

Article

Natural Hazard Impact in Protected Areas for Resilience Management: The Case of Wildfires in the Basilicata Region

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Abstract: Wildfires represent a significant threat to protected areas around the world. This threat has become even more pronounced in recent years due to climate change. These fires can destroy, among other things, natural habitats, cause a loss of biodiversity, and affect air quality. In addition, they can have a significant economic impact on countries that depend on tourism and protected area activities. In this context, Geographic Information Systems (GIS) can provide an important solution for fire management in protected areas. In this case study, the Basilicata region (Southern Italy) was taken as an example where data on protected areas and fire events are freely accessible and constantly updated. By exploiting several interoperable GIS tools, it was possible to perform a complex geospatial analysis that provided important information for sustainable and resilient land use planning. In particular, areas with the highest frequency of fires within or close to protected areas emerged, which can therefore be attended to at different planning levels. In addition, in general, the work has made it possible to implement simple methodologies of relational analysis between fires and protected areas that can be easily employed in administrative settings so as to make the territory more resilient to the expected increase in fires due to climatic changes.

Keywords: management; GIS; wildfires; Basilicata region; sDSS; geospatial fire analysis



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1. Introduction

In conservation biology, one of the main challenges is finding a balance between preserving natural landscapes and optimizing conservation efforts [1]. To address this challenge, the European Parliament adopted the Habitats Directive in 1992, also known as the Directive for the Conservation of Natural Habitats and of Wild Fauna and Flora [2]. This directive established the Natura 2000 network, which aims to maintain biological diversity while also considering economic, social, cultural, and regional aspects of sustainable development. The network includes Sites of Conservation Interest (SCIs) that host plant communities and species of flora and fauna listed in Annex I, II, IV, and V of the policy. The Natura 2000 network also incorporates Special Protection Areas (SPAs) previously designated under the European Bird Directive for the protection of bird species.

The Natura 2000 system in Italy consists of 2062 Sites of Community Interest (SCIs) and Special Protection Areas (SPAs), covering an area of about 18.7 million hectares, or 18.5 percent of Italy's land area. Among these sites, 34.5 percent are located in mountains, 23.3 percent in plains, and 42.2 percent in hills. Natura 2000 sites in Italy host a wide variety of natural habitats, such as forests, meadows, lakes, rivers, coastlines, dunes, and cliffs, which provide habitats for a wide range of flora and fauna species. In total, more than 4500 plant species and over 11,000 animal species have been identified, including some rare or endemic species [3]. However, Natura 2000 sites in Italy also face many threats, including urbanization, intensive agriculture, tourism, and infrastructure. In particular, fires are a major threat to these sites, with about 9000 fires occurring each year in Italy, often negatively impacting the biodiversity of Natura 2000 sites [4].

On average, around 450,000 hectares of natural and semi-natural areas are affected by wildfires every year in the Euro-Mediterranean (EU-MED) region, resulting in significant economic and environmental damages and the loss of human life [5]. The Mediterranean region has become a hotspot for wildfires due to climate variability, with extreme wildfire events with high energy release increasing in recent years, which exceed the control capacity and cause significant environmental, social, and economic impacts [6].

Moreover, the EU-MED region has experienced significant changes in land use, socio-economic transformations, and fire management processes in recent decades, which have heavily influenced the variability of fire regimes and worsened the phenomenon [7]. To effectively mitigate and adapt to these changes, it is crucial to assess the impact of climate change on modifications to the fire regime, including danger, risk, occurrence, and propagation. Such an assessment represents a fundamental knowledge base for implementing mitigation and adaptation measures [8].

In recent decades, many of Europe's best-preserved areas have been designated as protected sites within the Natura 2000 network. Unfortunately, the majority of forest fire damage in Natura 2000 areas has been observed in Euro-Mediterranean countries [9,10]. According to estimates, roughly 80,000 hectares of Natura 2000 sites have burned every year between 2000 and 2012, with Spain and Portugal being the most impacted nations. In some years, peak burns have surpassed 100,000 hectares, largely due to massive fires. For example, in 2021, Italy and Spain together accounted for 45% of the total burned area in protected regions. [11–13].

Although the problem of fire risk in protected areas is well known, protected area and firefighting planning strategies often move separately or implement synergies only at the time of the most critical period. But, for planning to make protected area territories more resilient to fire damage, it is necessary to implement an integrated approach that takes into account not only the possible causes but also statistical analysis, forecasting, and vulnerability protection at different spatiotemporal scales [14–16].

To begin to investigate the relationship between fire and protected areas for the purpose of more resilient land management, a preliminary analysis was carried out in the Basilicata Region (Southern Italy) using a GIS approach based on open data produced by public authorities so as to begin to lay the groundwork for the implementation of spatial decision support tools to reduce the impact of fire on natural habitats at greater risk [17]. Among the protected areas, the Natura 2000 network was chosen to be considered because it has a more focused approach to the conservation of biodiversity and natural habitats, while national parks have a broader approach to the protection of natural and cultural heritage, with the aim of also developing sustainable tourism and recreational activities.

