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Review

Decision Support System Development of Wildland Fire: A Systematic Mapping

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Abstract: Wildland fires have been a rising problem on the worldwide level, generating ecological and economic losses. Specifically, between wildland fire types, uncontrolled fires are critical due to the potential damage to the ecosystem and their effects on the soil, and, in the last decade, different technologies have been applied to fight them. Selecting a specific technology and Decision Support Systems (DSS) is fundamental, since the results and validity of this could drastically oscillate according to the different environmental and geographic factors of the terrain to be studied. Given the above, a systematic mapping was realized, with the purpose of recognizing the most-used DSS and context where they have been applied. One hundred and eighty-three studies were found that used different types of DSS to solve problems of detection, prediction, prevention, monitoring, simulation, administration, and access to routes. The concepts key to the type of solution are related to the use or development of systems or Information and Communication Technologies (ICT) in the computer science area. Although the use of BA and Big Data has increased in recent years, there are still many challenges to face, such as staff training, the friendly environment of DSS, and real-time decision-making.

Keywords: wildland fire; forest fire; decision support systems; systematic mapping

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1. Introduction

Wildland areas tend to be complex environments that cover one-third of the Earth's surface [1]. These locations are affected by various environmental and anthropic factors and by fires, which are the most dangerous and destructive due to the speed of their propagation [2]. Approximately 67 million hectares were affected worldwide by wildland fires between 2003 and 2012 [3]. At present, despite a century of rapid technological advances, losses due to wildland fires continue to increase due to several factors [4]. The most significant is climate change, since it is the basis of a world trend in the increase of wildland fire activity. Another is the increase in communities on wildlands prone to fires due to vulnerable constructions that are poorly prepared for fires. Attempts at fire exclusion instead of land management have brought about ecological changes that are another factor to consider. In light of these issues, Finney described the prevention of disasters caused by wildland fires and the success in their management more completely as risk reduction [4].

In addition, the impact caused by a wildland fire can be seen based on the damage caused to the ecosystem (flora and fauna) and to all types of organisms existing in the affected perimeter, as well as a reduction in the regenerative capacity of the forest itself and conservation of the water resource [2]. Destructive and recurring (high-intensity) wildland fires are one of the greatest dangers to the viability and sustainable development of wildlands, and they affect the natural and cultural surroundings, the economy, and the quality of life of local and regional populations [5].

Wildland fires are classified into three categories according to their location and size. The first is known as an underground fire, where only the smoke is visible and no type of flame can be seen. The second classification is a surface fire, which means that smoke and flames are visible. If the second case cannot be controlled, then the third category is reached: the crown wildland fire, which is most noteworthy and known for its high flames and for engulfing large amounts of forest [6]. On the other hand, in the literature, we can also classify the different types of wildland fires as: prescribed or controlled and uncontrolled, which tend to grow indefinitely [7]. To act appropriately on a wildland fire and reduce the risk, one must be aware of the situation and know as many details as possible in order to make decisions. Situational awareness becomes a critical factor in any activity where the complexity negatively affects decision-making [8].

To support the decision-making, global predictions have been generated in specific areas through monitoring. This can be done using different technologies, such as satellite images, IoT, sensor networks, and many others [9]. Generating accurate predictions and monitoring fires and/or the biophysical variables involved becomes a key factor for scientists and authorities to estimate the economic and environmental consequences of the disaster, in addition to using these events as key data to avoid future fires [10]. However, the great heterogeneity of the information and the wide variety of technologies can be counter-productive, since depending on the land, environmental factors, sensors or satellites, the estimations, and results can vary drastically [10]. Hence, it becomes relevant to accurately select the tools and technologies to be applied in the development of the Decision Support Systems (DSS) used in management. Not considering the foregoing can generate an enormous cost in resources, not only in economic terms but also in the response time in combatting wildland fires [11]. The origin of DSS is the integration of two main research streams, the theoretical study of organizational decision-making (integrates intelligence, design, and choice) and interactive computer systems [12]. Since some years, DSS has incorporated other disciplines, such as artificial intelligence, operations research, organizational studies, and management information systems. On the other hand, these systems incorporate activities such as the acquisition of information relevant to the problem that needs a decision and action; the analysis of all the data to develop intelligent recommendations; the determination of the appropriate actions to achieve the objectives and solve problems; and the creation of a permanent record of acquisition, analysis, and application of information [13].

From here, the need arises to know the DSS for the existing wildland fire management so as to understand the different tools and technologies used in the different geographic areas and topographies around the world. To this end, the methodology of systematic mapping proposed by Petersen [14] was applied, based on the systematic review work proposed by Kitchenham [15]. The author adapted the methodology from the medical research sector for use in Information and Communication Technologies (ICT). The aim of the study is to present, through a general view of the DSS used to combat wildland fires, the different technologies used, the spheres where these systems are deployed, and the kinds of problems they solve. The key concepts related to the problem are relevant to the study if they are related to wildland fires. On the other hand, the concepts key to the type of solution must be related to the use or development of systems or ICT in the computer science area. Those documents that met both conditions were selected. We are aware that several papers that contain an important contribution to support decision-making were not selected, because they did not include a description of the system used.

The document will be structured as follows: Section 2 will present the background of the studies. Section 3 will present the research methodology and will detail the steps to be applied. Section 4 will detail the activities performed during the systematic mapping and its results. In Section 5, a discussion is presented regarding the most noteworthy contributions to the literature. Section 6 presents the limitations of this study. Finally, Section 7 contains the conclusions.

2. Background

2.1. Decision Support Systems and Wildland Fires

DSS are the area of the discipline of information systems (IS) that concentrates on supporting and improving managerial decision-making [16]. Given the research available on DSS, various definitions have been provided by scholars to present the differing perspectives on DSS [17]. According to Trianni et al. [18], DSS involves computer systems that address issues that could be a combination of structured and unstructured components. Romiszowski presented DSS as involving decision problems that were continuous and had programmed and unprogrammed components [19]. Samuel et al. [20] provided another perspective and presented DSS as how computers are involved in the decision-making processes as part of an overall system for organizations. The purpose of the development of a DSS is an attempt to improve the effectiveness of the decision-maker. In a real sense, DSS is a philosophy of information systems development and use and not a technology [21].

The origin of DSS dates back to previous works in two main research streams: the theoretical study of organizational decision-making that integrates three phases: intelligence, design, and choice and interactive computer systems [12]. However, the study of decision-making and DSS has evolved, incorporating other disciplines such as artificial intelligence, operations research, organizational studies, and management information systems that have added richness and complexity to DSS research.

In terms of contemporary professional practice, DSS includes support systems for personal decision-making (PDSS), negotiation support systems (NSS) [16], group support systems (GSS) [22], executive information systems (EIS), online analytical processing systems (OLAP) [23], intelligent decision support systems (IDSS) [24], business intelligence (BI) [25], and business analytics (BA) [21]. According to Arnott, each of these “DSS types” represents a different philosophy of support, system scale, level of investment, and potential organizational impact [21]. On the other hand, they can use quite different technologies and can support different management groups. Figure 1 broadens Arnott’s analysis, including Big Data as a new type of DSS, since it combines BA with IDSS. The figure shows the evolution of DSS through partially connected subfields.

PDSS are small-scale systems normally developed for a manager, or a small number of independent managers, usually to manage a decision task that is made individually. A GSS consists of a set of software, hardware, language components, and software that supports a group of people who participate in a decision-making meeting [22]. In this case, the responsibility for the decision is shared by several managers.

NSS also operate in a group context, but as the name indicates, they involve the application of IT to facilitate the negotiations [16]. Two approaches arose, the first being problem-oriented and the second process-oriented [21].

AI techniques have been applied to support decisions, and these systems are normally called intelligent DSS or IDSS, although the term knowledge-based DSS has been used [24]. IDSS can be classified into two generations: the first involves the use of rule-based expert systems, and the second generation uses neuronal networks, genetic algorithms, and fuzzy logic.

