-0.21	-89.82	-87.08

Table 4. Distribution of open fires by burnt area size in coastal part of the Republic of Croatia in 2020.

Month	<=5 ha		>5 <=10 ha		>10 <=100 ha		>100 ha		Total fires
	Number	%	Number	%	Number	%	Number	%	
VI	156	98.11	1	0.63	2	1.26	0	0.00	159
VII	259	96.09	6	1.95	6	1.95	0	0.00	307
VIII	305	91.59	14	4.20	13	3.90	1	0.30	333
IX	207	97.64	4	1.89	1	0.47	0	0.00	212
X	47	95.92	0	0.00	2	4.08	0	0.00	49
VI-X	974	95.28	25	2.36	24	2.26	1	0.09	1060
I-XII	3604	92.27	110	2.82	167	4.28	25	0.64	3906

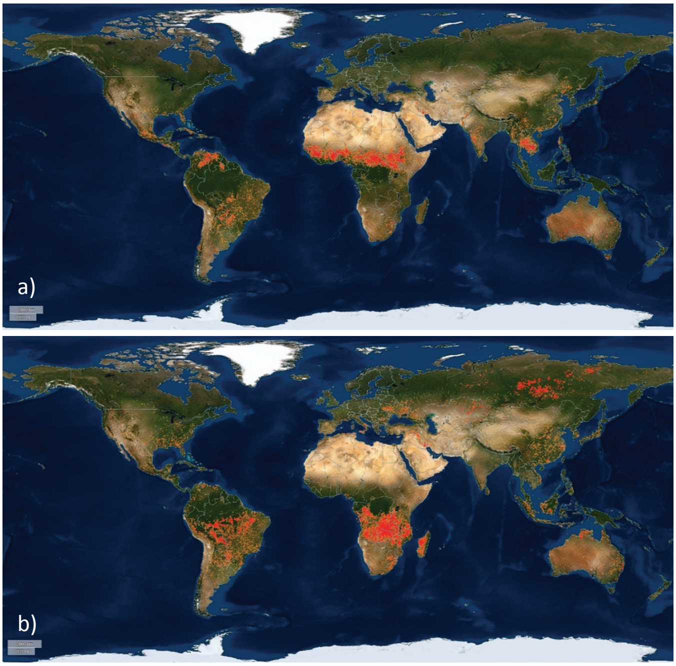

Figure 2. Examples of recent global fire activity (Modis/Terra Gridded Fire Hotspots) for: **(a)** 21–30 January 2019 (https://firms.modaps.eosdis.nasa.gov/map/#t:adv;m:advanced;d:2019-01-21..2019-01-30;l:grids,countries;@-1.5,-1.7,3z), and **(b)** 05–14 August 2019 (https://firms.modaps.eosdis.nasa.gov/map/#t:adv;m:advanced;d:2019-08-05..2019-08-14;l:modis_t,grids,country-outline;@1.7,3.4,3z). Each of these fire maps accumulates the locations of the fires detected by MODIS and images provided by the MODIS Rapid Response System (http://rapidfire.sci.gsfc.nasa.gov/firemaps/?2008011-2008020; accessed 25 October 2021).

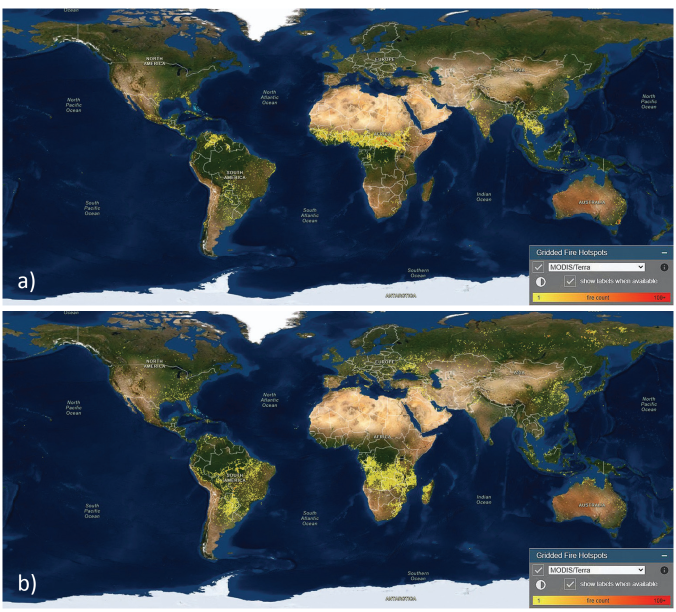

Figure 3. Examples of recent global fire activity (Modis/Terra Gridded Fire Hotspots) for: **(a)** 21–30 January 2020 (https://firms.modaps.eosdis.nasa.gov/map/#t:adv;m:advanced;d:2020-01-21..2020-01-30;l:grids,countries;@-1.5,-1.7,3z), and **(b)** 05–14 August 2020 (https://firms.modaps.eosdis.nasa.gov/map/#t:adv;m:advanced;d:2020-08-05..2020-08-14;l:grids,countries;@-1.5,-1.7,3z). Each of these fire maps accumulates the locations of the fires detected by MODIS and images provided by the MODIS Rapid Response System (http://rapidfire.sci.gsfc.nasa.gov/firemaps/?2008011-2008020; accessed 25 October 2021).