One of the starting points was the use of open data. Indeed, their importance in achieving the SDGs (sustainable development goals) was recognized. The provision of vital information on natural resources, government operations, public services, and population demographics through open data can play a crucial role in accomplishing sustainable development goals. By utilizing these insights, governments can prioritize their agendas and identify the most effective approaches to tackle national issues [18].

2. Materials and Methods

2.1. Study Area

Basilicata region (Figure 1) presents itself as a region of strong orographic contrasts. The area covered by the regional territory is 9992.24 km², of which 46.8 percent is mountainous, 45.2 percent is hilly, and only 8 percent has flat morphology. The region has a total of 58 Natura 2000 sites, covering an area of more than 117,000 hectares (about 18% of the regional territory). These include 29 Sites of Community Importance (SCIs) and 26 Special Protection Areas (SPAs), which have been identified on the basis of scientific and biogeographical criteria. The Natura 2000 Network in Basilicata is home to numerous rare or endangered animal and plant species, such as the otter, Apennine wolf, golden eagle, Lucanian chamois, and Palinuro primrose. Natura 2000 Network protected areas

in Basilicata also play an important role for the local economy, thanks to the tourism and land-use activities that take place there [3].

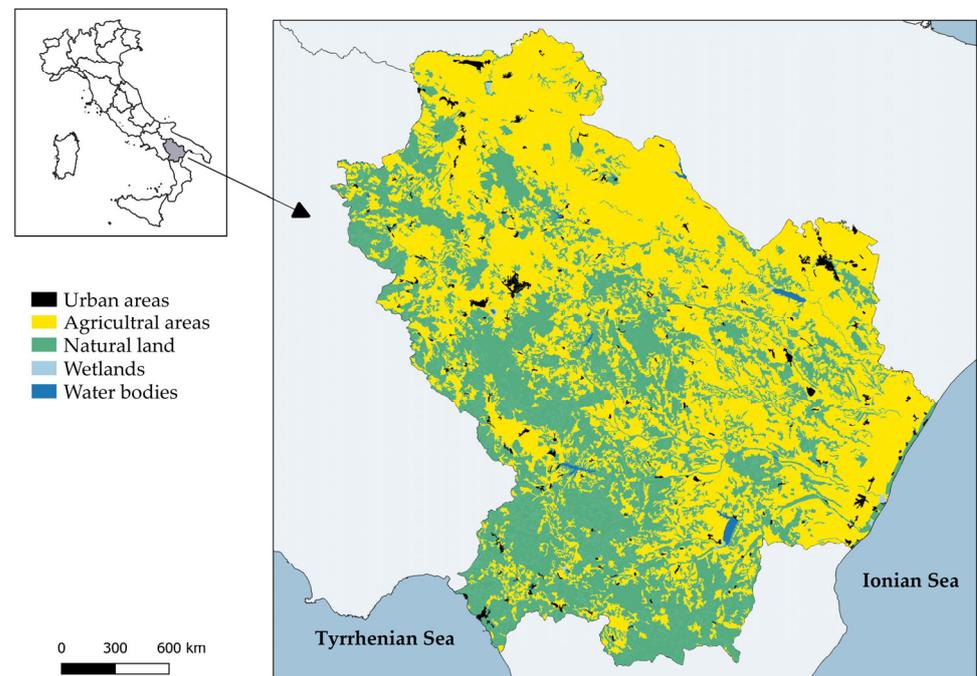


Figure 1. Location of study area and land use classification.

Regarding the trend of the fire phenomenon, in the three-year period, 2015–2017, in Basilicata, there was, in general, an increase in the incidence of the forest fire phenomenon compared to the period 2012–2014, which in turn increased compared to the previous three-year period, 2009–2011. The average values, in fact, are affected by the trend of the year 2017, which was the second worst in the last 15 years after 2007, followed by 2012. In the same range of values used, there are also those for 2016, in which the lowest values of the last 15 years were recorded.

2.2. Datasets

Any activity involving fire and protected area planning and monitoring needs an accurate and easily usable spatial database [19].

Many studies are based on the use of small-scale datasets such as EFFIS [20,21] datasets, but these often contain numerous errors because the accuracy is not validated in the field. Therefore, in order to meet the increasing need for the use of spatial data, it is important to use data that are as accurate as possible and at a scale appropriate for different levels of planning. At the European level, each nation has its own regulations. In Italy, the regions, in cooperation with the land control authorities, create the cadaster of fire-affected areas, which is based on national regulations. This cadaster makes it possible to identify the areas burned each year. In addition, some regions, such as Basilicata, make these data freely available online with a CC 4.0 license, in vector format providing an essential tool for sustainable land planning [22]. The data are provided via a download service (WFS—Web Feature Service) for data of forested areas and pastures traversed by fire from 2004 until 2022 (Figure 2). New geographic GIS technologies for both surveying and data management have made fire perimeter operations faster than those in the past [23].