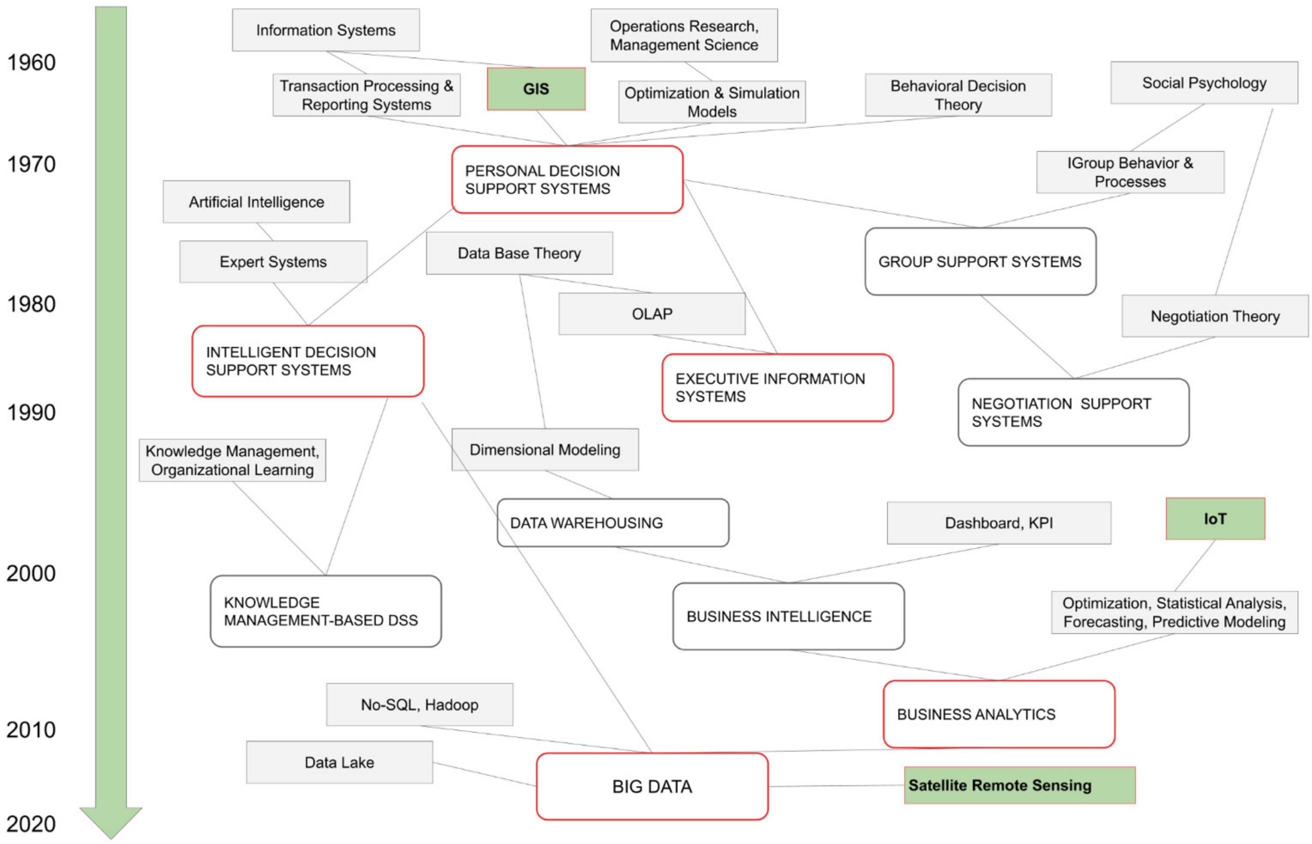


Figure 1. Evolution of DSS through partially connected subfields [21].

On the other hand, a data warehouse is a multidimensional set of databases created to provide information on management indicators for decision-makers [23]. These systems provide processed data to support user-centered decision-making through PDSS, EIS, and OLAP.

The management of organizational knowledge (OK) has garnered a great deal of attention by executives and academics since the beginning of the 1990s. The action of organizations to manage what they consider knowledge is vital in their ability to increase innovation and the competitive edge and to support decision-making [21]. OK affects the entire organization and involves the management of several areas that include IT, organizational behavior, organizational structure, economics, and organizational strategy.

Analytics, BA, and BI are often used interchangeably in the business literature, and they convert data into useful information [25]. However, they differ in the purpose and methodologies used. BA sequentially applies a combination of descriptive (what is happening); predictive (why something is happening, what new trends may exist, and what will happen next); diagnostic (why it happened); and prescriptive (what is the best course for the future) analytics to generate new, unique, and valuable information that creates an improvement in the measurable commercial performance. The analyzed data can be obtained from commercial reports, databases, and commercial data stored in the cloud. On the other hand, BI concentrates on consultations and the generation of reports and can include information sent from a BA approach. BI uses OLAP to display management indicators through charts and pivot tables [23].

Big Data emerged as an ecosystem capable of successfully addressing contemporary digital challenges [26,27]. Nowadays, Big Data integrates the GIS [28] based on cloud technology, including wildland fire modeling technologies [29]. This makes it possible to create last-generation fire management services. On the other hand, Big Data integrates several types of DSS, since its architecture can administer the data of the business together with data from users, social networks, and the data from the fires themselves. This is due to the ability to integrate a variety of data [30].

The growing concern for subjects such as environmental quality or the sustainability of natural resources has led environmental decision-makers to use DSS, because they have evolved considerably and are equipped with a variety of tools such as graphs, interactive visual modeling, artificial intelligence techniques, fuzzy sets, and genetic algorithms [31]. This is due to the need to maintain the environment and global environmental well-being, the analysis required due to climate change, and the need to conserve species and biodiversity. Yet the management of natural resources due to the economic and recreational aspects is also necessary and must be considered by decision-makers.

The Wildland Fire DSS possesses many attributes that make it uniquely different from other decision systems that have been used in wildland fire management. These differences, along with implementation swiftness, represent a significant change in fire management practices [13]. Wildland Fire DSS fully utilizes all aspects of information management, facilitates the application of the latest science and technology, incorporates the most applicable attributes of accepted decision-making models, and modernizes fire management by advancing the decision-making capability [13]. According to the author, DSS should incorporate the following activities:

Acquisition: the rapid assimilation of all the relevant information for the topic or problem that needs a decision and action.

Analysis: the evaluation of all relevant data and information to develop recommendations to support decision-making.

Application: the process of making a decision, determining the appropriate actions to achieve objectives and solve problems.

Archive: the creation of a permanent record of the acquisition, analysis, and application of information.

The use of DSS by wildland fire administrators has increased rapidly due to the possibility of selecting strategies to manage wildland fires, considering both functional and economic efficiency. This has reinforced the ability to prevent and suppress wildland fires while protecting human life and property. Sakellariou conducted a study to analyze the state of the art of the DSS in use [5]. The systems have been classified as: (1) database management systems and mathematical/economic algorithms for the spatial optimization of fire fighting forces; (2) wildland fire simulators and satellite technology for the immediate detection and prediction of the evolution of wildland fires; and (3) GIS platforms that incorporate several tools to manipulate, process, and analyze geographic data and develop strategic and operating plans.

Themistocleous conducted a study that illustrates the contribution of Big Data to wildland fire prevention [29]. In this sense, Big Data can integrate all the types of systems previously mentioned. From Figure 1, we can see the types of DSS in red, which are those that have been used to solve wildland fire problems. Our study considers Big Data an important type of DSS in wildland fire administration, promising to be a technology that solves the current challenges.

Another point of view from the studies analyzed is that of Finney, who conducted a study on the use of modern wildland fire administration systems in terms of their historical context, mainly in the US, and analyzed some of the features of the systems and human culture that affect the potential impact of the innovations and engineering technologies [4].

On the other hand, Chuvieco analyzed various technologies used as support in wildland fires. That analysis followed the different categories of fire management: prevention, detection, and post-fire assessment [32].

Noble's study analyzed the adoption of DSS in the US Forest Service. The results indicated that fire administrators appreciate many components of DSS but see them mainly as a means to document fire management decisions [33]. This is due to several problems that must be faced when a wildland fire breaks out, such as the following: (1) it is difficult to communicate with all the members of a work team exactly when required, and therefore, the DSS cannot be used with all the information that it provides; (2) depending on the threat level, decisions are made only through conversations and expert judgment, not using data from the DSS; and (3) the lack of qualified personnel to use the DSS correctly. Noble notes that these factors influence the adequate use of the DSS, causing a low level of adoption.

A recent study on the use of technology tools to improve decision-making in wildfires at the U.S. Forest Service increased the ability of line officers to communicate their decisions more clearly and transparently to their colleagues and partners [34]. The system analyzed was Risk Management Assistance (RMA). The study by Schultz et al. revealed the complexity of adopting risk management in wildfires and, also, in other similar contexts, such as emergency management. The authors concluded that the integration of data-driven analytics into the risk management process supports decision-making during incidents by providing more operationally relevant information. Some examples of fire analysis include weather forecasts, safety zones and escape routes, suppression difficulty maps, and fire control location probabilities. Incorporating analytics is not a substitute for making real-time adjustments based on human judgment, but it can inform more strategic response decisions. Infusing risk management into the fire management system has the potential to improve decision-making, improve the safety and effectiveness of wildfire responses, and usher in a necessary change in wildfire management.

2.2. Challenges for the Use of DSS in Wildland Fires

This section describes the challenges of using DSS in wildfires, considering different points of view. Some of the authors included challenges for a specific DSS, others in its regional context, and others according to the findings found in a review or state-of = the-art technology.

Noble carried out a study on the adoption of DSS for wildland fire management in the USA [33]. Through interviews with the personnel who worked in different wildland fire roles, he found the following challenges that must be considered in the construction of DSS. See Table 1.

Table 1. Challenges for DSS in wildland fires in the USA according to Noble [33].

Challenge	Description
Lack of time	The interviewees explained that the operating pace of the fire frequently exceeds the managers' capacity to make a decision through a DSS. The time required to prepare a quality decision through a DSS and that is supported by careful analysis is often underestimated compared to the time invested in developing a strategy through dialogue.
The complexity of the DSS	Generally, the interviewees indicated that the DSS are not friendly, so they require full training in their correct use.
Lack of availability of users skilled in the use of DSS	Fire managers perceived that the DSS are more useful at reporting the decision-making when there are qualified personnel available to develop a fire management strategy using the decision-making process.
The high level of experience needed to execute DSS	One of the main challenges in the use of DSS, as the interviewees described it, was bringing together the right people at the right time to make a prompt decision.

These factors contribute to managers using DSS mainly for documentation instead of facilitating informed decision-making on the risks and effects in the field.

On the other hand, Finney explained that three challenges were evident and others according to their own cultures and beliefs. Table 2 describes these challenges.

Table 2. Challenges for DSS in wildland fires according to Finney [4].

Challenge	Description
Evident	(1) Acquiring knowledge of the physical science of the fire, (2) developing practical methods and tools to use this knowledge and educate the personnel, and (3) benefitting from having specialized knowledge accepted within the fire management culture must be appreciated and valued for the purposes of strategic planning and implementation
Culture and beliefs	(1) All fires are harmful and potential natural disasters, and (2) suppression is necessary, sufficient, and effective at protecting communities and natural resources.

Finney explained that belief culture has even greater validity, more than a fact-driven analytical system. The author explained that the most challenging feature of wildfire culture is that it shuns responsibility, except when you can blame yourself for starting a fire. There is no responsibility for the individual and collective actions (or inactions) that perpetuate the disaster cycle (land management, suppression, construction, zoning, etc.), and therefore, there is little incentive for any group to avoid continuing to perform their cultural roles [4].

