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# Traditional Fire Knowledge: A Thematic Synthesis Approach

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**Abstract:** Building fire-adaptive communities and fostering fire-resilient landscapes have become two of the main research strands of wildfire science that go beyond strictly biophysical viewpoints and call for the integration of complementary visions of landscapes and the communities living there, with their legacy of knowledge and subjective dimensions. Both indigenous fire management (IFM) and local fire management (LFM) are rooted in traditional fire knowledge and are among the most important contributions that rural communities can make to management partnerships. Focusing specifically on traditional fire knowledge (TFK), we examine the scholarly literature on TFK using a thematic synthesis approach. We extract themes from the literature and cluster and synthesize them into four analytical themes: (a) TFK within the fire ecology global research field; (b) the role of TFK in integrated fire management; (c) governance; and (d) TFK within global fire management research needs. Who the researchers are, the topics they study, how they approach these topics, and where they focus can help us also to understand possible biases in their contributions to the topics. The analysis conducted reveals the existing gap in current research on local fire knowledge among non-Indigenous populations. This paper offers a call to action to include indigenous and non-indigenous local knowledge and voices on this important topic. Evidence drawn from the thematic synthesis of the literature can help to re-focus research and awareness on this multidisciplinary phenomenon.

**Keywords:** traditional fire knowledge; indigenous fire knowledge; local fire knowledge; cultural knowledge of fire ecology; agricultural burning; pastoral burning; shared wildfire governance; systematic literature review; thematic synthesis; fire ecology

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## 1. Introduction

Traditional fire knowledge (TFK) has evolved as a branch or dimension of traditional ecological knowledge (TEK). For a long time, "tradition" was, and still is today, a problematic word which, from an anthropological perspective, has been tied to a reductionist vision of culture, hampering the possibility of a more holistic or broader view [1–4]. Tradition would indeed mean that which is "conventional" in specific territories or settings. For this reason, some scholars favour the term "indigenous knowledge" as less value-laden [5]. Nevertheless, the use of the term "Traditional Ecological Knowledge" has become established, among others, through the work of the International Conservation Union (IUCN) working group. Berkes et al. have developed a working definition of traditional ecological knowledge as a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment [6]. This definition further recognizes that traditional ecological knowledge is an attribute of societies with historical continuity in

resource use practice [7,8]. By and large, these are nonindustrial or less technologically advanced societies, many but not all of them indigenous or tribal [6]. Obviously, not all traditional practice and belief systems were ecologically adaptive in the first place; some became maladaptive over time due to changing conditions. This could also be the case for the traditional use of fire in some scenarios and under some socio-ecological change conditions.

The growing interest in traditional knowledge since the 1980s is indicative of the need to gain further insights into indigenous and/or local practices of resource use from an ecological perspective. Over the last few years, the UN Sustainable Development Goals (SDGs) and the Sendai Framework of Action (SFA) 2015–2030 have focused on holistic approaches towards indigenous disaster risk reduction (DRR) processes. However, it is still not clear how indigenous knowledge complements and contributes to DRR [9]. Central to this goal is addressing Indigenous peoples' socio-economic inequities arising from colonial and neo-colonial practices, as well as utilizing their socio-cultural-environmental worldviews, knowledge, and practices in DRR to reduce risk and facilitate resilience. However, achieving this goal requires gaining a holistic understanding using critical qualitative and indigenous research to understand the historical and contemporary complexities of the indigenous worldviews, knowledges, and practices that impact Indigenous peoples' DRR interpretations, behaviours, and actions [10,11].

If we focus on wildland fire science and, in general, the use of fire as a tool for land management, traditional fire knowledge began to establish a clear research line in the 1990s with work that focused on the environmental impact of aboriginal landscape burning and the implications for the development of a comprehensive understanding of the dynamics and evolution of the biota. The seminal work of Bowman on aboriginal landscape burning and paleoecology in Australia [12] was soon followed by studies focusing on the role of different anthropogenic fire regimes in contemporary ecosystems that have not been destroyed by European colonization [13–17]. The array of research quickly expanded the range of both indigenous territories (Kakadu National Park and Arnhem Land in Australia, New Zealand, Brazilian Amazon and *Cerrado*, Southwest China, Indonesia, Malaysia, South India, Southern Mali, Southern Ethiopia, Kenya, Northern Patagonia, Alaska, California, and Northwest USA, Canaima National Park in Venezuela, Mexico, Bolivia, etc.) and cultures analysed and the topics studied: managing the landscape, mitigating destructive wildfires [18], and reducing greenhouse gas emissions [19–23]; rituals, ceremonies, and other traditions [24]; promoting biodiversity and food security [25,26]; and generating sustainable livelihoods in a way that can inspire adaptive management solutions [20,27,28].