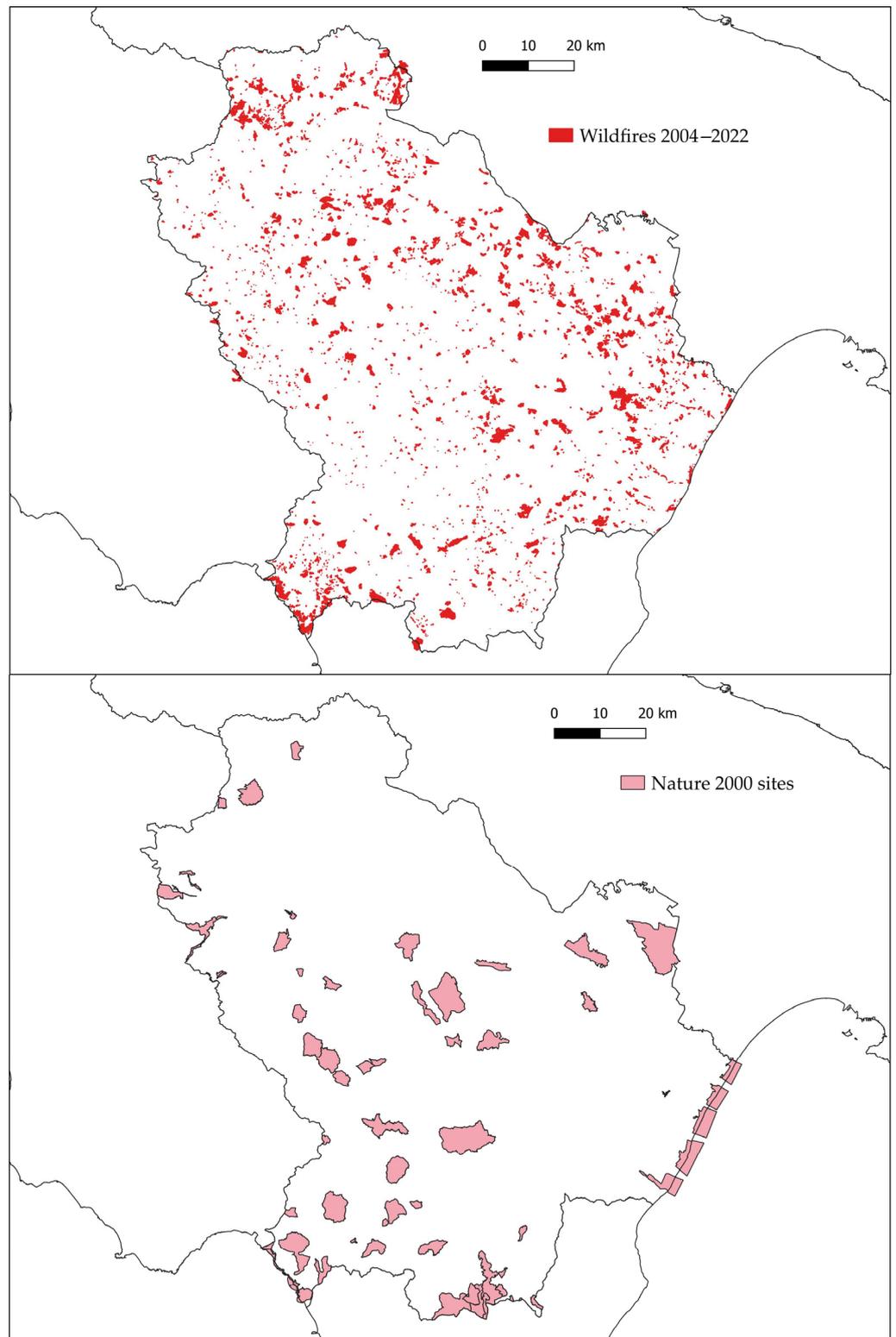


Figure 2. Wildfires localization between 2004 and 2022 (**top**) and Natura 2000 sites (**bottom**) in Basilicata region.

Open data provided by the Basilicata Region were also used for protected areas of the Natura 2000 network. In particular, we focused only on Sites of Community Importance (SCI) and protected habitats (Figure 2).

Natural habitats found in Natura 2000 sites are classified using the classification of the European Habitat Classification System, known as EUNIS (European Nature Information System). This system was developed to provide a standardized and harmonized classification of natural habitats found in Europe, and it allows for the precise identification and description of habitats under conservation.

The EUNIS classification is based on ecological criteria, i.e., the floristic and faunal composition, soil characteristics, and climatic conditions of the habitats. The classification involves the use of a series of hierarchical categories, starting from the broadest units (Level I) to the most detailed units (Level IV).

2.3. Spatial Analysis Implementation

After data collection (Figure 3), in order to implement the first spatial analyses that are useful for creating secondary databases, some basic features of QGIS 3.18 software were employed. The purpose of creating these secondary databases is to create supporting or starting data for fire monitoring in Natura 2000 protected areas and thus provide tools that can be used for a more resilient planning of territories, and in this case, of the Basilicata region. The basic spatial analyses that have been used are user-friendly, so they can be used by any technician working in public offices dealing with protected areas. First of all, the GIS approach allows the easy management of spatial data and especially makes simple but very useful statistics in fire planning [24].