Zaimes et al. analyzed the problems faced by six Black Sea countries regarding protected areas and wildland fires [35]. The authors demonstrated the need to include ICT for the suppression of wildland fires and the management of protected areas through expert surveys. They concluded that there is a growing awareness of the adverse impacts of climate change on protected areas and the frequency of wildland fires in the future. Table 3 summarizes these challenges.

Table 3. Challenges for DSS in wildland fires in the Black Sea according Zaimes [35].

Challenge	Description
implementation of ICT	ICT allows (1) changes in forest management, (2) better monitoring, (3) increased awareness information on the suppression of wildland fires, and (4) greater training of personnel to improve the conservation of protected areas.

According Martell [36], forest and wildland fires are natural ecosystem processes, but fire can and often does pose significant threats to public safety, property, and forest resources. They explained the challenges for fire managers that are charged with the responsibility for achieving an appropriate balance between the beneficial and detrimental impacts of fires. Table 4 summarizes these challenges.

Table 4. Challenges for DSS in wildland fires according to Martell [36].

Challenge	Description
achieving an appropriate balance between the beneficial and detrimental impacts of fire	Sound fire management calls for (1) fuel management, (2) fire prevention and detection, (3) the suppression of potentially destructive wildfires, and (4) the modified suppression of some wildfires, allowing some beneficial wildfires to burn, and the use of prescribed fires to achieve ecosystem management objectives.
how to contain a fire	Containing a fire is complicated by uncertainty concerning the weather and its impact on fire behavior and suppression resource effectiveness. (1) The resources used for the initial attack vary by agency, and the determination of which resources to dispatch and the order in which they are dispatched to each fire varies by agency and by fire. (2) Assess the fuel, weather, and topography and its impact on fire behavior and suppression crew effectiveness, all the while keeping in mind that wind and other weather variables can, and often do, change dramatically.
safety of the fire crews is paramount	Initial attack operations pose many complex decision-making challenges to the incident commander, who must resolve his or her decisions under uncertainty.

Martell explain modern fire management agencies face far more complex decision-making problems. The development of modern transportation and telecommunications systems have supported the creation of national and international collaborative agreements that make it possible for fire mangers to quickly mobilize much larger and more costly suppression forces than was ever the case in the past [36].

On the other hand, Pacheco et al. explained that wildfire management has been struggling with escalating devastation, expenditures, and complexity [37]. Given the copious factors involved and the complexity of their interactions, uncertainty in the outcomes is a prominent feature of wildfire management strategies at both the policy and operational levels. Therefore, improvements in risk handling and in risk-based decision support tools have a key role in addressing these challenges [37].

The author explained that a major challenge is the governance of the risk, which includes risk management, looking at the coordination or reconciliation requirements when a variety of actors is present, considering the historical and legal background, guiding principles, value systems, and perceptions, as well as organizational imperatives. In this context, the role of risk-based decision support is also challenged to be widened and encompass these additional aspects [37]. After conducting a literature review, they concluded that the implementation of DSS raises other important challenges, as described in Table 5.

Table 5. Challenges for DSS in wildland fires according to Pacheco et al. [37].

Challenge	Description
General Challenges	(1) The involvement of multiple stakeholders who must be considered in the decision-making processes, (2) the need for adaptation to local contexts, (3) and the strong influence of external pressures and opinion leaders on adoption decisions, (4) and how users perceive the system.
Risk-based analysis	(1) A risk-based analysis is required for the integration of risk handling and fire management, in order to improve the prioritization of future efforts to mitigate the risks associated with these natural and human caused disturbances. This asks for more research in biophysical and social sciences with a dynamic spatiotemporal perspective about fire spreading and effects models to fuel treatment effectiveness, climate change impacts, and social preferences. (2) Is required for the integration of risk handling and fire management, in order to improve the prioritization of future efforts to mitigate the risks associated with these natural and human-caused disturbances.

Another challenge to consider is the incorporation of studies of the physicochemical properties of the soil to analyze the effects of forest management after a wildland fire [38].

Opportunities to change wildfire outcomes, measured as reduced risks for both developed and ecological values, are primarily achieved through proactive fire management rather than emergency response [4]. In this regard, engineering should be encouraged to focus on research that increases the knowledge of wildfire behavior, develops modeling tools for the application of strategic planning, and then enhances the education and training of fire professionals: foresters who can design and execute proactive projects and fire management strategies. DSS become a crucial tool for these tasks, since they integrate a set of valuable data, which allows engineers to observe the data from different perspectives, not only those of the forest fire when it occurs.

3. Research Methodology

The research methodology used is known as systematic mapping, which is designed to define processes that can recognize and categorize the results that have been published in a certain area [14].

The main objective of mapping in itself is to classify; thus, it seeks to identify the main focal points of publication. It responds to questions like: What has been done to date in area X? An existing limitation is that such studies do not consider the quality of the works included.

Systematic mapping is based on the following stages: (i) define the research objectives, (ii) define the research questions, (iii) establish the search string, (iv) select studies and filter studies, (v) classify, (vi) extract data, and a systematic map. Figure 2 presents a summary of these stages.

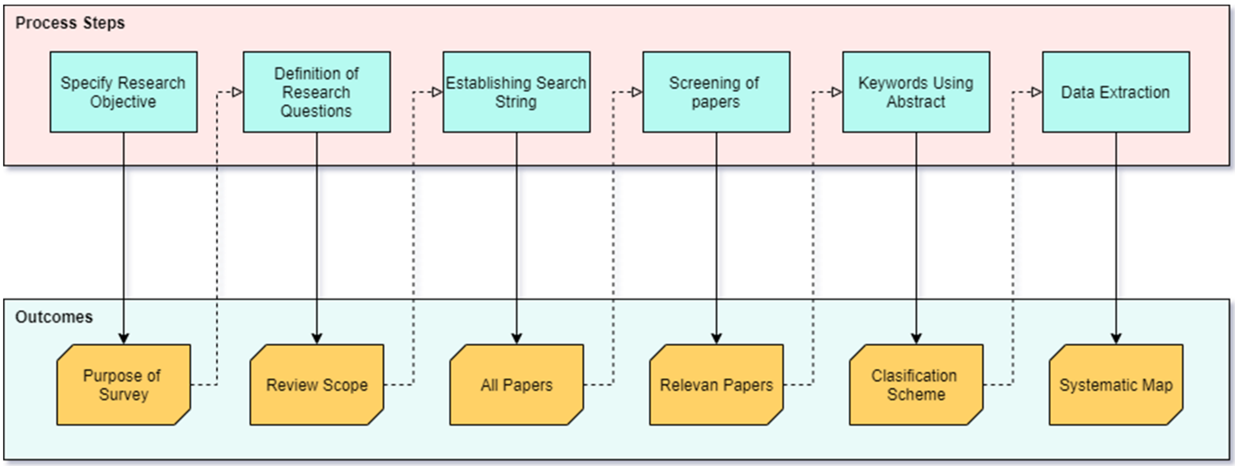


Figure 2. Stages of systematic mapping.

4. Activities Developed in Systematic Mapping

4.1. Research Objectives

The objectives of this research were as follows:

O1. Identify the studies that explain the use of DSS in wildland fire management.
O2. Characterize the DSS used in wildland fire management.
O3. Classify the types of DSS used according to the problems encountered in wildland fires.
O4. Identify the technologies used in the DSS for wildland fire support.
O5. Identify the type of research used and the study context.

4.2. Definition of the Research Questions

The research questions (RQ) were created using the methodology proposed by Kitchenham [15] through the PICO technique [39], where the population, intervention, comparison, and results are defined. This SLR addresses six research questions with their motivations, as shown in Table 6.

Table 6. Research questions.

N	Research Question	Main Motivation	Research Objectives
RQ1	What kind of wildland fire problems are solved through a DSS?	DSS have been used to solve various problems in wildfires. From different points of view, examples of problems are: early detection, prevention, mitigation, risk management, analysis of historical data, rescue, and simulations of scenarios, among others.	O1, O3
RQ2	What types of DSS were used?	DSS are classified according to Figure 1. Not all types of DSS have been used in wildfire management. The most used are PDSS, IDSS, EIS, BA, GSS, and Big Data.	O2
RQ3	What type of research was used, if it was a case study, experiment, or prototype?	Understanding the type of contribution is essential to determine the progress in the implementation of the DSS, especially those recently used, such as BA and Big Data.	O5
RQ4	In what context were these systems used, if it is in academia or in industry (real case)?	It allows to know the status of adoption of the DSS in the management of wildfire.	O5
RQ5	What technologies were used in the DSS found?	It allows to know the technologies used according to the type of DSS used and with respect to time.	O4
RQ6	How has the development of the DSS, for the management of forest fires, evolved over time?	It allows to analyze the evolution of the use of DSS in wildfire over time. With this, it is possible to discuss trends.	O1

4.3. Search String

The strategy used for the search was to use Boolean expressions, formed by the following keywords: "System", "Forest fire", and "Wildland Fire". The term "system" is used due to the definition of DSS according to Liu [12], since it integrates the theoretical study of organizational decision-making and interactive computer systems. In addition, year of publication was added as a condition to avoid out-of-date computer science systems or publications of systems not related to the computer science area. All this was disaggregated through the OR and AND Boolean expressions. The data sources used to test various search strings were Scopus and Google Scholar. Once the relevant string was selected (see Table 3), a search process was carried out in the sources Scopus, WoS, IEEExplore, ACM, MDPI, Springer, and Elservier, finding 22,200 documents, respectively.

The search string in Table 7 was applied to Titles, Abstracts, and Keywords in all the sources mentioned.

Table 7. Search string.

