

A Systematic Map of the Research Trends in Wildfire Management in Mediterranean-Climate Regions

Renata Martins Pacheco, João Claro

Abstract—Wildfires are becoming an increasing concern worldwide, causing substantial social, economic, and environmental disruptions. This situation is especially relevant in Mediterranean-climate regions, present in all the five continents of the world, in which fire is not only a natural component of the environment but also perhaps one of the most important evolutionary forces. The rise in wildfire occurrences and their associated impacts suggests the need for identifying knowledge gaps and enhancing the basis of scientific evidence on how managers and policymakers may act effectively to address them. Considering that the main goal of a systematic map is to collate and catalog a body of evidence to describe the state of knowledge for a specific topic, it is a suitable approach to be used for this purpose. In this context, the aim of this study is to systematically map the research trends in wildfire management practices in Mediterranean-climate regions. A total of 201 wildfire management studies were analyzed and systematically mapped in terms of their: Year of publication; Place of study; Scientific outlet; Research area (Web of Science) or Research field (Scopus); Wildfire phase; Central research topic; Main objective of the study; Research methods; and Main conclusions or contributions. The results indicate that there is an increasing number of studies being developed on the topic (most from the last 10 years), but more than half of them are conducted in few Mediterranean countries (60% of the analyzed studies were conducted in Spain, Portugal, Greece, Italy or France), and more than 50% are focused on pre-fire issues, such as prevention and fuel management. In contrast, only 12% of the studies focused on “Economic modeling” or “Human factors and issues,” which suggests that the triple bottom line of the sustainability argument (social, environmental, and economic) is not being fully addressed by fire management research. More than one-fourth of the studies had their objective related to testing new approaches in fire or forest management, suggesting that new knowledge is being produced on the field. Nevertheless, the results indicate that most studies (about 84%) employed quantitative research methods, and only 3% of the studies used research methods that tackled social issues or addressed expert and practitioner’s knowledge. Perhaps this lack of multidisciplinary studies is one of the factors hindering more progress from being made in terms of reducing wildfire occurrences and their impacts.

Keywords—Management Mediterranean-climate regions, policy, wildfire.

I. INTRODUCTION

OVER the last decades, wildfires are becoming an increasing concern worldwide [1], [2]. These

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contemporary fire regimes are causing substantial social and economic disruptions due to the destruction of infrastructure, degradation of ecosystem services, loss of life, and smoke-related health effects [3]. Given the extent of these impacts, it is important that forests and fires are effectively managed [2]. This is especially relevant in Mediterranean-climate regions (MCR), in which fire is not only a natural component of the environment but also perhaps one of the most important evolutionary forces [4].

MCR are present in all the five continents of the world [5], and although they only occur on about 2% of the world’s total land area [6], these climatic regions are major centers for human population [7]. The largest MCR is the Mediterranean Basin, corresponding to 73% of the total land area, followed by California and Southwestern Australia (10% each), Central Chile (4%), and the Cape region (3%) [5].

The elevated presence of woody biomass and the dense cover of Mediterranean-climate shrublands cause them to be very flammable, especially under dry summer conditions with low humidity. Fire is, therefore, a significant disturbance in all Mediterranean-type ecosystems today [5], being that catastrophic fires have recently occurred in the Mediterranean Basin, Israel, California, South Africa, southern Australia [3], and Chile [7]. Given that all these regions share the same unusual climatic regime, sometimes Mediterranean-type ecosystems have provided classic cases for comparative ecological function studies [5]. In this sense, considering that these regions have many similar structural features, it may be beneficial to investigate trends in wildfire management research related to any of them, as the resulting knowledge might apply to all.

Given that large-scale wildfires are becoming an increasing concern [8], and that, in spite of large governmental investments, consensus on fire and ecosystem management is still lacking [1], it is important to map the research trends on the topic and understand what has been its focus and what is still missing. Considering that the main goal of a systematic map is to gather and catalog a body of evidence to describe the state of knowledge for a particular topic or question [9], it is a suitable approach to be used for this purpose. Systematic mapping does not aim to answer a specific question as does a systematic review but instead collates, describes, and catalogs available evidence, following the same rigorous, objective, and transparent processes, covering the breadth of science often needed for policy-based questions [9]. In this sense, the objective of this paper is to describe the research trends in wildfire management practices in MCR through a systematic mapping process. The map describes the wildfire management

studies in terms of: Year of publication; Place of study; Scientific outlet; Research area (Web of Science) or Research field (Scopus); Wildfire phase; Central research topic; Main objective of the study; Research methods; and Main conclusions or contributions. Based on these results, implications for policy, practice, and research are discussed.