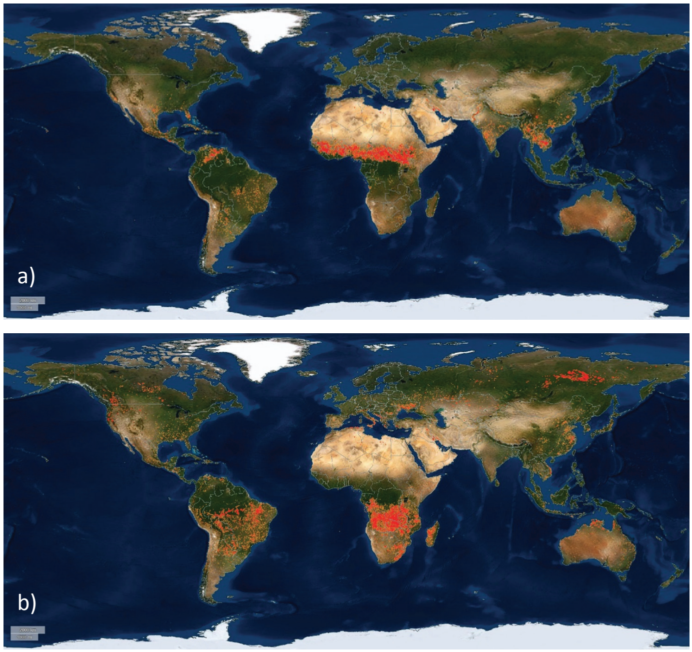

Figure 4. Examples of recent global fire activity (Modis/Terra Gridded Fire Hotspots) for: **(a)** 21–30 January 2021 (https://firms.modaps.eosdis.nasa.gov/map/#t:adv;m:advanced;d:2021-01-21..2021-01-30;l:modis_t,grids,country-outline;@1.7,3.4,3z); and **(b)** 05–14 August 2021 (https://firms.modaps.eosdis.nasa.gov/map/#t:adv;m:advanced;d:2021-08-05..2021-08-14;l:modis_t,grids,country-outline;@1.7,3.4,3z). Each of these fire maps accumulates the locations of the fires detected by MODIS and images provided by the MODIS Rapid Response System (http://rapidfire.sci.gsfc.nasa.gov/firemaps/?2008011-2008020; accessed 25 October 2021).

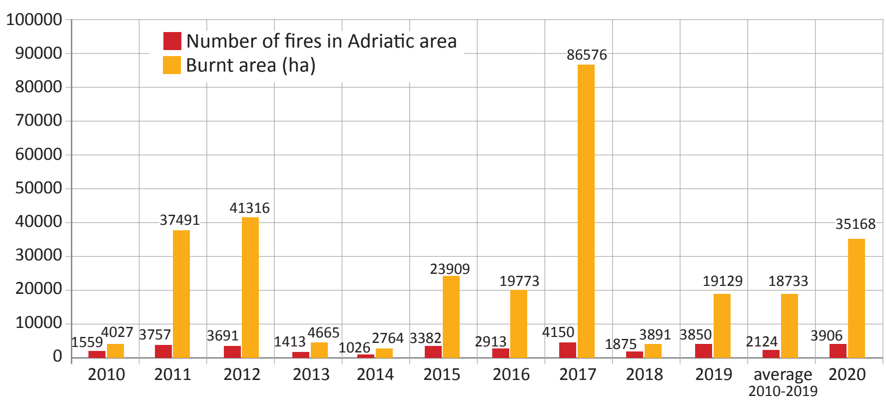

Figure 5. Croatia's coastal belt with the annual number of fires and affected land area in the period from 2010 to 2020. Source: Croatian Firefighting Association (2020).