Sources	Search String	Item
IEEEXplore, ACM, MDPI, Elsevier Springer Link, WoS, and Scopus	"system" AND ("Forest fire" OR "Wildland fire")	Titles, Abstract, Keywords

4.4. Screening of Relevant Papers

None of the papers were precisely relevant to the research questions. Therefore, these papers needed to be assessed according to the actual relevance. For this purpose, we used the search process defined by Dybå and Dingsøyr [40] for a screening of relevant papers. In the first screening phase, papers were selected based on their titles, and we excluded those studies that were irrelevant to the research area. In the second screening, we read the abstract of each paper selected in the first screening phase. Furthermore, inclusion and exclusion criteria were also used to screen the papers.

We excluded the following types of papers:

- Articles not published in the English language.
- Articles published other than conferences, journals, and technical reports.
- Articles published before 2010.
- Articles that did not include the use of DSS for support in wildland fires.
- Incomplete articles or that did not resolve a problem.
- Papers that were not relevant to the search string.

Papers were selected based on the given exclusion criteria, and after examining the abstracts of the selected studies, we decided to include them in the next screening phase.

4.5. Keywording Using the Abstract

To find the relevant papers through keywording using the abstracts, we used a process defined by Petersen et al. [14]. Keywording was done in two phases. First, we examined the abstract and identified the concepts and keywords that reflected the contributions of the studies. Concepts related to the problems to be solved and the types of solutions developed were found. The concepts related to the problems were relevant to the study if they were related to wildland fires. On the other hand, the concepts related to the types of solutions must be related to the use or development of systems or ICT. Those documents that met both conditions were selected.

In the second phase, the results and conclusions sections were reviewed. These sections provide information on the results obtained with the support of the system or ICT used to solve a problem in wildland fires. Special care was taken to select the documents that presented a clear solution to improve decision-making.

Various work meetings were held in order to achieve a correct selection of relevant documents. In the meetings, each researcher and assistant showed the results of the review of the abstracts and the results and conclusions. This allowed the resolving of doubts.

4.6. Study Selection Process

Figure 3 shows the results of the selection and search processes. Initially, 22,200 articles were selected when the search protocol was applied in the selected repositories. The selection process was applied based on the inclusion and exclusion criteria, keywords, titles, abstracts, and full articles of the retrieved articles. Three researchers selected papers based on searching through the designed search string. Then, the same research applied the selection criteria based on the title of the paper, obtaining a set of 3851 papers. Relevant titles were those that included the following key concepts: forest, fire, forest fire, wildland fire, wildfire, system, and DSS.

Eliminating duplicate papers, a new set of 2745 papers was obtained.

We analyzed the abstracts of each paper, selecting those that showed the use of DSS in wildland fires. We considered the characteristics described by Zimmerman [13] to determine if the papers described a DSS. Some of these features were based on the following components: acquisition, analysis, application, and archival. On the other hand, the author explained that the DSS have a constant flow of data; since they are acquired from various data sources, they are quickly processed to be analyzed and, finally, visualized at the right moment for decision-making.

A Cohen's kappa coefficient of 0.92 was used to determine an acceptable level of agreement between the authors [41]. For this, 20 papers were selected at random, which were reviewed by the researchers. Each paper was marked with the categories YES, NO, or DOUBT. This process was repeated several times until an index greater than 0.9 was obtained. When there was DOUBT, the abstract was analyzed as a team. Furthermore, after reading the full abstracts of the 2745 articles selected in the duplication phase, we selected 1470 papers based on their abstracts.

After reading the results and conclusions sections, we selected 183 pertinent papers that contained the necessary data to answer the research questions. The full paper was read only when necessary, as some documents did not include a results section.

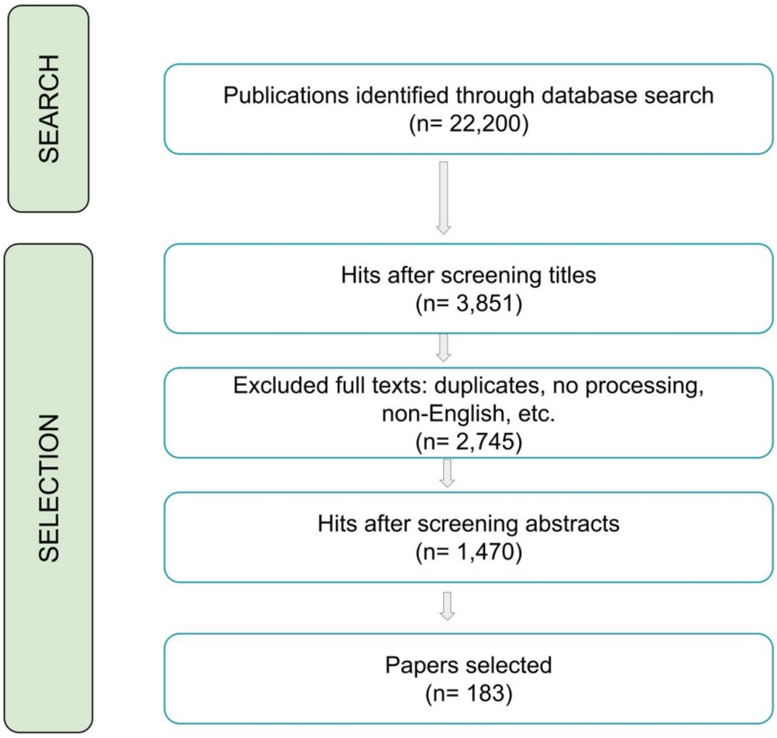


Figure 3. Papers selection process.

4.7. Data Extraction Method

The data extraction strategy was applied to provide a set of possible answers to the research questions defined.

The following classifications were considered on the basis of the RQ designed:

(i) Types of problems: These are classified according to the problem of wildland fire management that they solve. The most noteworthy problems include the divergence between the beginning of the fire and the detection, which, in this work, will be mentioned as a detection issue. Other types will be the monitoring of sectors with a potential fire hazard, the management of a fire that already is active, the prediction of future fires, the simulation of fire behavior, the prevention of how fires are generated, and the generation of access routes.

(ii) Types of DSS: These are classified according to the DSS presented in Figure 1. In the area of wildland fires, we found PDSS, IDSS, EIS, GSS, BA, and Big Data.

(iii) Types of research: The possible classifications are case study, experiment, or prototype. Case study corresponds to the process of focusing on a single case from a group or defined place; therefore, its results are inherent and exclusive to that group or place. An experiment corresponds to a procedure in which the goal is to make a discovery, prove a hypothesis, or verify a known fact. A prototype is a first product or proof of concept.

(iv) Context in which it is used: This is the developed context of the study, either in academia or industry (real case). The academia context is considered when the work is carried out within a research center, institute, university, or other. The industry context is used when the work was carried out in an organization, company, or business.

(v) Technologies used: These are all the technologies mentioned in the studies analyzed. Several technologies were used for the data intake, processing, analysis, and visualization of the results.

Figure 4 presents the classification scheme.

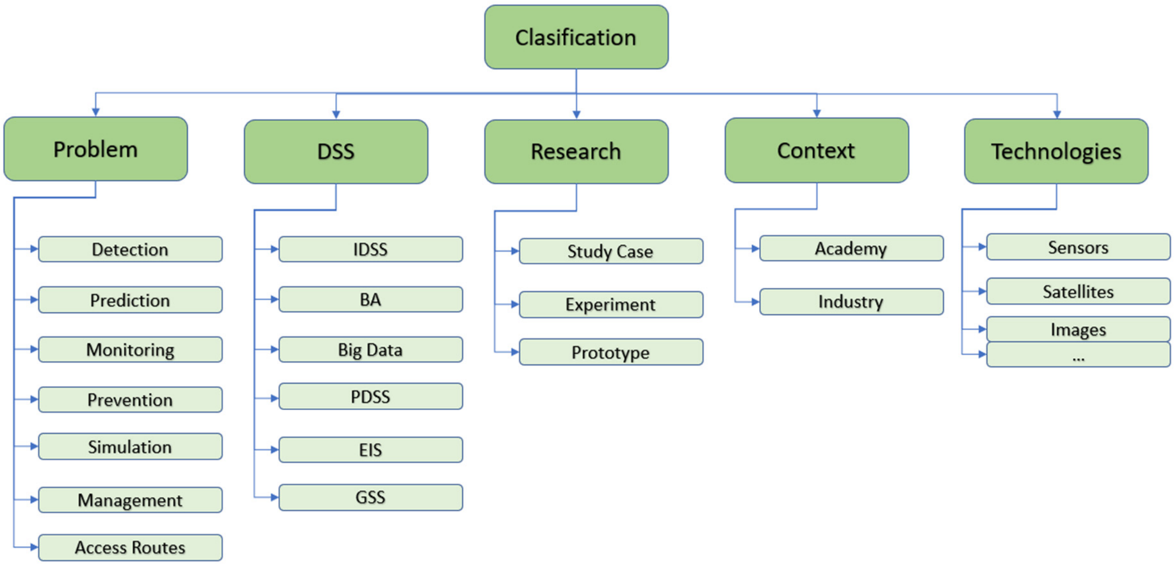


Figure 4. Classification scheme.

4.8. Selection of Results

To answer our research questions, we brought together 183 primary studies in this section. After analyzing the studies selected, we tried to answer each question with the information extracted. Table A1 presents the list of articles, the dissemination channel, the year of publication, and the number of citations. This makes it possible to obtain data from the main dissemination channels in this area of study.

4.9. Results of Systematic Mapping

In this section the designed RQ are answered. A discussion of the most relevant aspects also occurs.

Figure 5 presents the Systematic Map obtained. The bubble graph represents the number of studies found according to the classification. Thus, for example, it was found that 36 studies solved problems of monitoring through PDSS. On the other hand, 13 studies explained the use of EIS to solve management problems. The figure shows that, in 2014 and 2015, the number of studies in this area decreased. However, in recent years, it has increased considerably.