II. MATERIALS AND METHODS

Our methodological procedures are based on [9] for systematic mapping in environmental sciences, on the PRISMA (Preferred Reporting Items for Systematic Reviews) guidelines for systematic reviews [10] and few other studies with similar scopes [11], [12]. In the following sections, the scope and specificities of this study are described.

A. Geographic and Ecosystem Scope

MCRs are present in all five continents; more specifically, they are found in California, Chile, South Africa, Australia, and the Mediterranean Basin [6]. The global distribution of this climatic type displays remarkably regular patterns, showing a direct association to the general circulation of the world's atmosphere and its seasonal displacements. Areas of Mediterranean-climate are situated between latitudes 32° and 40° north and south of the equator. Equatorward, the climate tends to be desertic, and poleward precipitation values tend to increase, and rainfall is more distributed throughout the year [4]. These regions tend to display mild, wet winters and warm, dry summers. This climatic regime typically has 90% or more of annual precipitation falling in the six cool season months, and frequent periods of extended droughts during the summer, causing the vegetation to be highly flammable, that is, fire-prone [5].

B. Literature Search

Our search focused on peer-reviewed studies that explicitly addressed issues related to wildfire management in MCRs. For that purpose, we searched the online databases of SciVerse Scopus (*title*, *abstract* and *keyword* fields) and Thomson Reuter's Web of Science (*title* and *topic* fields), as done in other systematic review papers [12], [13]. We restricted our searches to studies in English and used the following search string in both databases: **fire AND ("mediterranean-climate" OR "mediterranean environ*" OR "mediterranean region" OR "mediterranean eco*" OR "mediterranean forest") AND (manag* OR polic*)*. We opt to use the asterisk (*) in some of the search terms because it potentially increases the number of retrieved studies. For example, in the case of **fire*, studies containing both "fire" and "wildfire" in one of the search fields are retrieved, contributing to rising the total number of results.

C. Selection Criteria

Once the searches were done, the title, abstract, and keywords of the studies found were reviewed to verify if they were aligned with the scope of our study. The ensuing inclusion criteria were applied to select the studies to be further analyzed: *Partially or totally about a region of*

Mediterranean-climate; (we accepted the studies that identified themselves as being conducted in a MCR) and *Addresses situations directly linked to any stage of wildfire management*. The exclusion criteria were the following: *Not about Mediterranean-climate regions*; *Not focus on wildfires*; *Not focus on the management of situations linked to wildfires*; and *Only provides information that could help in the development of management practices or public policies about wildfires*.

D. Data Extraction

Following the screening phase, the full texts for the selected studies were retrieved and reviewed. Information was extracted from each paper according to the ensuing analysis topics: *Year of publication*; *Place of study*; *Name of publication*; *Web of Science research area*; *Scopus research field*; *Wildfire phase*; *Central research topic*; *Objectives of the study*; *Research methods*; and *Main conclusions or contributions*.

For the analysis of the last four topics, as is typical in systematic mapping studies [9], coding systems were used since that type of information is not standardized. They will be presented along with the results in the next section.

III. RESULTS AND DISCUSSION

The search on both databases was performed on February 19th, 2019. In total, the literature search yielded 1042 studies, of which 613 were retrieved on Scopus and 429 on Web of Science. After removing the duplicates, a total of 743 studies were left to be screened, by reading the abstracts and applying the inclusion and exclusion criteria previously defined. In this phase, 535 studies were excluded. Most of them either did not focus on wildfires (i.e., wildfires were a secondary issue on the study) or they only provided information that could help in the development of management practices or public policies about wildfires, i.e., they were more focused on describing ecological processes or physical phenomena and not on how to manage them. Finally, we were left with 208 studies to extract information. Of those, we were able to retrieve 202, and one was excluded after reading the full text because it did not focus on a MCR. Most of the studies that were not found were either from conferences or were not included in the institutional subscriptions to which both authors had access. Fig. 1 illustrates the just-described process.

Next, we discuss the main results from the 201 studies reviewed for the systematic map, according to the analysis topic. It is worth noting that no systematic review or systematic mapping studies were retrieved in our search, which reinforces the novelty and relevance of this work. Studies that help to illustrate the findings are referenced throughout the discussion. For more details on the studies, please look at the Systematic Map [88].