Recently, Nikolakis and Roberts conducted a refined conceptual framework analysis of the scientific and scholarly literature on indigenous fire management (IFM), contributing to the development of a theory of IFM and examining the ontological, epistemological, and methodological issues within this evolving and dynamic phenomenon [29].

The spreading, acceptance, and integration of the *fire ecology paradigm* by a large part of the scientific community since the 1990s explains the launching of initiatives and papers such as the *Global Fire Initiative* of The Nature Conservancy and the report *Living with Fire—Sustaining Ecosystems & Livelihoods Through Integrated Fire Management* [30]. It is precisely in this report that it is claimed: "Governments and urban societies have also not recognized or understood the need of many rural societies to use fire. Policies and programs have been designed around the belief that rural people are the cause of fire problems. Instead, these policies should look to rural communities as part of the solution and provide them with incentives and technologies that build on their traditional knowledge of fire use so that they can more effectively manage fires that are needed or that occur" [30] (p. i). In this paper, the meaning of *Integrated Fire Management* implies a holistic or seamlessly woven comprehensive approach to address fire issues, and, as is made clear, concepts can be applied to all regions of the world irrespective of development status.

The EC-funded project "Fire Paradox" (2006–2010) defines *traditional burning* (or *traditional use of fire*) as the use of fire by rural communities, based on traditional know-how, for resource and territorial management. In publications disseminating the findings of the Project [31], researchers claim that more than 95% of fires in Europe are of anthropogenic origin. Some of the main causes would be associated with land management activities, such as the burning of agricultural and forestry waste or the burning of land for pasture renewal. Changes in socio-economic and environmental conditions in many European rural regions have increased the risk of traditional fire use practices, and regulation is therefore required. However, in some regions—as is the case in France—traditional burning practices have been maintained or re-established based on historical background and the integration of traditional know-how [32]. The European researchers state that there is considerable potential for the development of programmes to promote understanding and best practice in traditional fire use, so that appropriate traditional fire use can be integrated into prevention strategies [31]. In the same vein, following the published results of the EU-sponsored Fire Paradox research project, other scholars allege that in locations where TFK-based "pre-industrial anthropogenic fire regimes" still exist, ecosystem management strategies for adaptation to and mitigation of climate change could be conceivably implemented at a minimal economic and political cost to the state by local communities that have both the TFK and the adequate social, economic, and cultural incentives to use it [33].

However, the main ontological hindrance remains the concept of "traditional", here applicable to everything concerning the knowledge and use of fire. What are the limits of the word? The first step should be to try to clarify what we mean by traditional fire knowledge, especially when most of the contributions oppose traditional fire knowledge to *Western* knowledge. Is there no traditional fire knowledge in Western rural regions? WIPO (World Intellectual Property Organization) defines traditional knowledge (TK) as knowledge, know-how, skills, and practices that are developed, sustained, and passed on from generation to generation within a community, often forming part of its cultural or spiritual identity. The *International Council for Science* (ICSU) characterizes traditional knowledge as a cumulative body of knowledge, know-how, practices, and representations maintained and developed by peoples with extended histories of interaction with the natural environment. These sophisticated sets of understandings, interpretations, and meanings are part and parcel of a cultural complex that encompasses language, naming and classification systems, resource use practices, ritual, spirituality, and worldview. Finally, in the UNESCO glossary, we find the following definition of traditional knowledge: "Knowledge, innovations and practices of indigenous and local communities around the world. Developed from experience gained over the centuries and adapted to the local culture and environment, traditional knowledge is transmitted orally from generation to generation. It tends to be collectively owned and takes the form of stories, songs, folklore, proverbs, cultural values, beliefs, rituals, community laws, local language and agricultural practices, including the development of plant species and animal breeds. Traditional knowledge is mainly of a practical nature, particularly in such fields as agriculture, fisheries, health, horticulture, forestry and environmental management in general". Therefore, we understand traditional knowledge to include both Indigenous peoples and local rural communities whose ties to a territory go back decades or centuries. However, traditional knowledge (TK) and traditional cultural expressions (TCE) are both types of indigenous knowledge (IK), according to the definitions and terminology used in the UN Declaration on the Rights of Indigenous Peoples.