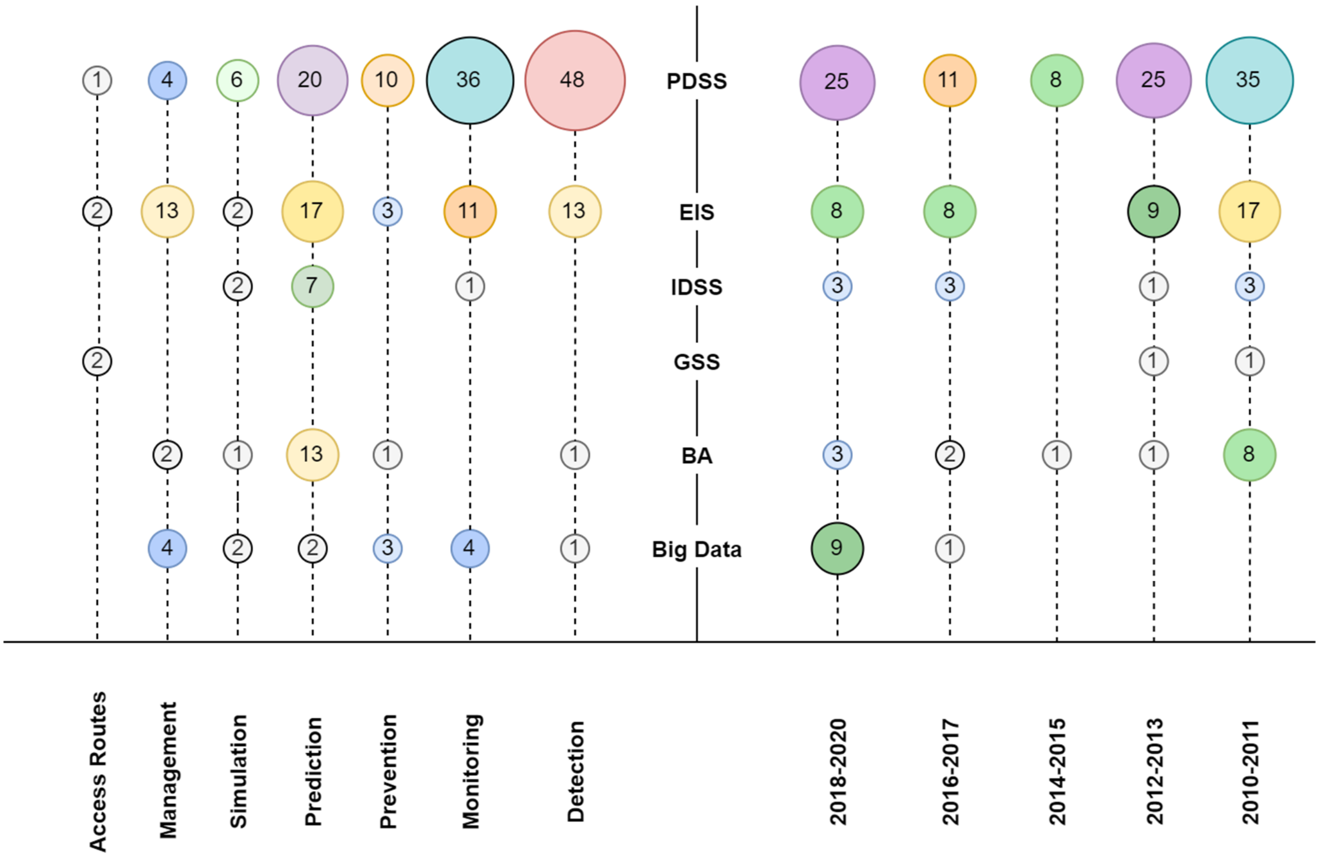


Figure 5. Systematic map.

4.10. Response to Research Questions (RQ)

In this section, the RQ designed in the first stage are answered.

RQ1. *What kind of wildland fire problems are solved through a DSS*?

Management problems were found in the abstract of the paper or in the introduction, and 26.57% of the papers presented predictions as a problem to be solved. On the other hand, 28.02% presented a need for detection and 22.22% for monitoring. This is consistent with the comment by Saoudi on the constant need for organizations in charge of firefighting to generate early detection [42]. It follows that the longer the time from its generation to its detection, the more difficult it is to control and fight it. The kinds of problems remaining focus mainly on management (8.7%) and the need for a simulation (5.8%) of the behavior based on different environmental factors. In addition, there was the need for prevention (7.73%) and the generation of access routes for the firefighters or organizations in charge of the rescue (0.97%). Figure 6 presents a graph of the number of studies found versus the problem to be solved.

It should be noted that other aspects and solutions to these problems are mentioned in the development of the papers that have not been considered in this study.

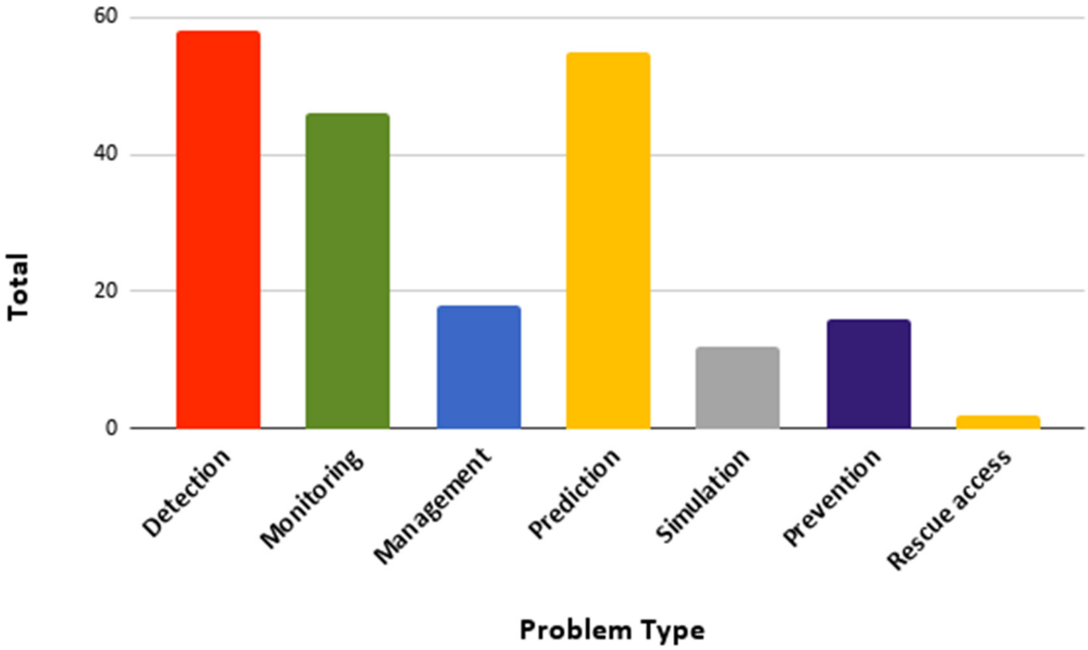


Figure 6. Number of studies found versus the problem to be solved.

RQ2. *What types of DSS were used*?

It was found that 5.46% of the works analyzed indicated the use of IDSS, 56.83% used PDSS, which included the use of GIS, 8.2% used BA, and finally, 5.46% used Big Data systems. Figure 7 summarizes these quantities. Table 8 presents the articles selected according to the type of DSS used.

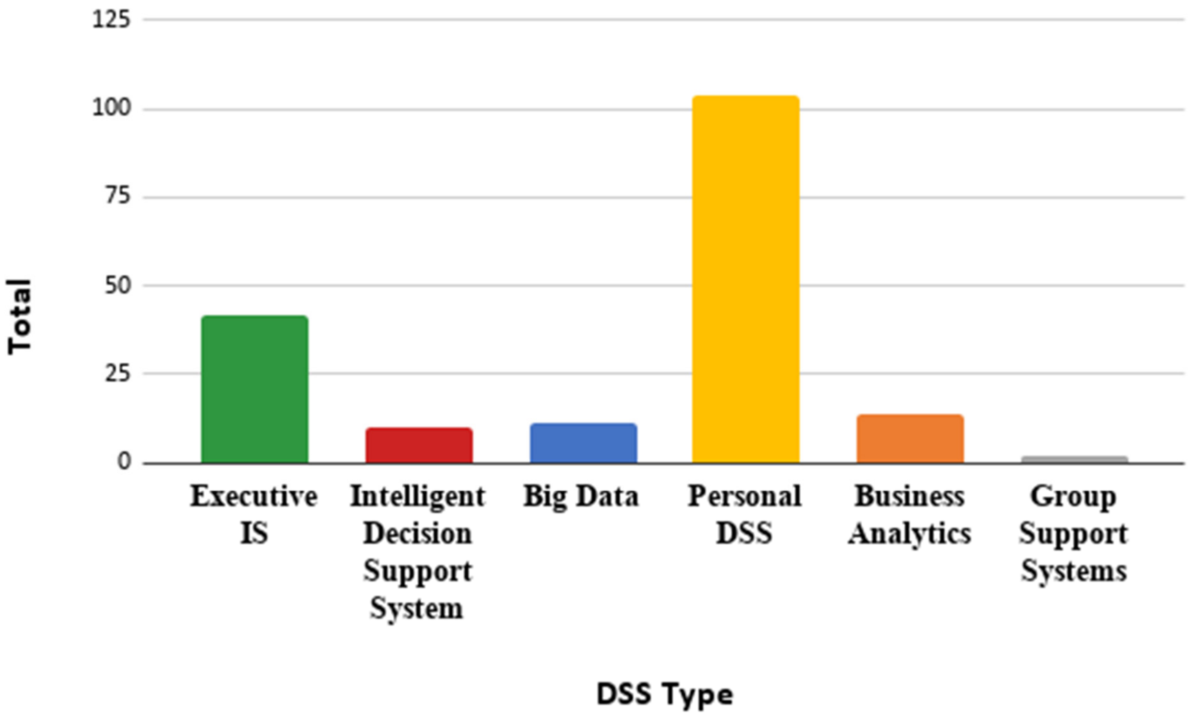


Figure 7. Number of studies by type of DSS.