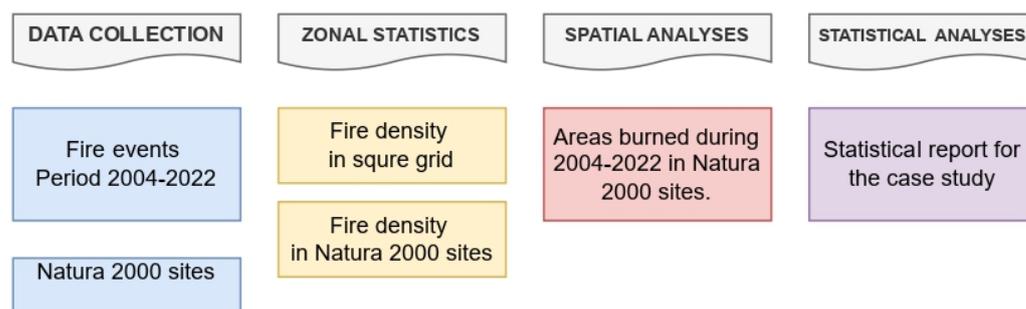


Figure 3. Workflow to describe the steps in the research.

The first operation performed was that of making a square-mesh grid (of 5 km sides) to aggregate the intervening fires from 2004 to 2022. In general, the use of a grid to represent spatial data in the environmental field makes it easier and faster to analyze and interpret geographic information while providing detailed and uniform data visualization. It also provides an objective method for comparing data across time and space [25].

Next, from the spatial query of Natura 2000 sites and burned areas, it was possible to identify the sites that had a higher number of fires during the period under consideration. For this analysis, we reasoned at the level of the entire protected area because, for management and planning purposes, each is managed by a different public agency, and therefore only the areas affected by fire were not analyzed.

In addition, the intersection of fire-affected areas and Natura 2000 sites was performed. This analysis, compared to the previous one, is especially useful for planning and environmental protection purposes as it allows us to discriminate, in detail, the areas with a higher historical fire occurrence and thus assess their post-fire vegetation dynamics.

Finally, the perimeters of the individual habitats were intersected with the dataset created by the previous operation so as to identify even more precisely which habitats are the most interesting from a conservation point of view that have been most affected by fire and thus need to be brought to the attention of targeted conservation strategies.

3. Results and Discussion

All the results obtained from these analyses are based on fires that occurred between 2004 and 2022. As a preliminary work to test and collect data and to have a starting

background knowledge, the fires were analyzed overall without distinguishing different years but considering the whole period. For more accurate analysis for planning purposes, a year-by-year assessment would be useful in the future. This does not imply an increase in difficulty since the GIS analysis techniques are identical.

The only survey conducted on a year-by-year basis involved the count of fires that occurred during the intervening period in the Basilicata region (Table 1). Given the ease of spatial and tabular data management, it is first possible to assess how the seasonality of fires has changed (Figure 4), i.e., the fire regime. Fire regimes refer to the typical fire conditions, including the frequency, density, intensity, severity, and seasonality of fires, that occur in a specific area over an extended period of time. Understanding the past and present fire regimes is crucial in predicting future changes and comprehending fire behavior over time and space. This is especially relevant in Mediterranean Europe, which is highly susceptible to wildfires due to its climate and vegetation features [26]. In the study area, the fire regime does not show any net trends. There is only one year (2007) with a much higher than average number of fires that should be investigated. The total number of fires is 6306.

Table 1. Number of fires for each year of the analysis period (2004–2022) in Basilicata region.

Year	n.	Year	n.
2004	16	2013	305
2005	242	2014	107
2006	262	2015	250
2007	1156	2016	105
2008	586	2017	525
2009	216	2018	99
2010	268	2019	326
2011	360	2020	259
2012	567	2021	372
		2022	285

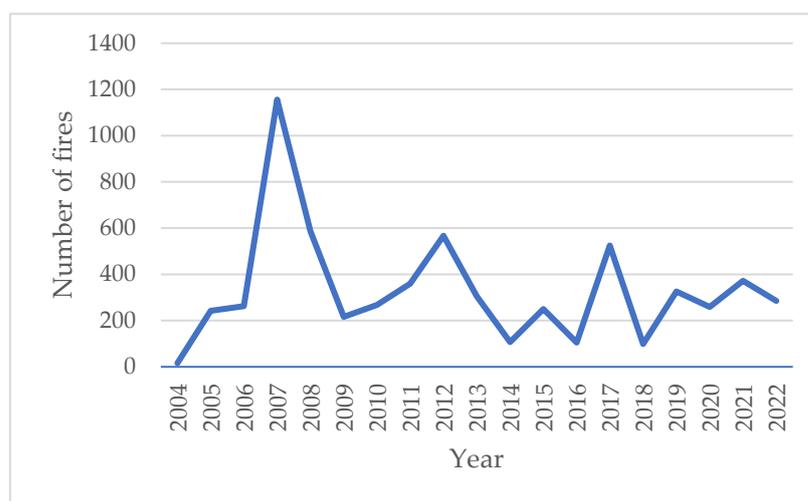


Figure 4. Trends in the number of fires during the investigated period.

The first proper result of this approach concerns the creation of a fire density map for the Basilicata region. Using various tools integrated within QGIS, the square grid was first realized. Then, with a zonal statistics operation, the polygons of the fires that occurred during 2004–2022 were counted. In this way, within the grid, QGIS made it possible to quickly count and then compute the density of fires that occurred.