A. Year of Publication and Place of Study

The temporal distribution of the studies spanned from 1996 till 2019 and showed an increasing trend over time, as illustrated in Fig. 2. It should be emphasized that the search on

the databases was conducted in February of 2019, so not all studies of that year are accounted for.

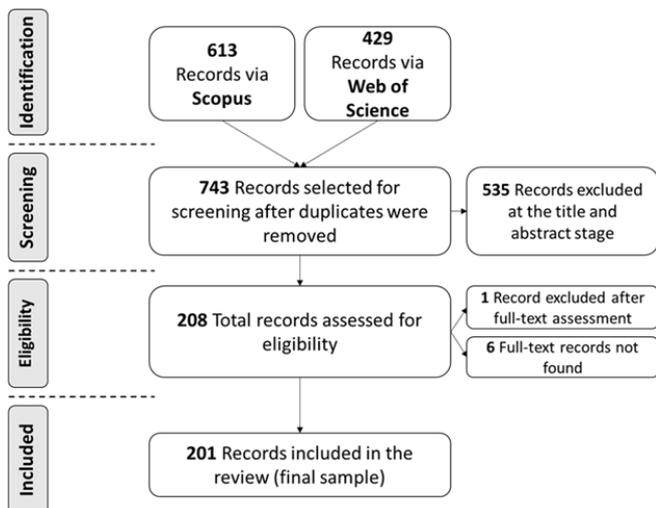


Fig. 1 Methodological approach used in the systematic mapping study following an adapted version of the PRISMA guidelines [10]

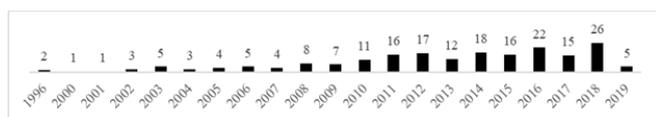


Fig. 2 Distribution of studies analyzed per year of publication (n = 201)

As for the places of study, their distribution according to the MCR they belong to is shown in Fig. 3.



Fig. 3 Distribution of studies according to their MCR (n = 201)

Most of the studies (78%) were conducted in the Mediterranean Basin. This result is to be expected since this region comprises about 73% of the world's Mediterranean-climate area [5]. By analyzing the percentages of land area occupied by each MCR, it is noticeable that the number of studies per region is distributed proportionally to its size.

Most papers address only a specific place (such as a natural park) in a single country [14]-[18]. Nevertheless, 15 studies (7%), such as [19] and [20], compared experiences/results within more than one MCR.

Within the Mediterranean Basin, Spain is the country with more studies, accounting for over a one-third of the publications within the Mediterranean Basin. This may be because Spain is one of the countries most affected by wildfires in Europe, both considering the number of fires and area burned [21]. Portugal and Greece each account for 12% of the studies within the Mediterranean Basin, being that both countries have recently experienced severe wildfire events. Next, Italy and France respectively correspond to 9% and 3%

of the studies within the Mediterranean Basin. These five countries account for almost 75% of the studies conducted within the Mediterranean Basin, and about 60% of the total of the studies analyzed. This indicates that research on this field, even though it is a concern in five continents, is very concentrated in a few countries.

B. Web of Science Research Area and Scopus Research Field

From the 201 studies analyzed, 179 (89%) were found on both databases, 21 (10%) only on Scopus and one only on Web of Science. The fact that Scopus rendered more results is relevant to note since some systematic reviews and maps with an environmental scope only use Web of Science as the database [22], [23], and that may be reducing the total number of studies retrieved.

Most environmental studies are multidisciplinary by nature, so it is relevant to analyze how the scientific outlet they are cataloged in each database. On Web of Science, the outlets were classified under 37 different areas, while in Scopus, they were classified under 19 fields. Table I shows how many studies were classified according to the number of areas (Web of Science) and fields (Scopus) in each database.

TABLE I
NUMBER OF STUDIES ACCORDING TO THE DATABASE

| Number of areas (WoS)/ fields (Scopus) | Number of Studies WoS | Number of Studies Scopus |
|---|--------------------------|-----------------------------|
| 1 | 108 | 86 |
| 2 | 35 | 88 |
| 3 | 31 | 17 |
| 4 | 6 | 8 |
| 5 | 0 | 1 |
| Total | 180 | 200 |

On Web of Science most studies were classified under only one area (60% of the studies found on the database), being that both "Forestry" and "Environmental Sciences" accounted for more than 30% of the studies each, followed by "Ecology", which accounted for more than 16% of the total. Even though these areas are considered multidisciplinary, the database did not index the outlets the studies were published in multiple areas, which could potentially help in their retrieval by researchers searching by specific areas of knowledge.