Table 8. Classification of articles by DSS type.

DSS Type	References
PDSS	[2,8–11,42–140]
EIS	[10,49,67,93,94,111,112,118,126,141–173]
IDSS	[89,98,99,173–179]
GSS	[111,158]
BA	[77,86,90,149,172,180–189]
Big Data	[29,45,145,181,190–195]

It was observed that the most widely used type of DSS continued to be the traditional PDSS (including GIS). Despite technological advances, with the application of AI and Big Data, there is low use of these in the field of forest fires. In this sense, the authors Noble [33] and Finney [4] were right to discover that the practical use of DSS contemplates several challenges that have not yet been solved, such as ease of use and the way in which information is delivered to the different roles when facing a forest fire. On the other hand, the lack of qualified personnel implies little use for forest fire management.

RQ3. *What type of research was used, if it is a case study, experiment, or something else?*

Figure 8 shows that 36.3% of the analyzed works used a prototype as a solution to the problems detected. It can also be seen that the distribution was relatively equitable between the two remaining: case study (37.5%) and experiment (26.3%).

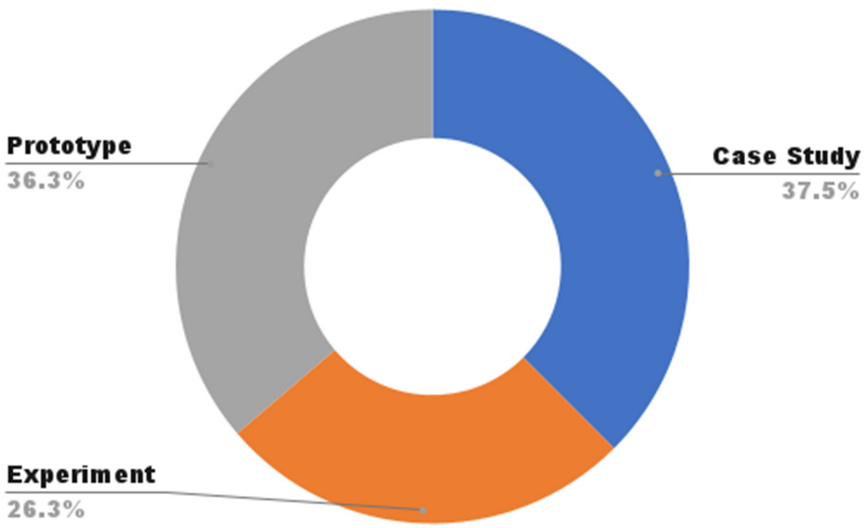


Figure 8. Types of research used.

RQ4. *What context were these DSS used in: academia or industry (real cases)*?

The majority (63.75%) of the papers come from academia, and the remaining (36.25%) from industry. This indicates that the research processes are developing, and technologies are constantly being tested that can more effectively support the management of wildland fires. This is beneficial from the point of view of continuous improvement.

RQ5. *What technologies were used in the systems found*?

Figure 9 presents a word cloud according to the technologies mentioned in the 183 studies analyzed. Both the wireless sensor networks and WSN tools were the most mentioned and outstanding. On the other hand, the use of cameras, GPS, IoT, GPRS, and Satellite Images was observed. The use of Cloud Computing and unstructured databases such as Hadoop is not yet massive.

Figure 9. Word cloud of the technologies.

Table 9 presents a summary of the main technologies used according to the papers' years of publication. It is observed that sensors and images have been used since 2010, which generate data to be processed by GIS. This data processing is usually slow due to the lack of smart technologies, and others that can work with a large volume of data. Cloud use is observed as an opportunity, since they are adequate services for the processing of a large volume of unstructured data at high speed. On the other hand, machine learning enables the development of smart systems to create predictions and self-learning.

Table 9. Technologies most frequently used between the periods of the defined years.

Years	Technologies
2018–2020	Cloud Computing, Machine Learning, Neural Networks, Sensors, Data Mining, real 3D image, Fuzzy Inference System, Big Data Tool
2016 and 2017	WSN, UAV, Satellite Images, aerial vehicles
2013–2015	ArcGIS, Sensores, Zigbee, MATLAB, MODIS
2011 and 2012	Sensors, Satellite Images, GPS, MODIS, Cámaras, GIS Tool
2010	Sensors, Satellite Images, GIS Tool

RQ6. *How has the development of DSS evolved over time*?

Figure 5 illustrates the constant presence of PDSS use (56.83%) and EIS (22.95%). On the other hand, it was observed that few studies were published in the period between 2014 and 2015. Although BA has been in use since 2011, only proposals were observed, unlike in recent years, in which it has been used for data analysis problem-solving and decision-making in the field. Big Data, on the other hand, has been used since 2016 as a solution for the analysis of unstructured data (data from experts). Only one paper was found in 2011 that proposed the use of Big Data for forest fire management.

It is worthy to note that there is a paucity of prediction systems employing complex algorithms, with a low number of publications between 2011 and 2015. This may be due to the small quantity and quality of the data used from the data sources, as is the case with sensors and images (see Figure 10).

Figure 10. Studies per year.

It should be emphasized that, among the cited technologies of every era, sensors are a type of technology that is always present in a large number of the studies. This is due to its optimal application for recording environmental data. In recent years, technologies related to large amounts of data have also appeared, such as neural networks, machine learning, and the cloud, which is consistent with the need to produce predictive algorithms but in a more complex form, with algorithms and "smart" systems. In this sense, Big Data is a type of DSS that can integrate these technologies, fulfilling an important role in managing the wildland fire risk.

5. Discussion

This section examines the relevant aspects of the DSS types found. For this, the analysis included the most-cited studies (more than 30 citations), where the impacts and contributions stood out. On the other hand, studies published in recent years were included in order to search for technological advances, problems, challenges, and opportunities.

In the study by Calkin et al. [161], what stood out as the main feature of the DSS used was the generation of combat strategies prior to wildland fires. The use of behavior models, geospatial analysis, datasets generated through biological sensors, and climatological prediction helped improve the problem of decision-making under a large number of external factors that altered the initial combat conditions.

Two works focused on another type of problem, making reference to the provision of a real 3D image of a fire, facilitating its access. This aspect helps improve the decision-making regarding the follow-up and mitigation of a fire. The article by Rossi et al. [164] used a prototype of static cameras in a controlled environment, so stereovision images could be taken. These generated more reliable information to predict the behavior of the fire. On the other hand, the study by De Ríos et al. [118] used a system with static cameras and unmanned aerial vehicles to produce a more feasible image in real time without jeopardizing the people or equipment when mounting a static system near a real fire. The work by De Ríos was significant, because it created safety for the extraction of images.

Unlike the previous studies, Petropoulos et al. [10] compared two types of GIS, one combining neural networks with a satellite image analyzer and a spectral angle mapping system to improve the information for decision-making. The analysis performed on the topographies, vegetation, and soil conditions stands out for producing highly varied results according to the technology used. The authors used combinations of technologies to obtain more concrete results.

In Bianchini et al. [188], a DSS with high calculating power was used to generate results. On the other hand, Denham et al. [183] used a new genetic algorithm to improve on Bianchini's results. As a result, they achieved a significant improvement in wildland fire detection time, which is why the impact can be seen directly. In the same area of prediction, Iliadis et al. [89] are conspicuous for being the only study that used risk analysis models through dynamic algebra, being able to predict the behavior of a fire based on previous knowledge. This had a tremendous impact on Greek fire departments, where their estimations predicted 35–40% of the area to be affected by wildland fires. This may seem small, but knowing 40% of the zones affected by wildland fires beforehand can be a breakthrough in taking preventive measures for those areas.

The work by Soliman et al. [82] stands out, because it combined sensor networks and neural networks in order to generate a DSS that can detect a wildland fire even earlier. Through a neural network, a DSS makes it possible to detect fires in under 20 s. The authors reported that the system gets it right in 98% of cases, which can have a tremendous impact on fighting fires.

On the other hand, Almeida et al. [131] developed a commercial system called Bee2Fire, which allows the detection of forest fires. The system scans the landscape using regular cameras and deep artificial neural networks. Bee2Fire searches for plumes of smoke above the horizon with an image classification approach. Once these networks were trained, the system was deployed in the field, obtaining a sensitivity score of between 74% and 93%, a specificity of more than 99%, and an accuracy of around 82%.

Peng et al. [132] studied a computer vision-based forest fire early warning imaging system. First, a close-up detection of moving targets was performed. A mixed Gaussian model algorithm was then used to determine if there were moving objects in the video. The flames were then tracked and identified on video. Next, it was determined whether it was a flame. The purpose is to draw its outline and give an alarm to the supervisory office when the result is a fire. This early warning system waits for the appropriate personnel to take care of it.

Budiyanto et al. [140] created a forest fire monitoring system for a wide area of fire-prone areas using a WSN (Wireless Sensor Network). The study also used the FIS (Fuzzy Inference System) method as a decision-making method with mathematical calculations that can improve the precision in the fire detection system so that the output of this method is the level of the fire status. The IoT is also used so that information can be received by users in real time through the Internet network. Based on test results on the designed system, Sugeno's Fuzzy Inference System (FIS) calculations on SN1 and SN2 are 100% accurate compared to manual calculations.

Athanasis et al. [190] presented a cutting-edge approach to improving decision support tools for natural disaster management with information from the social network Twitter. The novelty of the approach lies in the integration of GIS modeling outputs with real-time information from Twitter. A first prototype was implemented that integrated georeferenced Twitter messages in a web GIS for forest fire risk management and earthquake monitoring in real time. Following a highly scalable architecture that was based on Big Data components, the proposed methodology could be applied in different geographical areas, different types of social networks, and a variety of natural disasters.