Generally, from a firefighting planning perspective, historical fire density is assessed for well-defined administrative areas (municipal boundaries, for example). But for spatial

and environmental-level assessment and monitoring, it may be useful to spatialize the data within regular mesh grids. This makes the data comparable over time and standardizable with other spatial parameters.

This type of analysis makes it possible to identify areas with a historical occurrence of fires, and then, with the subsequent superimposition of information layers related to protected areas, it is possible to classify the areas that need to be given more attention from an environmental protection point of view. The survey carried out in the Basilicata region during the period from 2004 to 2022 shows that there are three cores with recurrent fires, of which 100 occurrences have been reached or exceeded (Figure 5).

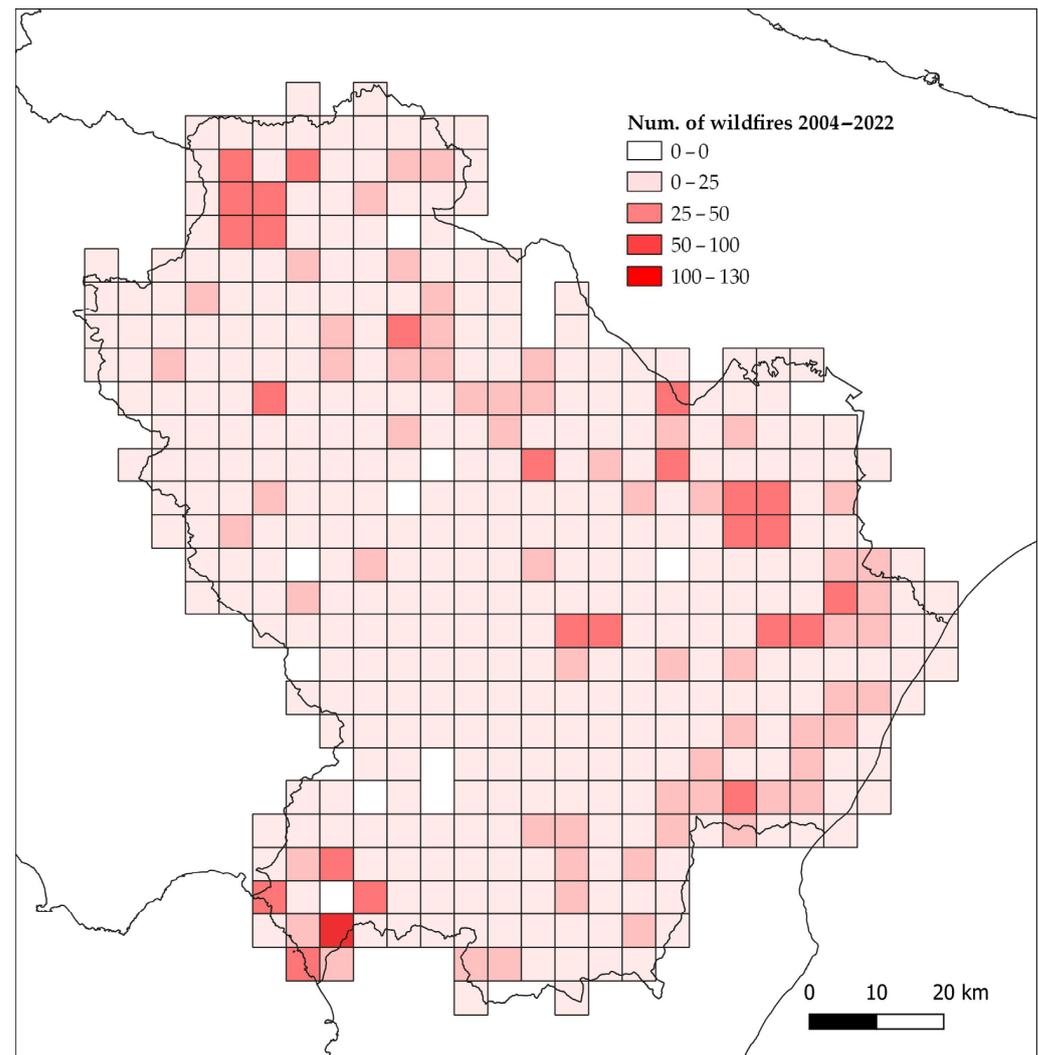


Figure 5. Density of the number of fires within the analysis grid.

Subsequently, to estimate the number of fires within Natura 2000 sites and related habitats, burned areas, densities, and perimeters of protected areas were interpolated.

Forest fires are often the ones that are given the most attention, not only because they affect forests but also because everything is connected to these ecosystems.

The damage caused by fires is not only limited to forest heritage, but it has direct and indirect impacts and effects on habitats, animal biodiversity, and soil. The prevalence of direct consequences (killing or injury caused by temperatures, smoke, and flames) over indirect ones is directly related to the speed of fire spread and is inversely related to the mobility of organisms or, for soil fauna, their ability to benefit from refuges from the flames.

It is abundantly clear that the severity and frequency of fires in the same area affect animal, fungal, and bacterial populations more negatively.