Be that as it may, what is certain is that the scientific literature seems to have accepted this unquestioned assimilation between traditional knowledge and indigenous knowledge, depriving any local/traditional knowledge that is not bound to Indigenous/Aboriginal communities of the recognition of traditional knowledge worthy of protection. There are, of course, exceptions to this trend [33–42], but they are clearly a minority within the scientific literature as a whole. This is not only due to the fact that many of the papers are in languages other than English—indeed, in the search we identified some papers in other languages through the abstracts and keywords—but also because they are not included in journals indexed within the two main world databases of bibliographic references and citations of periodicals, *Web of Science* and *Scopus*. These are the two main databases of scientific content relevant to research. Any publication on local fire knowledge outside these databases has less visibility. Moreover, indigenous fire knowledge is equally prevalent in journals and papers not included in these databases, so that the contrast in the research focus remains.

Furthermore, some of the scholars contributing to this topic and focusing on non-Indigenous communities avoid the use of the term traditional fire knowledge in favour of other concepts, such as pastoral fire use or pastoral management. Indeed, the debate and the evolution in the use of different concepts to describe the phenomenon is significant enough in itself. The terms range from *historical fire-use practices* [43] to *vernacular understandings of fire* [44], *preindustrial anthropogenic fire regimes* [42], *traditions of fire knowledge and practice* and *cultural knowledge of fire ecology* [45], *traditional fire-use* [46] or *informal fire management regimes* [37], with the latter limited to traditional land management in a subsistence context. Comparative studies between Indigenous communities and other local/rural communities are even scarcer [47].

When we address indigenous/aboriginal fire knowledge in this article, we do so by restricting it to specific communities that neatly fit into the category of Indigenous and the value-laden concept of tradition. Local fire knowledge, even rooted in tradition, is a much more fluid concept, which different experts have tried to characterize by resorting to a whole array of definitions that merely reflect the reluctance and insecurity when using the concept of tradition and the difficulties in cementing a strand of research that addresses local fire knowledge in rural communities with long-standing territorial roots. In fact, we used the concept of local fire knowledge as a general term, interspersed with other alternative definitions, to prove the absence of a sound body of research on non-Indigenous communities, which makes it difficult to reach a consensus on the concepts used.

In a nutshell, both indigenous fire management (IFM) and local fire management (LFM) are rooted in traditional fire knowledge and are among the most important contributions that rural/local people can bring to conservation management partnerships. However, researchers and managers may have difficulty accessing such knowledge, particularly where knowledge transmission has been damaged or wasted. If we go back to traditional ecological knowledge (TEK), some experts argue that the literature offers us cases coming from both traditional societies and modern societies with locally evolved management systems. The important aspect is whether or not there exists local knowledge that helps monitor, interpret, and respond to dynamic changes in ecosystems and the resources and services that they generate [6].

Focusing specifically on traditional fire knowledge (TFK), the first and foremost objective of our work is a thematic synthesis that will allow us to identify analytical themes in recent scholarly productions. In a complementary way, and based on a systematic literature review, we try to address an epistemological window that we have identified, namely the unequal and contrasting focus on indigenous/aboriginal fire knowledge and local fire knowledge among the remaining rural communities. Perhaps a greening of society, which is becoming increasingly urban and reluctant to fire, considered as an environmental disaster and an additional factor of air pollution, can continue to hinder the

approach of practitioners and academics to the fire knowledge and management among non-Indigenous communities?

Before moving to the methodological aspects of this contribution, in the next section we try to go deeper into the ontological, epistemological, and contextual issues undermining the possibility of building a sound science of traditional fire knowledge. We also address the need to move towards new governance arrangements aiming to shape fire-adapted communities and resilient territories.

For this contribution, we examine the scholarly literature on TFK using a thematic synthesis approach, a grounded systematic literature review methodology [48]. We extract themes from the literature and cluster and eventually synthesize them into analytical themes. These analytical themes, similar in their construction to third-order constructs, are then used to characterize the corpus of the academic literature analysed. Additionally, we identify and map the affiliation of the first author of each paper and the territories under investigation, as well as the methods and types of research. Knowing who the researchers are, what topics they study, how they approach these topics, and where they focus can help us to understand possible biases in their contributions to the topic as a whole.

We acknowledge that much of the scholarly literature is from a Western perspective, and more specifically from publications in English, which is a significant limitation to this literature review. This paper offers a call to action to include Indigenous and non-indigenous local traditional knowledge and voices on this important topic. Evidence drawn from the thematic analysis of the literature can help to re-focus research and awareness on this multidisciplinary phenomenon.