Another study of note was that of Lin et al. [181], because it used a mixture of wireless sensor networks, dynamic inference systems, and Big Data with the purpose of generating accurate fire predictions through risk indices. These different technologies were applied due to the number of factors that can influence the chance of a wildland fire in a study area, from humidity and wind speed to population density and time of year. The authors mentioned that, at festive times and during the day, the risk was much greater than at night or during normal work schedules. Although their experiment was applied and it produced results according to expectations, they also remarked that the area of prediction was one of the most complex [181].

Sayad et al. [194] combined Big Data, Remote Sensing, and Data Mining algorithms (Artificial Neural Networks and SVM) to process the data collected from satellite images in large areas and extracted ideas from them to predict the occurrence of forest fires and prevent these disasters. To do this, they implemented a dataset based on Remote Sensing data related to the status of crops (NDVI) and meteorological conditions (LST), as well as a fire indicator "Thermal Anomalies"; these data were acquired from "MODIS"(Moderate Resolution Imaging Spectroradiometer), a key instrument aboard the Terra and Aqua satellites. The experiments were carried out using the Big Data platform "Databricks". The experimental results offered a high prediction precision (98.32%).

Finally, the study of Bielski et al. [145] stands out, because it worked with Big Data technology to manage fires in a more general sphere, from educating the population to providing monitoring systems to distributing information in a timely manner when a fire occurred. The authors used information from multiple sources, obtaining climatological data, and from social networks. Once the data with which a fire is detected has been processed, the system generates information for decision-making. The system provides support with information relevant to the citizenry or inhabitants of the affected sector so as to avoid human losses. The greatest impact is ensuring the protection of human life. Bielski's work solved the challenges identified by Finney, since the DSS makes it possible to manage the risk more than simply preventing, monitoring, or reporting on a certain wildland fire.

In this discussion, we analyze the main technologies recently used in DSS systems for wildland fire management. State-of-the-art solutions are presented that combine various recent technologies, such as Big Data, Remote Sensing, AI, 3D image, and photo processing, as well as Cloud Computing and data from Social Networks. These solutions can produce real changes in forest fire management if we consider the aspects mentioned by Noble and Finney: friendly systems, staff training, and data analyzed in real time, among others.

Figure 11 represents the relationships that exist between the problems encountered when facing a forest fire versus the types of DSS used so far.

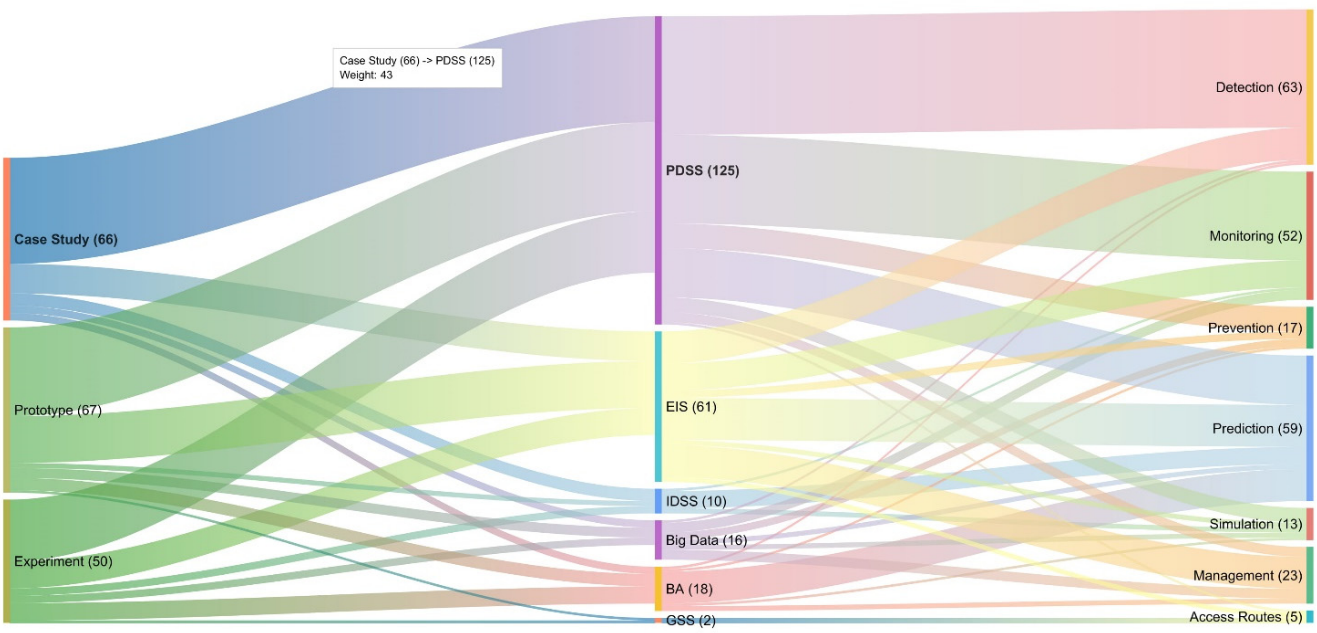


Figure 11. Relationship between the problems encountered and the use of DSS.

6. Limitations of the Study

There have been four kinds of threats to validity identified in this section [14]. The main limitations of the study are inherent to any research work, given that it is impossible to ensure absolute impartiality.

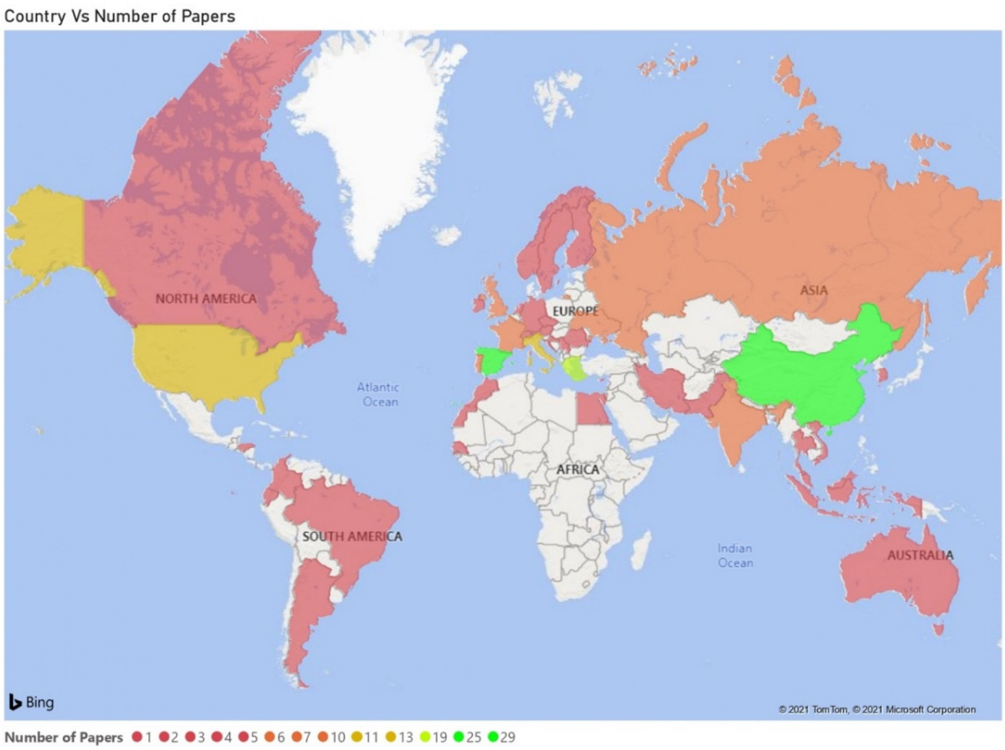
6.1. Construct Validity

In Systematic Mapping, threats to construct validity are relevant to the classification of selected studies. A search string was performed using IEEE Xplore, ACM, Science Direct, Springer, Elsevier, MDPI, WoS, and Scopus. Based on the search engine statistics, we found most of the research papers related to DSS and wildland fires. To mitigate the risk of losing essential and related publications, we searched the related articles from state-of-the-art reports and surveys.

The search string used is an important bias, since there are keywords that were not considered in order to obtain the largest possible set of studies. The string "system" AND ("Forest fire" OR "Wildland fire") was the one that yielded the largest number of studies to review. Examples of words not considered are wildfire, fire, "decision support", software, and application, because, by including them, the search engine reduced the number of documents to be reviewed, leaving out possible important studies.

Some papers that were not mentioned in this study, and that can be found using the wildfire AND system string, are references [196–198].

From the definition of the inclusion and exclusion criteria, leaving aside technical reports and works in languages other than English, it is possible that some studies in other languages were relevant or observed points that the selected ones did not. On the other hand, it is possible that papers from countries that are recognized in the field of wildland fires were not included. Figure 12 shows a map with the papers selected by country.



Country	Total
Argentina	2
Australia	2
Brazil	2
Canada	4
China	29
Croatia	3
Cyprus	2
Ecuador	2
Finland	2
France	7
Germany	4
Greece	19
India	10
Iran	3
Italy	11
Malaysia	5
Morocco	4
Netherlands	4
Not Defined	2
Portugal	7
Russian Federation	7
South Korea	4
Spain	25
Sweden	2
Turkey	5
Ukraine	6
United Kingdom	7
United States of America	13
Viet Nam	2
Total	**195**

Figure 12. Papers selected by country.

6.2. Internal Validity

This type of validity handles the extraction data analysis process, in which three authors identified the classification of the selected articles and the data extraction process while one author reviewed the results. The subjectivity when applying the aforementioned criteria for the selection of the studies was already applied by three reviewers. In order to minimize this bias, Cohen's kappa index was used [41], obtaining a value of 0.92, which is acceptable.

Another inherent bias is the initial filtering method. By only reviewing the titles and abstracts, the possibility remains that some of the discarded studies contained important information to answer the research questions.