A total of 539 fires occurred in protected areas out of 6306 total fires, which is just over 11 percent. A number that is particularly concentrated in two Natura 2000 sites (Figure 6 and Table 2), which together account for 35% of the fires that occurred. This information is particularly useful to those managing the planning activities of the relevant sites, as these data are often overlooked by planners.

This map is even more important when put in relation to areas (Table A1). In fact, the area of some sites was found to be more than 20% burned at least once and more than 40% burned in two cases. These data can also be returned in map format as expressed illustratively in Figure 7. Another important analysis is the relationship between burned areas and habitats of conservation interest.

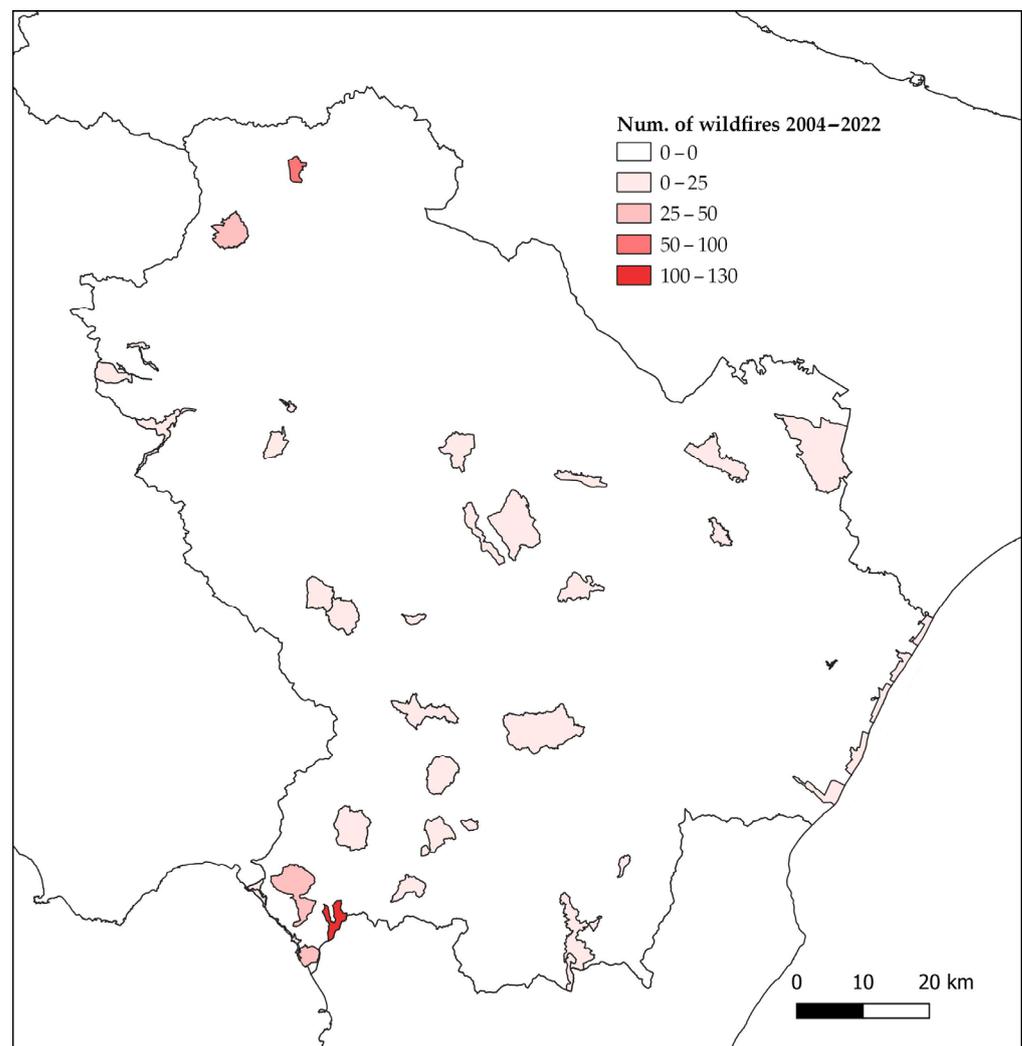


Figure 6. Number of fires within Natura 2000 sites in Basilicata region.

Table 2. Natura 2000 sites with a number of fires greater than 1.

Natura 2000 Site	Num. of fires	Natura 2000 Site	Num. of Fires
Valle del Noce	104	Lago S. Giuliano e Timmari	8
Lago del Rendina	83	Monte Paratiello	6
Monte Vulture	40	Murge di S. Oronzio	5
Marina di Castrocucco	38	Foresta Gallipoli—Cognato	4
Monte Coccovello—Monte Crivo—Monte Crive	26	Monte Li Foi	4
Gravine di Matera	24	Serra di Calvello	4
Costa Ionica Foce Agri	21	Costa Ionica Foce Basento	3
Acquafredda di Maratea	18	Bosco Cupolicchio	2
Bosco Pantano di Policoro e Costa Ionica Foce Sinni	15	Bosco della Farneta	2
Costa Ionica Foce Bradano	14	Gole del Platano	2
Costa Ionica Foce Cavone	14	Monte Raparo	2
Isola di S. Ianni e Costa Prospiciente	13	Serra di Crispo, Grande Porta del Pollino e Pietra Castello	2
Bosco Vaccarizzo	12	Valle Basento Grassano Scalo	2
Monte Alpi—Malboschetto di Latronico	12	Abetina di Laurenzana	1
Monte Sirino	11	Abetina di Ruoti	1
Valle Basento Ferrandina Scalo	11	Fosso La Noce	1
Dolomiti di Pietrapertosa	10	Lago Duglia, Casino Toscano e Piana di S.Francesco	1
Lago Pertusillo	10	Monte di Mella-Torrente Misegna	1
Monte Volturino	9	Monte La Spina, Monte Zaccana	1
		Timpa delle Murge	1
		Vallone Delle Ripe, Torrente Malta e Monte Giano	1