As for Scopus, almost the same number of studies was classified under one or two fields (43% and 44% of the studies found on the database, respectively). Of the studies classified under only one field, "Environmental Science" and "Agricultural and Biological Sciences" were the most common, respectively representing 24% and 10% of the studies retrieved in the database. As for the studies published in outlets indexed under two fields, the most common combination was exactly "Environmental Science" and "Agricultural and Biological Sciences," representing almost 30% of the studies found on this database. Considering this, Scopus seems to be a database that is better adapted to deal with multidisciplinary studies.

It is also interesting to note that about 2% of the retrieved

studies in both databases were published in outlets classified under the “Economics” area (WoS) or “Economics, Econometrics, and Finance” field (Scopus). Considering that “management” and “policy” were two of the keywords used, and usually social, environmental, and economic aspects should be accounted in these contexts [24], [25], more studies that addressed economic issues related to fire management were expected.

C. Wildfire Phase and Central Research Topic

Fig. 4 shows the distribution of studies according to the fire phase they addressed.

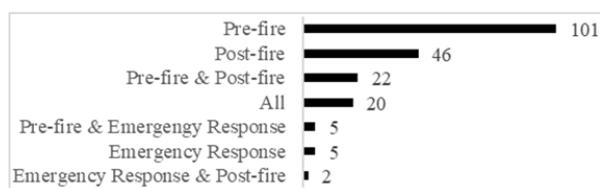


Fig. 4 Distribution of studies according to the wildfire phase they focused on: “Pre-fire,” “Emergency Response,” “Post-fire,” and combinations (n = 201)

For the wildfire phases, we adopted the following classification for the studies: “Pre-fire”, when they focused on management aspects that took place before the wildfire occurrence, such as fire prevention measures; “Emergency Response”, when the focus was on the actions to be taken during the wildfire occurrence, such as the optimization of the use firefighting resources; and “Post-fire”, when the study addressed issues that followed the occurrence of the wildfires, such as the mapping of the burned area and salvage logging. Also, some studies addressed more than one fire phase, so all possible combinations of the previous three categories were also considered.

More than 50% of the studies focused on Pre-fire issues, while about 23% addressed Post-fire concerns. Around 11% of the studies addressed situations linked to both Pre-fire and Post-fire aspects, usually because they used wildfire data to create models to try to predict future fire behaviors or the most suitable pre-fire interventions [26]-[28]. For example, [27] used post-wildfire seedling germination data to help in determining if future fire prescriptions would be recommended from an ecological perspective.

About 10% of the studies addressed all phases of the wildfires, and it stood out that their focus tended to be more of a social nature, trying to understand the causes of fires and their impacts on society [19], [29], [30]. For instance, [19] compared the social experiences of wildfires both in Greece and in the United States, revealing similarities in both places, such as the loss of traditional fire practices.

Only about 6% of the studies dealt with “Emergency Response,” either by itself or combined with other fire phases. Of the ones that dealt exclusively with “Emergency Response”, most were focused on operational aspects [31]-[33], such as the determination of response times for the deployment of terrestrial resources for wildfire fighting [32]. The remainder studies were mostly concerned with predicting wildfire behavior to help in firefighting actions [34], [35], such as trying to predict daily fire occurrence with readily available spatio-temporal data [34].

To analyze the main research topic each study addressed, we used a coding system based on the research topics proposed by The International Association of Wildland Fire [36]. Other categories were also added to represent better the topics of the studies (see the Systematic Map). Fig. 5 presents the codes used along with the distribution of studies according to them.