## 2. Background: Knowledge Types and Governance Approaches

### *2.1. Ontological Obstacles and Epistemological and Contextual Differences*

Nikolakis and Roberts [29], in their attempt to develop a theory of indigenous fire management by confronting Indigenous and Western science knowledge systems, characterise the latter as scientific paradigms that create knowledge through critical reasoning, replicable methodologies, peer review, and written documentation, with ecological science increasingly focused on holistic systems thinking, resilience theory, and social-ecological systems. However, other scholars have argued against over-emphasising the differences between Western and traditional knowledge and questioned whether the dichotomy is real [49].

If we deliberately discard the concept of indigenous fire knowledge in favour of the more inclusive one of cultural knowledge of fire ecology, we could see how, in general, both the administration and the academy have tended to portray rural populations as ignorant and destructive fire setters, in the face of abundant evidence to the contrary [44]. Conservation policies have often suppressed non-scientific forms of knowledge and ways of knowing nature, along with the social practices of the groups that are informed by such knowledge [50–52]. This process has unfolded in both developing regions [53–55] and Western countries [34,42,47,56]. In fact, some scholars speak of a process of epistemic supremacy that should be reversed to achieve greater cognitive justice in conservation areas and ensure that conservation aims are achieved [52]. Environmental justice struggles are deeply contextual, and the foundations are therefore important for conservation researchers to avoid (re)producing universal conceptions about what constitutes justice and injustice.

Furthermore, Mary Huffman examined the hypothesis that traditional social-ecological fire systems around the world include common elements of traditional fire knowledge (TFK)—both in developed and underdeveloped regions. She provides ample evidence that many elements of TFK are common across social-ecological systems; the combinations of elements in each place, multiplied by the local manifestation of each element, result in many different local or regional pyrogeographies, as defined by Bowman and Murphy [57]. Huffman warns against the fact that the longevity of traditional fire knowledge and practice faces serious threats at precisely the time when climate change promises disruptions in

fire activity that will be problematic for Indigenous and nonindigenous societies alike. In responding to the context of change and uncertainty, central governments tend to adopt the pathological response of command and control during times of fire increase, further constraining traditional fire management. The researcher argues for the opposite response: to seriously engage traditional practitioners in solving fire problems of global significance [47].

In addition to the above reasoning, other scholars argue that local knowledge is useful when resorting to scientific knowledge is not feasible. Local ecological knowledge (LEK) and, more specifically, cultural knowledge of fire ecology can shed light on ecosystem change, especially in under-researched areas. However, for ecosystem planning and fire management purposes, it is necessary to assess the accuracy and validity of LEK and determine where such knowledge is situated in a community, and how evenly it is spread [58].

Obviously, not all researchers are uncritically in favour of incorporating local knowledge of fire use into land and ecosystem management. The question of scale and contextual knowledge has become an issue of discussion. Traditional fire knowledge (TFK) depends on ecosystem type and season, and this creates challenges for knowledge sharing. Traditional knowledge and practices are typically place-based and relevant to a specific fire regime and ecological context. Different scientists define this form of knowledge about the use of fire for ecosystem management among local communities as site-specific, detailed, and often reasoned as well as articulate, unwritten knowledge [59]. Focusing on indigenous knowledge, Wohling argues that it is not adapted to the scales and kinds of disturbances that contemporary society is exerting on natural systems. Furthermore, he complains that the concept of indigenous knowledge has gained such rapid currency that it has tended toward an essentialized and universal truth rather than remaining a diverse range of highly localized and contested knowledge. He maintains that non-indigenous interpretations of indigenous knowledge have propelled us toward reified meanings, abstracted concepts, and an information-based taxonomy of place. The result could be the diminishing and ossifying of a dynamic living practice and the failure to recognize expressions of indigeneity in contemporary forms [60].

Nevertheless, following the theses of Berkes et al. [6] and the findings of Huffman [47] and other academics, we agree that indigenous and nonindigenous examples help emphasize the point that probably none of the examples is purely traditional; rather, they all incorporate both Western science and local practice [61]. Whether a practice is strictly traditional or contemporary may not be the key issue. The important aspect is whether or not there exists local knowledge that helps track, understand, and address dynamic changes in ecosystems and the ecosystem services they generate.