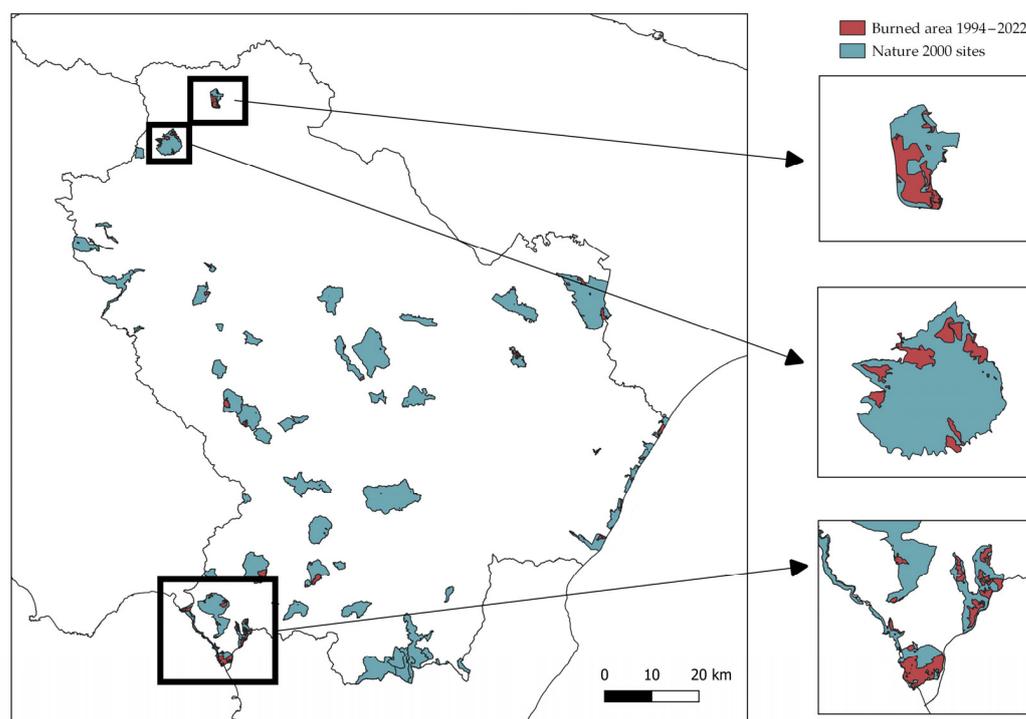


Figure 7. Examples of burned areas within Natura 2000 sites.

Spatial analysis made it possible to summarize (Table A2) how many fires occurred in different habitats. Habitat code and description are in accordance with EUNIS coding. What emerges is that the habitats where more fires occurred were Pannonian-Balkan turkey oak-sessile oak forests, *Quercus ilex* and *Quercus rotundifolia* forests, Pseudo-steppe with grasses and annuals of the Thero-Brachypodietea, semi-natural dry grasslands and scrubland facies on calcareous substrates, and Thermo-Mediterranean and pre-desert scrub. All habitats of conservation affected by fire fall into the categories of forest and grassland habitats. The analysis, performed at the level of individual habitat types, allows for greater fire monitoring with a view to resilient land use planning because it allows for better discrimination of areas on which specific strategies will need to be implemented.

In fact, all these data that can be extrapolated from the proposed approach can be usefully employed in a Spatial Decision Support System (sDSS), which will be carried out later and in continuation with the work presented in this paper. sDSS has become an increasingly important tool in the management of protected areas. Using satellite technology and geospatial data, these systems can collect real-time information on vegetation cover, soil moisture, air temperature, and other environmental parameters, which can be used to prevent and manage wildfires. In particular, SDSSs are used to monitor protected areas and identify potential hotspots, such as areas with a higher density of dry vegetation or the absence of firebreaks. In this way, protected area managers can take early action to mitigate risks and prevent fires. In the event of an emergency, SDSSs can provide real-time information on fire spread and wind direction, enabling emergency responders to plan firefighting and evacuation actions more effectively. In addition, data collected from SDSSs can be used to improve management strategies for protected areas and to prevent fires in the future through planning environmental restoration and land management actions.

4. Conclusions

The overall context calls for a rethinking of fire management strategies, shifting the attention, efforts, and commitments more and more toward prevention, which must

necessarily integrate short-term objectives with medium-term to long-term ones in order to respond to climate challenges and the need to increase forest stock, especially in urban areas.