DISCUSSION

The summer of 2020 fire season can be characterised by having a mean monthly air temperature equal to or higher than the multiyear average (1981 – 2010). In June, the temperature was lower in the southern Adriatic and northern Adriatic, while August was the hottest month. Precipitation was unevenly distributed, higher than average in some places, while others were marked by a precipitation deficit. This indicates the localised and torrential character of precipitation that is not uncommon in the summer months, when vertical cloud development is typical and can result in heavy rains. In September, a period of above average temperatures was recorded, with rain at the start and end of the month, while in October rain was frequent and even heavy (Mokorić et al. 2020). Following such weather conditions, that year's summer fire season was not extreme, given the lack of pronounced, long-term heat waves that cause the drying of the deepest soil layers. However, relatively unfavourable weather conditions in that season were seen in the occasional occurrence of strong winds, such as on 7 July when the Adriatic was affected by strong to gale-force Bora (northeasterly) wind with gale gusts, which is an extraordinary occurrence in the summer (Mokorić et al. 2020). Figure 6 shows the fire threat conditions in the Croatian bioclimatic area in 2020, while Figure 7 shows the deviations from the ten-year mean of the monthly threat class of vegetation fires according to Mokorić et al. (2020). An analysis of the fire weather index (FWI) for the start and spread of vegetation fires categorised into a threat class by colour shows that the seasonal threat class for summer was moderate (June, July, August) in the northern Adriatic and continental Croatia in Figure 2. A high threat (red) was present for the central and southern Adriatic areas. If these data are compared with trends in Europe, the situation cannot be considered favourable, as over the period 1980–2012, the FWI significantly increased for southern and eastern Europe, and for Europe as a whole (European Commission 2018, 2020).

Comparison of the monthly mean vegetation fire threat class for the 2020 summer season (June – August) with the ten-year average (2003 – 2012) in Figure 7 shows that the mean class was significantly lower than average in the northern Adriatic and mountainous Croatia, and slightly higher than average for most of southern Croatia. Several synoptic situations were detected in the 2020 fire season that could negatively influence a vegetation fire, since in addition to the associated strong winds with changing

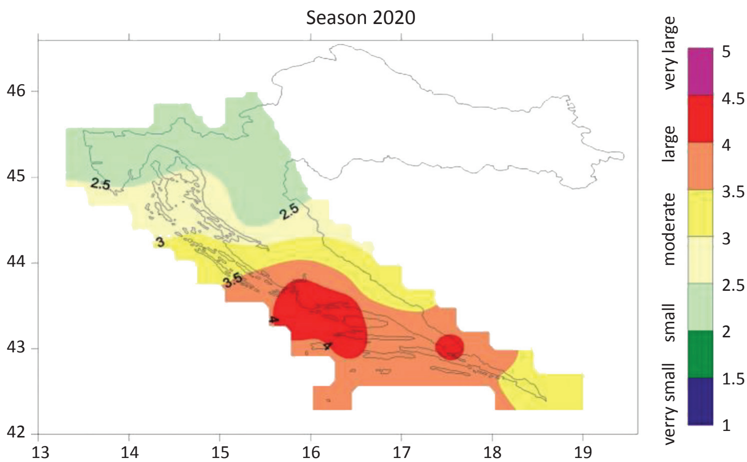

Figure 6. Mean monthly vegetation fire threat class for the 2020 fire season by Mokorić et al. (2020).

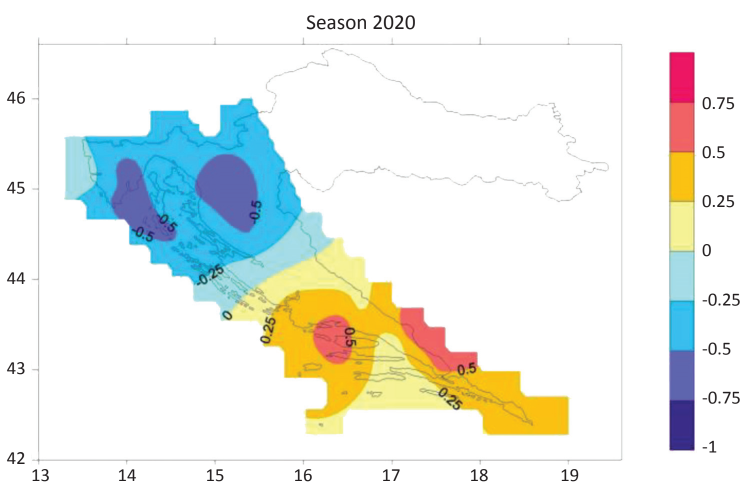

Figure 7. Deviations from the monthly mean vegetation fire threat class for the 2020 fire season, in comparison with the ten-year average (period 2003–2012) by Mokorić et al. (2020).

direction and the sparse and non-uniform distribution of precipitation, there were also appearances of instabilities within the relatively dry air mass. When the threat class was high or very high in combination with this described synoptic situation, then warnings were issued based on specific criteria with regard to the speed and direction of wind shifts, and the values of the Haines index as an indicator of dry air instability.