6.3. External Validity

External validity is related to the generalizability of this study. The results of the systematic mapping were considered concerning the domain of Systems in Wildland Fires, and the validity of the results presented in this document referred only to the domain of DSS. The classification of the articles and the search string presented in this research can help professionals as a starting point for wildland fire research and the use of DSS.

6.4. Conclusion Validity

The threat of the validity of the conclusion is related to the identification of inappropriate relationships that can generate an incorrect conclusion. In the mapping study, a conclusion validity threat referred to the different elements, such as incorrect data extraction and missing studies. To lessen this threat, the data extraction and selection process were clearly defined in the previous paragraph on internal validity. Traceability between the extracted data and the conclusion was strengthened through the direct generation of frequency diagrams and bubble diagrams generated from the data collected through the application of a statistical analysis.

7. Conclusions

This paper presented a systematic mapping of studies on DSS for wildland fire management to obtain an overall view of the solutions presented by industry and the scientific community.

For this, a set of six research questions was designed, which were answered using different classifications from the selected works by type of problem addressed, the type of DSS used, the main technologies used, the type of contribution, and the context.

The studies described the use, development, and impact of DSS to solve these problems. One of the most important factors of those found was the need to apply correct technologies to suitable lands, since changes in the climatic or geographic factors can make it a more useful tool than in other situations, as well as the utility of the data and their correct management for these tools. In addition, within the studies themselves, the need for tools that generated responses in appropriate timeframes stood out, since it is one of the scarcest variables in combatting wildland fires.

There is a trend in the use of Big Data for the management of wildland fire risk, since this can provide systems with monitoring, prevention, and the management necessary to distribute information in a timely manner. We found 10 studies published in recent years that indicated the use of different data sources, such as climatological data, sensors, satellite images, data from social networks, photographs, and expert data. On the other hand, Machine Learning techniques have been incorporated to achieve systems that adapt to the context of the fire, pre-activating the use of alarms and schemes that represent the real situation of forest fires.

Big Data delivers relevant information to the citizenry or to the inhabitants of the affected sector to avoid human losses. Despite these advances, there are still many problems and challenges to be solved. More user-friendly systems are required for the use of all types of users in forest fires, greater training in the use and analysis of data, visualization systems that can be used in the field, providing relevant information for the equipment, and the integration of the DSS.

Author Contributions: F.V. contributed to the planning of the SRL, paper writing, and formatting. A.C. contributed to the organization and direction of the SRL and paper writing. M.C. and P.A. contributed to the methodological support and expert judgement and figures and tables. All authors have read and agreed to the published version of the manuscript.

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

Appendix A

Table A1. Selected Papers.

Reference	Title	Authors	P. Channel	Year	Citations
[178]	3D Fire Front Reconstruction in UAV-Based Forest-Fire Monitoring System	Sherstjuk V, Zharikova M, …	IEEEXplore	2020	
[127]	A Novel Forest Fire Detection System Using Fuzzy Entropy Optimized Thresholding and STN-based CNN	Avula SB, Badri SJ, Reddy G	IEEEXplore	2020	
[128]	A Retrospective on ASPires: An Advanced System for the Prevention and Early Detection of Forest Fires	Peinl P.	ACM	2020	
[129]	An IoT-based forest fire detection system	Scicluna, D.	IJET	2020	
[130]	Architecture of embedded intelligent video analysis system for forest fire prevention	Zhang B., Zhang Z.	IOP	2020	
[131]	Bee2Fire: A deep learning powered forest fire detection system	de Almeida R.V., Crivellaro F., Narciso M., Sousa A.I., Vieira P.	SciTePress	2020	
[132]	Design of Forest Fire Warning System Based on Machine Vision	Peng J, Zhang H, Wu H, Wei Q	Springer	2020	
[189]	Development of an Intelligent System for Predicting the Forest Fire Development Based on Convolutional Neural Networks	Stankevich T.S.	Springer	2020	
[133]	Early Forest Fire Detection System using Wireless Sensor Network and Deep Learning	Benzekri W, Moussati A El, Moussaoui O, Berrajaa M	IJACSA	2020	
[134]	Efficient Forest Fire Detection System Based on Data Fusion Applied in Wireless Sensor Networks	Jilbab A, Bourouhou A	IJEEI	2020	
[135]	Fireanalyst: An effective system for detecting fire geolocation and fire behavior in forests using mathematical modeling	Güllüce Y., Çelik R.N.	TUBITAK	2020	
[136]	Forest Fire Detection and Alerting System	Minu O, Ramsiya M, Thasini A, Narayanan KV, Arun K	IEEEXplore	2020	
[137]	FOREST FIRE DETECTION SYSTEM USING IOT	Khan S., Jain S, MN Anusha, YP Kalyan	IJEAST	2020	
[138]	Forest Fire Detection System using LoRa Technology	Gaitan NC., P Hojbota	IJACSA	2020	
[139]	IoT-fog enabled framework for forest fire management system	Srividhya S., Sankaranarayanan S.	IEEEXplore	2020	
[140]	Optimization of Sugeno Fuzzy Logic Based on Wireless Sensor Network in Forest Fire Monitoring System	Budiyanto S., Silalahi LM., FA Silaban, …	IEEEXplore	2020	
[45]	'Portugal Without Fires', A Data Visualization System to Help Analyze Forest Fire Data in Portugal	Gonçalves D., Lima B., Moura J.M., Ferreira L.	Springer	2019	

[44]	Fuzzy-Based Forest Fire Prevention and Detection by Wireless Sensor Networks	Toledo-Castro J., Santos-González I., Caballero-Gil P., Hernández-Goya C., Rodríguez-Pérez N., Aguasca-Colomo R.	Springer	2019	
[143]	Strategic and tactical planning to improve suppression efforts against large forest fires in the Catalonia region of Spain	Gonzalez-Olabarria J.R., Reynolds K.M., Larrañaga A., Garcia-Gonzalo J., Busquets E., Pique M.	ScienceDirect	2019	1
[141]	Mapping combined wildfire and heat stress hazards to improve evidence-based decision making	Vitolo C., Di Napoli C., Di Giuseppe F., Cloke H.L., Pappenberger F.	ScienceDirect	2019	
[92]	Spatial pattern analysis and prediction of forest fire using new machine learning approach of Multivariate Adaptive Regression Splines and Differential Flower Pollination optimization: A case study at Lao Cai province (Viet Nam)	Tien Bui D., Hoang N.-D., Samui P.	ScienceDirect	2019	
[173]	Data Mining Approach to Predict Forest Fire Using Fog Computing	Aakash R.S., Nishanth M., Rajageethan R., Rao R., Ezhilarasie R.	IEEEXplore	2019	
[180]	Scalability of a multi-physics system for forest fire spread prediction in multi-core platforms	Farguell A., Cortés A., Margalef T., Miró J.R., Mercader J.	Springer	2019	1
[2]	Design and development of forest fire monitoring terminal	Wu F., Lv X., Zhang H.	IEEEXplore	2019	
[43]	Development of forest fire early warning system based on the wireless sensor network in Lawu Mountain.	Yahya Dewangga Z., Koesuma S.	ICOPIA	2019	
[142]	Detection and monitoring of forest fires using Himawari-8 geostationary satellite data in South Korea	Jang E., Kang Y., Im J., Lee D.-W., Yoon J., Kim S.-K.	MDPI	2019	
[9]	Adaptive Neuro Fuzzy Inference System (ANFIS) based wildfire risk assessment	Kaur H., Sood S.K.	JETAI	2019	
[191]	COMBINING SOCIAL MEDIA AND AUTHORITATIVE DATA FOR CRISIS MAPPING: A CASE STUDY OF A WILDFIRE REACHING CROATIAN CITY OF SPLIT.	Tavra M, Racetin I, Peroš J	IAPRSSIS	2019	
[194]	Predictive modeling of wildfires: A new dataset and machine learning approach	Sayad YO, Mousannif H, Al Moatassime H	ScienceDirect	2019	
[195]	Studies on Big Data Mining Techniques in Wildfire Prevention for Power System	Zhou T, Li B, Wu C, Tan Y, Mao L, …	IEEEXplore	2019	
[144]	Prediction and management system for forest fires based on hybrid flower pollination optimization algorithm and adaptive neuro-fuzzy inference system	Ahmed K., Ewees A.A., Hassanien A.E.	IEEEXplore	2018	1
[174]	GIS-based spatial prediction of tropical forest fire danger using a new hybrid machine learning method	Tien Bui D., Le H.V., Hoang N.-D.	ScienceDirect	2018	3
[47]	Implementation of Information Technologies in the Organization of Forest Fire Suppression Process	Smotr O., Borzov Y., Burak N., Ljaskovska S.	IEEEXplore	2018	

[181]	A fuzzy inference and big data analysis algorithm for the prediction of forest fire based on rechargeable wireless sensor networks	Lin H., Liu X., Wang X., Liu Y.	ScienceDirect	2018	3
[145]	Coupling early warning services, crowdsourcing, and modelling for improved decision support and wildfire emergency management	Bielski C., O'Brien V., Whitmore C., Ylinen K., Juga I., Nurmi P., Kilpinen J., Porras I., Sole J.M., Gamez P., Navarro M., Alikadic A., Gobbi A., Furlanello C., Zeug G., Weirather M., Martinez J., Yuste R., Castro S., Moreno V., Velin T., Rossi C.	IEEEXplore	2018	1
[46]	An intelligent wireless system for field ecology monitoring and forest fire warning	Zheng Y., Zhao Y., Liu W., Liu S., Yao R.	MDPI	2018	
[94]	An INSPIRE-compliant open-source GIS for fire-fighting management	Grasso N., Lingua A.M., Musci M.A., Noardo F., Piras M.	Springer	2018	1
[93]	Forest Fire Monitoring System Based on UAV Team, Remote Sensing, and Image Processing	Sherstjuk V., Zharikova M., Sokol I.	IEEEXplore	2018	
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