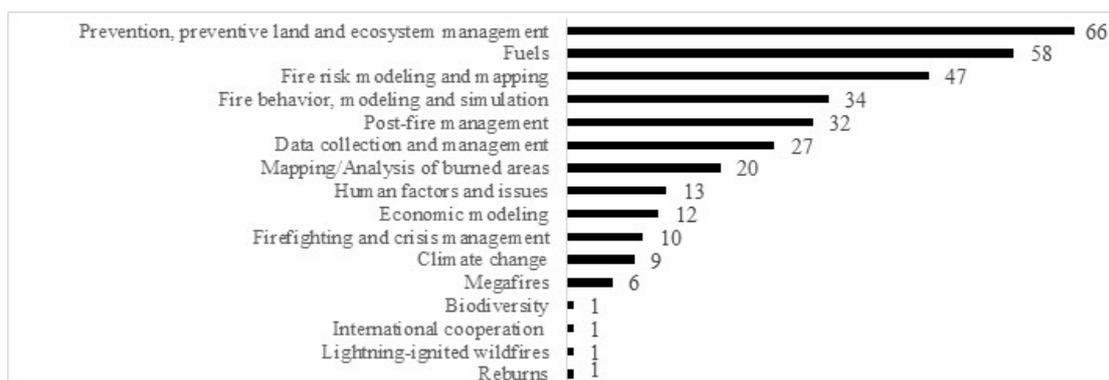


Fig. 5 Distribution of the central research topics of the analyzed studies. Some studies had more than one central research topic

We found a total of 16 central research topics, being that some studies had more than one focus. A total of 23 studies (12%) were classified as having three central research topics, 91 (45%) as having two central research topics, and 87 (43%) as having only one central research topic. No temporal trends were noticeable in terms of an increasing focus in a specific research topic. Considering that over 50% of the studies dealt

with Pre-fire issues, it is coherent that the four most common central research topics are related to that fire phase. Around 33% of the studies had “Prevention, preventive land, and ecosystem management” as one of the central research topics, followed by 29% dealing with “Fuels,” 23% focused on “Fire risk modeling and mapping,” and 17% on “Fire behavior, modeling, and simulation.”

Studies focused on “Post-fire” issues represented around 23% of the total, which is in alignment with the fact that about 16% of the studies had the research topic of “Post-fire management.” As for the studies that addressed “All” fire phases, most of them (60%) had at least one of the research topics related to “Data collection and management.” It is interesting to note that about 6% of the studies had “Economic modeling” as one of their central research topics even though only 2% of the studies were published in outlets classified as such on the databases. This suggests the importance of indexing the outlets that potentially publish multidisciplinary

studies in more fields or areas within the databases or, depending on how the search is being done, relevant references might not be retrieved.

D. Main Objective of the Studies

As for the objectives of the studies, the coding system used is analogous to the “central research topic,” but wording adjustments were made, and more categories were added to better represent the goals of the publications. Fig. 6 shows the distribution of studies according to their main objective.

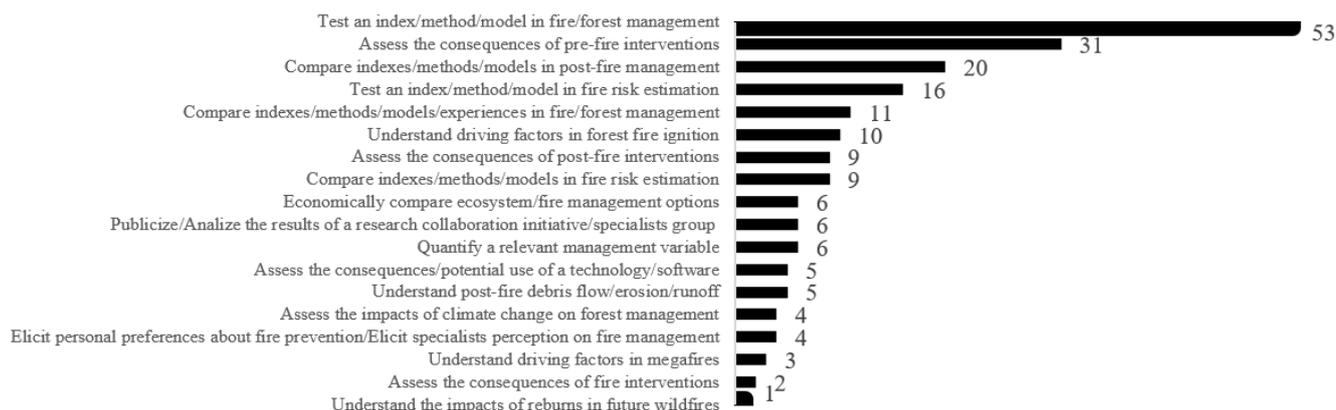


Fig. 6 Distribution of the main objective of the studies (n = 201)

We found a total of 18 categories and, similarly to what were observed in the “Central research topic,” no temporal trends of increase or decrease of studies having certain objectives were observed. Analyzing the results collectively, four types of research objectives can be highlighted in terms of the actions they entail. They aimed to: Test (34 %); Assess (25%); Compare (23%); and Understand (9%). All the fire phases were addressed by studies having these objectives. The studies that had the goal to “Test” were designed to analyze either indexes, methods or models for the management of fire or forests, or to estimate fire risk [35], [37]-[39]. As for the studies aiming to “Assess,” they mostly described the consequences or the impacts of environmental interventions, climate change, and use of technologies [40]-[42]. The ones that aimed to “Compare” mostly contrasted different management options or fire risk estimation methods either in terms of their efficiency or economically [43]-[46]. Lastly, the studies that sought to “Understand” were mostly focused on describing or modeling driving factors or physical phenomena to support management actions [47]-[50].