This translates, for example, into using data, modeling tools, and innovative approaches to analyze the risk of an area by considering all its components and integrating them with the assessment of coherence among the policies that insist on that area. The aim is to identify and implement specific measures, however closely related to sustainable development objectives, that can strengthen the resilience of ecosystems and communities to the risk of forest fires in the context of changing climate change.

In general, today, the data that can be used at the European level are those of the EFFIS system, which does not count fires of less than 30 hectares, which are the vast majority of fires affecting Italy and other Mediterranean regions, and institutions generate confusion by disseminating data on the number of interventions practiced by the fire brigades without providing reliable and immediate data on the size of the burned areas and the municipalities most affected. Fortunately, for the Basilicata region, open data has proven to be far more reliable than EFFIS, and it has been verified that the use of this form of data is essential for proper land monitoring.

In this study, an initial expeditious and immediate mode of analysis was provided such that it can be used even without high technical expertise and useful information can be derived by public decision-makers. It is necessary to invest post-fire resources strategically, in situations that provide key ecosystem services, and in priority areas. To move from an approach that chases emergencies to a strategy of post-fire intervention, it is necessary to define at the land-use planning stage, even before fires occur, the priority areas for intervention, the most appropriate technical solutions, and their timing to maintain key services. Pre-fire planning of recovery interventions would allow timely interventions (in advance of the first post-fire growing season) contemplating possible waiver procedures. For all this, certainly, an integrated approach based on GIS analysis proved essential.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Natura 2000 sites and the percentage relationship between site area and areas covered by fire. For coding refers to [27].

Nature 2000 Site	ha Area	ha Fire	Fire %
Marina di Castrocuoco	810.72	381.46	47.05
Lago del Rendina	670.33	268.93	40.12
Valle del Noce	967.61	323.28	33.41
Acquafredda di Maratea	552.25	104.63	18.95
Valle Basento Ferrandina Scalo	732.94	138.40	18.88
Monte Alpi—Malboschetto di Latronico	1561.08	260.97	16.72
Monte Vulture	1903.98	258.02	13.55
Costa Ionica Foce Bradano	1155.65	152.59	13.20
Serra di Calvello	1641.35	157.80	9.61
Monte Sirino	2619.36	214.61	8.19
Monte Coccovello—Monte Crivo—Monte Crive	2981.11	213.29	7.16

Table A1. Cont.

Nature 2000 Site	ha Area	ha Fire	Fire %
Monte Li Foi	970.32	64.04	6.60
Isola di S. Ianni e Costa Prospiciente	417.67	25.83	6.19
Bosco Pantano di Policoro e Costa Ionica Foce Sinni	1794.10	95.74	5.34
Dolomiti di Pietrapertosa	1312.52	60.52	4.61
Gravine di Matera	6968.49	317.82	4.56
Monte Volturino	1858.45	80.18	4.31
Bosco Vaccarizzo	291.66	11.67	4.00
Costa Ionica Foce Agri	2414.68	91.68	3.80
Costa Ionica Foce Basento	1392.75	39.37	2.83
Costa Ionica Foce Cavone	2043.98	29.88	1.46
Monte Paratiello	1140.01	14.29	1.25
Timpa delle Murge	153.22	1.12	0.73
Fosso La Noce	43.29	0.31	0.71
Abetina di Laurenzana	324.39	2.10	0.65
Bosco della Farneta	297.95	1.50	0.50
Lago S. Giuliano e Timmari	2574.50	12.51	0.49
Monte Raparo	2019.97	9.65	0.48
Valle Basento Grassano Scalo	881.98	2.98	0.34
Lago Pertusillo	2042.04	4.99	0.24
Abetina di Ruoti	162.01	0.33	0.20
Foresta Gallipoli—Cognato	4288.78	4.53	0.11
Murge di S. Oronzio	5459.95	3.97	0.07
Monte La Spina, Monte Zaccana	1065.24	0.73	0.07
Vallone Delle Ripe, Torrente Malta e Monte Giano	344.32	0.03	0.01
Monte di Mella-Torrente Misegna	1565.17	0.16	0.01
Serra di Crispo, Grande Porta del Pollino e Pietra Castello	460.99	0.01	0.00
Gole del Platano	1383.10	0.02	0.00
Lago Duglia, Casino Toscano e Piana di S.Francesco	2425.89	0.00	0.00
Bosco Cupolicchio	1762.85	0.01	0.00

Table A2. Habitat (according to EUNIS coding) and number of fires.

Habitat Code	Num. of Fires	Habitat Code	Num. of Fires
91M0	91	2110-2120-2230	6
9340	87	1240	6
6220	78	9250	4
6210	63	2250	4
5330	60	1310-1420	4
2260	39	3170	3
8210	28	1420	3
3280	24	1410-6420	3
9260	23	1210	3
8130	23	95A0	2
91AA	22	6510	2
9220	19	6430	2
1410	19	4090	2
9210	17	1410-92D0	2
9180	14	1130	2
92D0	13	92A0	1
6210-62A0	8	91AA-9340	1
91F0	7	6170	1
9510	6	2250-2260-2230	1
62A0	6	1430	1

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