From 1980 to 2012, the FWI increased for Europe as a whole particularly in southern and eastern Europe (Venäläinen et al. 2014). The fact that the burnt area of the Mediterranean decreased over the same period suggests that fire management and suppression efforts in this region had some effect (Turco 2016). This is also seen in the data for Croatia, particularly for the 2020 fire season. Figure 8 shows the average burnt area, where the trends are positive in the sense of a reduction of the average burnt area over the past decade, with one prominent deviation in 2017, which was an above-average warm and dry year.

Figure 9 shows the clear influence of humans, regarding the intentional burning, with the aim of improving soil fertility. This is performed outside the fire season, usually in February and especially in March. These fires are associated with agricultural areas or on lands with non-forest vegetation. In some isolated cases, these fires can burn for days. From the aspect of combustible materials, these fires do not have a strong potential to spread, nor are they characterised by the same intensity as forest fires during the forest season. However, the practice of burning these fires has remained a common practice in the Mediterranean bioclimatic area. For example, most of the damage in Bosnia and Herzegovina occurred early in the 2019 season, between February and April. In total there were 144 fires over 30 ha mapped in the year, which burnt a total of 28,937 ha. The distribution of burnt area by land cover shows that most of the land was forest/wooded land (60%), followed by natural land (27%) and agricultural land (13%) (European Commission 2020). These trends can be a serious threat to fire spreading during the warmer part of the year, and to the further use of the agricultural land in the intended way. Under controlled conditions, these fires undoubtedly have a positive effect on arable lands, though it is important that they are not burnt during the fire season (Eales et al. 2018). New agricultural policies should be better aligned with forest and fire policies, promoting, for instance, livestock grazing and agroforestry whenever possible with other efficient tools to reduce fuel

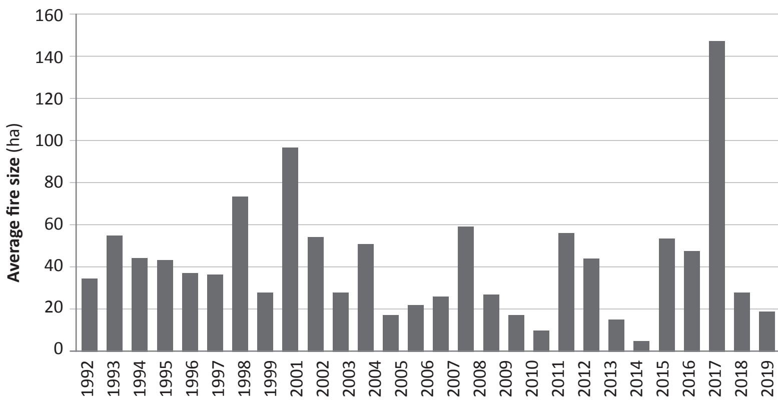

Figure 8. Average fire size in Croatia from 1992 to 2019 (Source: Directorate for Forestry, Hunting and Wood Industry, Ministry of Agriculture, Croatia; National Protection and Rescue Directorate, Croatia).

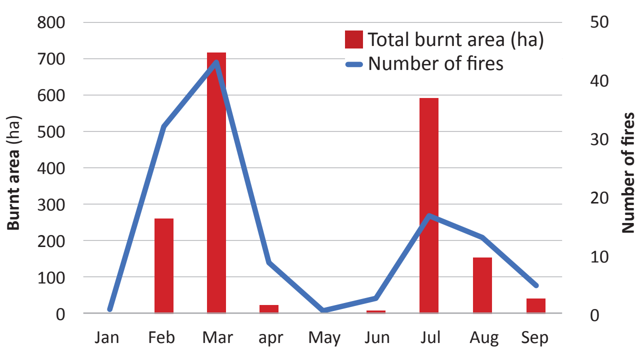

Figure 9. Monthly distribution of fires in 2019 (Source: Directorate for Forestry, Hunting and Wood Industry, Ministry of Agriculture, Croatia; National Protection and Rescue Directorate, Croatia).

biomass, such as prescribed burning (Ganteaume et al. 2021). Some authors have explained this technique in the following way. Prescribed burning is a land management technique that uses fire in a planned and supervised way over a predefined zone, without endangering adjacent areas. This ancient practice, often employed to clear land for agricultural and pastoral use, has become a modern tool for wildfire prevention by controlling the level of combustible materials on the ground. Prescribed burning is also used to maintain landscapes and open environments, to improve the habitat of fauna (particularly hunted species), to regenerate land in the aftermath of farming and to carry out thinning operations (Delattre 1993, Goldammer 1994). In Croatian Adriatic coast there are still problems with abandoned terraces as fuel storage of forest fuel.

Prescribed burning for wildlife in southern Europe is far less developed than in other areas of the world, and the environmental implications remain poorly understood (Fernandes et al. 2013).