Individually, the three most frequent objective categories account for more than 51% of the studies. This suggests that, even though there is a reasonably large spectrum of possible research objectives, most studies try to address similar research questions, even within different contexts. For example, more than 26% of the studies had the main objective to “Test an index/method/model in fire/forest management.” The studies within this category are very broad in scope, varying from cattle grazing and vegetation management for

multiple land uses [51], the use of GIS-based decision support systems to optimize the route to forest fires [31], as well as the proposition of a framework for comprehensive wildfire management [52].

The second most frequent research objective, accounting for more than 15% of the studies, is to “Assess the consequences of pre-fire interventions.” Considering that more than 50% of the studies are centered on Pre-fire issues, it is reasonable that many studies specifically address the consequences of interventions that occur before the wildfires. The scope of themes within this category is narrower, being that most address forest and fire management issues [14], [53]-[55] or fuel management [15], [56], [57]. It is also interesting to note that all MCRs have studies with this research objective, which might be indicative of its central importance in fire management.

To “Compare indexes/methods/models in post-fire management” was the third most frequent research objective, accounting for almost 10% of the studies. This is coherent since more than 15% of the studies have “Post-fire management” as their central research topic. The studies with this objective did not vary much in scope, being that most are concerned with the consequences of post-fire interventions in soil erosion processes [43], [58], [59] or vegetation dynamics and salvage logging [60]-[62]. Studies with this research objective were only found for the Mediterranean Basin and California. Similarly, studies aiming to “Understand post-fire debris flow/erosion/runoff” were performed in these same regions [48], [63], [64]. These studies represent a little over

2% of the total and differ from the previous category in that instead of aiming to manage a post-fire situation, they focus on just trying to model it and propose guidelines to manage the identified issues. As for the objectives with fewer studies, they were mostly either very specific in scope (climate change effects, mega-fires, reburns, etc.) or focused on the “Emergency Response” fire phase, which was the least studied of all.

E. Research Methods

The coding system used to analyze the research methods

employed in each study is based on the categories used in the systematic review conducted by [12] since the scope of their study was similar. Nevertheless, the category “Field observations and assessments” that they proposed was suppressed, since in the present work all field studies reported some type of measurement or sampling, and either “Field measurements” or “Field sampling and/or laboratory analysis” categories better represented them. Fig. 7 shows the 12 categories used to classify the studies.

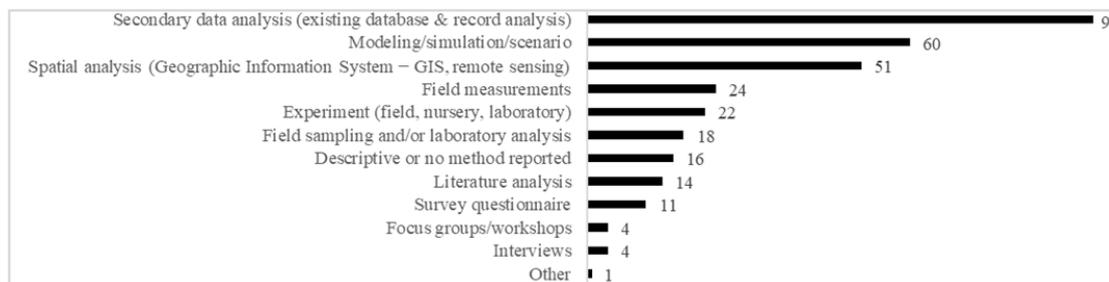


Fig. 7 Distribution of the research methods employed by the analyzed studies. Some studies used more than one research method

Examining the studies in terms of their methodological approach, it stands out that most studies (about 84%) employed quantitative research methods, which are linked to rational and objective measurements of observable phenomena. Only 16% of the analyzed studies employed at least one qualitative method, focusing on the assessment of subjective phenomena (e.g., ideas, opinions, patterns). It should be emphasized that only 2% of the studies used both quantitative and qualitative methods. This perhaps indicates a deficiency in the field since, in the environmental management context, there is a growing body of literature asking for an integrated approach in which the two research paradigms are seen as being complementary to each other [25].