Almost all Mediterranean countries have adopted measures to increase public awareness of forest fires, and the focus is nearly always put on accidentally caused fires. The target is the adult public - residents or tourists - located in areas of risk. School children are also the target of specific programmes (Calabri 1986); in Croatia there is a very useful programme of Croatian Agrometeorological Society called Agrometeorological mosaic for youth (2016 – until nowadays): "The fire, fierce enemy of the forest", including an animated film and a comic "The fire is not a joke" (https://www.hagmd.hr/projekti/2016/94).

According to Alexandrian et al. (2000), the management of forests for the prevention of fires is carried out in a very similar way throughout the Mediterranean basin. It is based on the creation of tracks, firebreaks and water reserves. The estimated social and economic costs of wildland fire are known to be huge, but are largely unquantified (FAO 2007 in Flannigan et al. 2009). Direct suppression costs would easily be in the many billions of dollars. Wildland fires can have many serious negative impacts on human safety (Viegas 2002).

Furthermore, for the countries in southern Europe, particularly Mediterranean countries, it is necessary to note the climate factor that is critical for the fire regime. According to some authors (Moreira et al. 2012), abandoned lands and forestation of former agricultural lands are the main reason for the accumulation of combustible materials, and a potential connection of larger areas in the landscape to create fires of greater dimensions. This claim, however, is only partly justified, since it only pertains to abandoned and overgrown agricultural lands. For forest lands or agricultural lands that have been directly planted or have indirectly become forested (through succession), there is an important difference. Forest plantations, most often pine plantations, just as perennial agricultural crops, contain higher quantities of combustible materials. However, it is key whether or not those forest plantations have an intended goal, as prescribed in the forest management plan. With a specific goal and management in those plantations, forestry silvicultural works (cleaning and thinning) must be performed. These works ensure high quality stands, with lower quantities of dry dead fuel. When these forest stands are further opened with forest roads and trails, this can mean an important difference in relation to those areas that are left to natural succession and to overgrown agricultural lands.

Adequate fire protection requires measures of surveillance and monitoring using new technologies, including remote sensing (satellite monitoring, video surveillance, thermal cameras, unmanned aerial vehicles, e.g., drones). The use of other new technology, such as geographic information system (GIS) and remote sensing have largely facilitated the monitoring and supervision of fires. GIS is a computer system that combines geographic data with other types of data and displays them on maps. The use of GIS increases the speed and quantity of data processing and display. Remote sensing is a method of collecting and interpreting information on distant areas without the need for any physical contact. Aircraft, satellites and space probes are typical platforms for observation in remote sensing.

Operational methods of mapping burnt areas include ground-based or airborne global positioning system (GPS) surveys and interpretation of post-fire aerial photography or satellite imagery (Kolden and Weisberg 2007, Zell and Kafka 2012). According to Thomas and McAlpine (2010), fire detection could be established by passive detection (based on the random travels of the public over the area of interest), organised detection (systematic detection designed by fire-management organisations to locate fires where they occur), fixed detection (takes the form of fire towers or lookouts strategically positioned across a landscape) and aerial detection (involves flying aircraft along set lines across a landscape searching for fires, where planes fly at altitudes of 600–1500 m at specific times of the day to maximise detection probability).

MODIS (Moderate Resolution Imaging Spectrometer) is a highly sensitive instrument carried on the Terra and Aqua satellites. This instrument records the Earth's surface in a range of wavelengths from 0.4 to 14.4 µm in 36 channels, with a spatial resolution of 250, 500 or 1000 m. MODIS detects fires based on an algorithm that uses radiation data in the 11 µm (precisely 11.03 µm) wavelength channel and the T11 temperature channel (Figure 2, 3, 4), and the 4 µm (precisely 3.959 µm) wavelength channel with accompanying T4 temperature channel. The use of new technology is desirable in all cases, even though it is unable to influence the number of fires, because the dominant factors continue to be climate and human activity. The justification of their use is seen in the rapid detection of fires, enabling a quick setting up of fire protection systems, a rapid response and arrival to the site and localisation of the fire, which ensures minimal burnt area. According to the data of the Croatian Firefighting Association (for 2020), the average fire-fighting session for vegetation fires in the Mediterranean part of Croatia is approximately 3 hours and 37 minutes, and for Croatia as a whole it is approximately 2 hours and 33 minutes. It is also important to state that this includes the time until the complete extinguishing of the fire, which also includes the time of guarding the entire fire area after localisation, when the majority of the fire-fighting personnel have returned to the station or rerouted to other fire sites. In a preventive sense, fire modeling and the development and integration of fire behavior, fuel treatment and fire suppression strategies into one model have recently been present (Konoshima et al. 2008, Bettinger 2010).

CONCLUSIONS

In the Mediterranean bioclimatic area, wildfires are primarily caused by human activities and climatic conditions. In years marked with extreme drought or extremely hot summers, these conditions are correlated with a high number of fires and large areas affected by the fire. In Croatian Adriatic 2020 fire season was above average in comparison with the period of 2010 to 2019, indicating that there were more fires and more area burnt than during the ten-year average. However, burnt area index (BAI) is less than five-year average (2015-2019). The key point was probably the year 2017. with the extremely hot summer and drought.

Even under such conditions, the fire season can be well organised with systematic reaction to fire. This is primarily facilitated by the use of new remote sensing technology with the existing systems of surveillance and monitoring, and the application of technical works in agriculture and forestry that enable openness and access to large complexes, and reduce the quantity of dry combustible matter. Forest fires are essential for many global ecosystems, and a smaller part of the forest ecosystem needs fire for forest renewal, and in the control of insect infestation and disease. In fire prevention, prescribed burning is a method used by firefighters to reduce the build-up of fuel to reduce future fire intensity. However, frequent and large-scale fires have negative impacts on air quality and water quality, biodiversity, soil and landscape aesthetics. Forest fires also threaten the attempts to mitigate climate change, due to the release of large amounts of greenhouse gases, and they can also cause economic damage and loss of human life in populated areas. Fire risk depends on many factors including climatic conditions, which is particularly significant in the Mediterranean region. Climate change is expected to have a strong impact on forest fire risk in Europe, as recognised by the EU strategy on adaptation to climate change (European Commission 2021).

Author Contributions

Conceptualization, DB; methodology,TD and DB; validation RR and DB; formal analysis, MA and DB; investigation, DB; resources, DB and TD; writing—original draft preparation, DB; writing—review and editing, DB and MA; visualization, MA; supervision, TD and RR. All authors have read and agreed to the published version of the manuscript.

Funding

The study did not receive funding.

Acknowledgments

Authors would like to thank to Croatian Firefighting Association for administrative support.

Conflicts of Interest

The authors declare no conflict of interest.

REFERENCES

Alexandrian D, Esnault F, Calabri G, 1999. Forest fires in the Mediterranean area. *Unasylva (FAO)* 50(197): 35-41.

Ayanz JSM, Schulte E, Schmuck G, Camia A, Strobl P, Liberta G, Giovando C, Boca R, Sedano F, Kempeneers P, McInerney D, Withmore C, Santos de Oliveira S, Rodrigues M, Durrant T, Corti P, Oehler F, Vilar F, Amatulli G, 2012. Comprehensive Monitoring of Wildfires in Europe: The European Forest Fire Information System (EFFIS). In: Tiefenbacher J (ed) Approaches to Managing Disaster: Assessing Hazards, Emergencies and Disaster Impacts. IntechOpen, London, UK, 87-108. https://doi.org/10.5772/28441.

Barčić D, Dubravac T, Vučetić M, 2020. Potential Hazard of Open Space Fire in Black Pine Stands (*Pinus nigra* J.F. Arnold) in Regard to Fire Severity. *South-east Eur For* 11(2): 161-168. https://doi.org/10.15177/seefor.20-16.

Bettinger P, 2010. An Overwiev of Methods for Incorporating Wildfires into Forest Planning Models. *Mathematical and Computational Forestry and Natural Resources Sciences* 2(1): 43-52.

Bond WJ, Keeley JE, 2005. Fire as a global "herbivore": the ecology and evolution of flammable ecosystems. *Trends Ecol Evol* 20(7): 387-394. https://doi.org/10.1016/j.tree.2005.04.025.

Calabri G, 1986. Public information and education for forest fire prevention. In: ECE/FAO/ILO Seminar on Methods and Equipment for the Prevention of Forest Fires. Inst. Nac. Conservación de la Naturaleza (ICONA), Madrid, Spain, pp. 180-183.

Croatian Firefighting Association, 2020. Annual report on execution of activity programmes and special fire protection measures of interest for the Republic of Croatia in 2020. 31 p. [In Croatian].

Delač D, Kisić I, Bogunović I, Pereira P, 2021. Temporal impacts of pile burning on vegetation regrowth and soil properties in a Mediterranean environment (Croatia). *Sci Total Environ* 799: 149318. https://doi.org/10.1016/j.scitotenv.2021.149318.

Delač D, Kisić I, Zgorelec Z, Perčin A, Pereira P, 2022. Slash-pile burning impacts on the quality of runoff waters in a Mediterranean environment (Croatia). *Catena* 218: 106559. https://doi.org/10.1016/j.catena.2022.106559.

Delattre E, 1993. Évaluation des actions communautaires: vers une coopération internationale. *Incendies de forêts en Europe du Sud*, 271.