Analyzing the results in terms of the number of methods employed, 59% used two main ones. The most frequent combination was “Modeling/simulation/scenario” and “Secondary data analysis,” which accounted for 16% of the studies. Most of these studies (12% of the total) had the main objective to “Test an index/method/model in fire/forest management”, which indicates a coherency between the objective of the research and employed method, especially when considering that for modeling studies there is the need to have a solid database available. With these methods and objective, we found studies from the North and South America MCRs [17], [65], besides various countries from the Mediterranean Basin [26], [66].

The second most frequent combination of research methods was “Spatial analysis” and “Secondary data analysis,” which accounted for 12% of the studies. Once again, to “Test an index/method/model in fire/forest management” was the most common objective of the studies, corresponding to 5% of the total. The main difference in this context is that most studies deal with spatial models, using satellite or terrain data to map or quantify relevant fire management variables [67]-[70].

Within this scope, studies from South America [67] and Australia [68] were found, but most are from the Mediterranean Basin.

A single method was used by 42% of the studies. In this scenario, “Secondary data analysis” was the most used research method, corresponding to 10% of the studies. Studies that use this method were found from all the MCRs, and most of them address temporal fire trends [20], [71], [72]. Logically, secondary data (especially databases) are needed to perform this type of temporal study. The second single most used method was “Descriptive or no method reported,” accounting for 7% of the studies. This method was mostly used in books and more qualitative papers. Studies of all MCRs used this method [29], [73], [74].

In total, only about 32% of the studies included some form of fieldwork among the research methods employed [60], [61], [75]. Most of the work that was not included in this systematic mapping study was fieldwork because even though they may bring valuable insight for fire or forest management practices, that was not their focus.

Finally, only seven studies employed either “Interviews” or “Focus groups/workshops,” which are methods most commonly used in social sciences research. Some of them aimed to integrate local actors into fire policy development [30], [76], others analyzed human factors linked to fire management [77], [78], or aimed at incorporating expert knowledge in the development of new fire policies [16], [61]. Considering that studies with interdisciplinary approaches, particularly those embracing inclusion of the “social” in research, may be valuable in tackling environmental management problems [25], there is an indication of a knowledge gap here and potentially important research opportunities.

F. Main Conclusions or Contributions

The last aspect analyzed in each study was its main conclusion or contribution, according to its authors. Once again, the coding system used for this analysis is analogous to the “Objective of the study,” since it is expected that the

conclusion is in alignment with the aim of the research. Fig. 8 shows the distribution of the main conclusion or contribution of the studies. Once more, as expected, considering the previous analysis, no temporal trends were observed.



Fig. 8 Distribution of the main conclusions of the studies (n = 201)

Almost 30% of the studies contributed by proposing a “New interesting approach/technology that can be used in wildfire/forest management” and more than 11% by offering a “New interesting approach/technology that can be used in wildfire risk management.” In the first case, more than half of those studies had the objective to “Test an index/method/model in fire/forest management,” and more than 30% focused on “Pre-fire” issues. Studies from three MCRs were found within this context [16], [52], [79]. In the second case, almost half of the studies had the goal to “Test an index/method/model in fire risk estimation,” and considering that “fire risk” is the topic, all of them were focused on “Pre-fire” or “Pre-fire & Post-fire” issues. Only studies from California and the Mediterranean Basin were found within this scope [80], [81]. Overall, this suggests that new and potentially useful knowledge, both in terms of procedures and technology, is being produced for forest, fire or wildfire risk management, and perhaps the Mediterranean regions that have not conducted studies within this scope, may also benefit from it.

About 15% of the studies concluded that there was the “Need to change a procedure in place.” Around one-third of these studies had the objective to “Compare indexes/methods/models/experiences in fire/forest management.” All but one of the studies within this scope were focused on “All” the fire phases, and most were focused in the Mediterranean Basin, but included other regions [19], [82]. This suggests that perhaps newer practices and models can better assist in fire or forest management. In this same sense, only three studies concluded that “Procedures in place are working” [40], [77], [83], which reinforces the argument that more scientific knowledge for forest management is needed.