Directorate for Forestry, Hunting and Wood Industry, 2019. National Protection and Rescue Directorate, Ministry of Agriculture, Croatia.

Dove NC, Hart SC, 2017. Fire reduces fungal species richness and in situ mycorrhizal colonization: a meta-analysis. *Fire Ecol* 13(2): 37-65. https://doi.org/10.4996/fireecology.130237746.

Eales J, Haddaway NR, Bernes C, Cooke SJ, Jonsson BG, Kouki J, Petrokofsky G, Taylor J, 2018. What is the efect of prescribed burning in temperate and boreal forest on biodiversity, beyond pyrophilous and saproxylic species? *Environ Evid* 7(19): 2-33. https://doi.org/10.1186/s13750-018-0131-5.

FAO, 2006. Fire management – global assessment. Food and Agriculture Organization of the United Nations, Rome, Italy, 151 p.
Fernandes PM, Davies GM, Ascoli D, Fernández C, Moreira F, Rigolot E, Stoof CR, Vega JA, Molina D, 2013. Prescribed burning in southern Europe: developing fire management in a dynamic landscape. *Front Ecol Environ* 11(1): 4-14. https://doi.org/10.1890/120298.
Flannigan MD, Krawchuk MA, de Groot BWJ, Wotton BM, Gowman LM, 2009. Implications of changing climate for global wildland fire. *Int J Wildland Fire* 18(5): 483-507. https://doi.org/10.1071/WF08187.
Ganteaume A, Barbero R, Jappiot M, Maillé E, 2021. Understanding future changes to fires in southern Europe and their impacts on the wildland-urban interface. *Journal of Safety Science and Resilience* 2(1): 20-29. https://doi.org/10.1016/j.jnlssr.2021.01.001.
Goldammer JG, 1994. Forest fires in Southern Europe. Overview of EC actions: Towards an international cooperation? *Int Forest Fire News* 11: 38.
Gómez-González S, Ojeda F, Fernandes PM, 2018. Portugal and Chile: longing for sustainable forestry while rising from the ashes. *Environ Sci Policy* 81: 104–107. https://doi.org/10.1016/J.ENVSCI.2017.11.006.
Konoshima M, Montgomery CA, Albers HJ, Arthur JI, 2008. Spatial endogenous fire risk and efficient fuel management and timber harvest. *Land Ecom* 84: 449-468.
Keeley JE, Bond WJ, Bradstock RA, Pausas JG, Rundel PW, 2011. Fire in Mediterranean ecosystems: ecology, evolution and management. Cambridge University Press, Cambridge, UK, 522 p. https://doi.org/10.1017/CBO9781139033091.
Keeley JE, Syphard AD, 2017. Different historical fire-climate patterns in California. *Int J Wildland Fire* 26(4): 253-268. https://doi.org/10.1071/WF16102.
Kolden CA, Weisberg PJ, 2007. Assessing accuracy of manually mapped wildfire perimeters in topographically dissected areas. *Fire Ecol* 3: 22-31. https://doi.org/10.4996/FIREECOLOGY.0301022.
Koo E, Pagni P, Weise DR, Woycheese JP, 2010. Firebrands and spotting ignition in large-scale fires. *Int J Wildland Fire* 19(7): 818-843. https://doi.org/10.1071/WF07119.
Littell JS, McKenzie D, Peterson DL, Westerling AL, 2009. Climate and wildfire area burned in western U.S. ecoprovinces, 1916–2003. *Ecol Appl* 19(4): 1003-1021. https://doi.org/10.1890/07-1183.1.
Mokorić M, Kalin L, Hojsak T, 2020. Šumski požari. Analiza požarne sezone 2020. godine. Služba za vremenske analize i prognoze, DHMZ. Available online: https://radar.dhz.hr/duzs/analiza/2020.pdf (15 Jun 2022). [in Croatian].
Moreira F, Arianoutsou M, Vallejo R, de las Heras J, Corona P, Xanthopoulos G, Fernandes P, Papageorgiou K, 2012. Setting the Scene for Post-Fire Management. In: Moreira F, Arianoutsou M, Corona P, De las Heras J (eds) Post-Fire Management and Restoration of Southern European Forests, Managing Forests Ecosystems. Springer, Dordrecht, Netherlands, 19 p. https://doi.org/10.1007/978-94-007-2208-8_1.
Moreira F, Ascoli D, Safford H, Adams MA, Moreno JM, Pereira JMC, Catry FX, Armesto J, Bond W, González ME, Curt T, Koutsias N, McCaw L, Price O, Pausas JG, Rigolot E, Stephens S, Tavsanoglu C, Vallejo VR, Van Wilgen BW, Xanthopoulos G, Fernandes PM, 2020. Wildfire management in Mediterranean-type regions: paradigm change needed. *Environ Res Lett* 15: 011001. https://doi.org/10.1088/1748-9326/AB541E.