Finally, less than 1% of the studies contributed in terms of developments in firefighting. This is coherent with the fact that only 2% of the studies focused on the “Emergency Response” phase of the fires. This reinforces the notion that most of the research efforts in wildfire management are not directed at firefighting or suppression, unlike most of the public investment that tends to favor fire suppression over prevention [8], [84].

G. Implications for Policy, Practice, and Research

The results of this study showed that there is an increasing trend of publications about wildfire management. Most studies are, however, centered around five European countries, and only 7% involved more than one MCR. Perhaps there are opportunities for more research collaboration amongst these regions, especially considering that, even though the number of publications on the topic is growing, so are the number of wildfires [84]-[86].

Proper wildfire management requires knowledge from multiple disciplines. Nevertheless, the results showed that the publication outlets tended to be indexed in few knowledge areas, and more than 25% of the publications were papers published in three journals. Once again, considering that despite the rising number of studies on the topic, wildfire occurrences are also increasing, perhaps the type of studies currently being developed do not address the entire complexity of the issue, and more multidisciplinary work is needed to effectively tackle the problem.

As for the databases used, Scopus yielded more results and seemed to do a better job in indexing the publication outlets in multiple fields of knowledge. This information is relevant for future systematic reviews or mapping studies within the environmental context since Web of Science tends to be more used for this purpose [22], [23].

In terms of the fire phase, most studies addressed “Pre-fire” issues, more specifically with central research topics related to preventive measures and fuel management. In this sense, this research trend seems to be in alignment with European guidelines that are “shifting the focus from suppression to prevention and increasing the awareness and preparedness of populations at risk” [8].

As for the central research topic, only 12% of the studies addressed “Economic modeling” or “Human factors and issues.” This suggests that the triple bottom line of the sustainability argument (social, environmental, and economic) is not being homogeneously addressed by fire management research, which might negatively affect professional

development, as well as at the practitioner level [25]. In this sense, the Forest Service of the US Department of Agriculture has recognized that some fire impacts have not been researched from a social science perspective [87]. In this same context, the United States' National Wildfire Coordinating Group has acknowledged that social issues have broadened the scope of the fire hazard problem, making fire management more extensive and complex. They also highlight the need for scientific research that includes sociological and economic factors [24].

Regarding the objectives of the studies, more than 25% aimed at testing new approaches in fire or forest management. This suggests that new management knowledge is being produced. However, it is difficult to know how much of it is preventing or reducing wildfire effects, once again considering that the number and even size of fires are increasing.

As for research methods, most studies used secondary data analysis in some stage of their work. This shows the importance of keeping track of wildfires occurrences and recording all information relevant for management. Very often, this information was used in fire modeling or spatial analysis studies. The methods employed in these studies were not deeply analyzed since it extrapolates the scope of this paper, but some studies seemed to be very similar in scope, and with similar contributions.

Combining qualitative and quantitative approaches is considered important when trying to address the big picture of environmental management [25]. In this sense, perhaps there is a need for more fieldwork, as well as the use of social-economical methods and mixed research approaches to better reflect the entire wildfire phenomena in MCRs. This might be especially relevant since not all five regions had studies that employed a variety of research methods.

Finally, in terms of conclusions and contributions, most studies proposed or tested new forest or wildfire management approaches and concluded that their use on the field was promising. Once more, this suggests that new and, in theory, useful knowledge on fire management is being produced. However, considering that the number of recorded wildfires has increased in recent years, how is this knowledge being helpful and useful in effectively tackling this issue? Should perhaps research on wildfire management change its scope, focusing on policy matters and addressing more practical issues, with mixed research approaches? Would we then see a reduction in the number of wildfires and their impacts on society and the environment? Answering these questions goes beyond the scope of the present study, but the results indicate that even though there is substantial research on the topic of wildfire management, the complexity of the problem, in terms of its social, economic, and environmental components, has not been entirely addressed.

IV. CONCLUSIONS

The present study aimed to help understand the current state of the research in wildfire management, in all its phases, through systematic mapping. The results showed that there is an increasing number of studies being developed on the topic,

but most of them are conducted in few Mediterranean countries, having similar focuses and employing similar research methods. The depth and quality of these studies were not assessed since it surpassed the goal of the present paper, but this might very well be the focus of systematic reviews that could help in informing wildfire policies with scientific knowledge. Nevertheless, the results indicate that there is a lack of studies that are more multidisciplinary in their approaches, and that incorporate expert and practitioner knowledge. Perhaps this absence is one of the factors hindering more progress from being made in terms of reducing wildfire occurrences and their impacts.

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