Martínez J, Vega-García C, Chuvieco E, 2009. Human-caused wildfire risk rating for prevention planning in Spain. *J Environ Manage* 90: 1241-1252. https://doi.org/10.1016/J.JENVMAN.2008.07.005.
Mouillot F, Field CB, 2005. Fire history and the global carbon budget: a 1°× 1° fire history reconstruction for the 20th century. *Global Change Biol* 11(3): 398-420. https://doi.org/10.1111/J.1365-2486.2005.00920.X.
Ojeda F, 2020. Pine afforestation, herriza and wildfire: a tale of soil erosion and biodiversity loss in the Mediterranean region. *Int J Wildland Fire* 29(12): 1142-1146. https://doi.org/10.1071/WF20097.
Pausas JG, Llovet J, Rodrigo A, Vallejo R, 2008. Are wildfires a disaster in Mediterranean basin? – A review. *Int J Wildland Fire* 17(6): 713-723. https://doi.org/10.1071/WF07151.
Syphard AD, Keeley JE, Pfaff AH, Ferschweiler, K, 2017. Human presence diminishes the importance of climate in driving fire activity across the United States. *P Natl Acad Sci USA* 114(52): 13750–13755. https://doi.org/10.1073/PNAS.1713885114.
European Commission, 2018. Commission Staff Working Document — Evaluation of the EU Strategy on adaptation to climate change accompanying the document 'Report from the Commission to the European Parliament and the Council on the implementation of the EU strategy on adaptation to climate change', 225 p.
European Commission, Joint Research Centre, 2020. Forest fires in Europe, Middle East and North Africa 2019. Publications Office, Luxembourg. https://doi.org/10.2760/468688.
European Commission, 2021. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions 'Forging a climate-resilient Europe — the new EU strategy on adaptation to climate change'.
Thomas PA, McAlpine R, Hobson P, 2010. Fire in the Forest. Cambridge University Press, Cambridge, UK, 225 p. https://doi.org/10.1017/CBO9780511780189.
Turco M, 2016. Decreasing fires in Mediterranean Europe. *PLoS ONE* 11(3): e0150663. https://doi.org/10.1371/journal.pone.0150663.
Vallejo VR, Arianoutsou M, Moreira F, 2012. Fire Ecology and Post-Fire Restoration Approaches in Southern European Forest Types. In: Moreira F, Arianoutsou M, Corona P, De las Heras J (eds) Post-Fire Management and Restoration of Southern European Forests. Managing Forests Ecosystems vol. 24. Springer, Dordrecht, Netherlands, pp. 93-119. https://doi.org/10.1007/978-94-007-2208-8_5.
Van der Werf GR, Randerson JT, Giglio L, Collatz GJ, Kasibhatla PS, Arellano AF Jr, 2006. Interannual variability in global biomass burning emissions from 1997 to 2004. *Atmos Chem Phys* 6(11): 3423–3441. https://doi.org/10.5194/acp-6-3423-2006.
Van Wagner CE, Pickett TL, 1985. Equations and FORTRAN Program for the Canadian Forest Fire Weather Index System. Forestry Technical Report 33, Canadian Forestry Service, Petawawa National Forestry Institute, Chalk River, Ontario, Canada, 18 p.
Van Wagner CE, 1987. Development and structure of the Canadian forest fire weather index system. Forestry Technical Report No 35, Canadian Forestry Service, Ottawa, Canada, 35 p.
Van Wagner CE, 1993. Prediction of crown fire behavior in two stands of jack pine. *Can J Forest Res* 23(3): 442-449. https://doi.org/10.1139/x93-062.
Venäläinen A, Korhonen N, Hy**värinen O, Koutsias N, Xystrakis F, Urbieta IR, Moreno JM, 2014.** Temporal variations and change in forest fire danger in Europe for 1960–2012. *Nat Hazard Earth Sys* 14(6): 1477-1490. https://doi.org/10.5194/nhess-14-1477-2014.
Viegas DX, 1998. Forest fire propagation. *Phil Trans R Soc A* 356(1748): 2907-2928. https://doi.org/10.1098/RSTA.1998.0303.

Viegas DX, 2002. Proceedings of the IV International Conference on Forest Fire Research & Wildland Fire Safety Summit. Luso, Coimbra, Portugal, 18-23 November 2002.

Zell D, Kafka V, 2012. Mapping recent fire history in Wapusk National Park and greater park ecosystem with Landsat imagery. Parks Canada Agency, National Fire Centre, Gatineau, QC, Canada. Available online: https://sites.ualberta.ca/~wildfire/2012/Posters/Zell.pdf (15 June 2022).