Another conflict issue revolves around ethical questions of appropriation and integration of local knowledge into the scientific knowledge system. Positivist studies that compare local knowledge to science are fraught with ethical and methodological challenges. Some scholars caution against the fact that local knowledge and science can complement one another, but it is not advisable to integrate them in a way that co-opts local knowledge for scientific purposes [58]. In some cases, it has been reported that training and employment with wildfire management agencies provide an opportunity for Indigenous people to connect and care for the country, while simultaneously allowing for the breaking of traditional rules surrounding what knowledge is shared with whom in the context of indigenous cultural burning [62]. Other scholars maintain that in northern Australia attempts to integrate "traditional ecological knowledge" and Western science have resulted in a de facto transfer of the social and ritual responsibility of burning the country from specific Indigenous custodians (traditional owners and managers) to Indigenous rangers, non-Indigenous fire ecologists, and other non-Indigenous actors [24].

Another example of a collision between Western and indigenous ontologies could be reframing land management by indigenous fire ecologists as carbon farming. We allude to the initiative involving the community management of landscape fire to reduce annual greenhouse gas emissions (GHGE) from savanna burning [19]. The contrast between place-oriented ontologies of land, law, and cosmic order and their Western counterparts in sovereignty, land law, and financialization is inescapable [63].

### *2.2. Environmental Governance and Uneven Power Dynamics: Towards Adaptive Approaches and Territorial Resilience*

Last but not least, there remains the question of the resilience of TFK systems under the influence of climate change. Resilience is broadly understood as the capability of a social or natural system to maintain function through periods of change, or alternatively, to reorganize and adapt to meet new challenges (Resilience Alliance). In general, the resilience of a territory combines knowledge, learning experiences, a sense of place, social networks and local infrastructures, diversity, and economic innovation, as well as participatory governance [64]. Whether or not TFK systems are resilient is a contentious issue. Berkes et al. [6] argue that traditional ecological knowledge and practice may be characterized as "resource management from a resilience point of view", using qualitative management wherein feedback of resource and ecosystem change indicates the direction in which management should move. Traditional ecological knowledge can be viewed as a "library of information" on how to cope with dynamic change in complex systems. It may help connect the present to the past and re-establish resilience [65].

A major area of research, given the multiple elements of fire knowledge and the specialised combinations that characterise the pyrogeographies of different localities, is the extent to which traditional fire managers can reorganise and reallocate these elements to meet their needs as local socio-ecological systems change [47]. Following Huffman's observation, in what ways will TFK systems as a whole be resilient in the face of climate change and in what ways will they be vulnerable [47]?

As noted above, participatory governance is typically a key ingredient in territorial sustainability, but its effective integration and implementation is far from easy. The cultures of fire prevention and fire-fighting agencies have shaped institutional identities and management interventions. Central to such institutional cultures is knowledge production, which is shaped by political-economic processes, dominant narratives, and institutional desires to produce "conservation" landscapes [66]. This policy science emerged from an institutional culture that favours fire suppression as a means to recreate a desired, imaginary forest [67].

The opening of a dialogue on fire management between government agencies and local communities has become increasingly evident and different approaches have been devised. Yet, it is clear that further developments in community participation need to take place in order to avoid the appropriation of local knowledge systems by institutions, and to better reflect more equitable fire governance [68]. Overcoming the gaps derived from different experiences and historical worldviews, and building mutual trust and respect are the main challenges when integrating multiple perspectives through the "intercultural interface" of institutions working on environmental management and governance [69,70].

Pioneering experiences have been developed in collaborative research based on improved dialogue and knowledge sharing between scientists, institutions, indigenous and local communities, as well as in the implementation of fire management, including "controlled" and "prescribed" burning [71]. Despite global optimism, the challenge is not easy, and it sometimes depends upon routine persuasive labour and fragile cross-cultural diplomacy [72]. Some projects have developed participatory geographic information systems (PGIS) for the assemblage and communication of traditional knowledge vital to fire and fuel management, while preserving linkages to broader cultural contexts [73,74], while others have co-produced fire and seasons calendars [75].

Sharing our collective understanding of fire, derived from traditional and scientific/technical knowledge systems, can benefit landscapes and people [68,76,77]. According to different scholars, it has been concluded that the successful management of wildland fire and fuels requires collaborative partnerships that share traditional and *Western* fire knowledge through culturally sensitive consultation, coordination, and communication for building trust [77]. Other experts go beyond the concept of collaborative partnership and, in an attempt to avoid uneven power dynamics that might influence knowledge production [24], land management bureaucracy, and vested economic interests [29], suggest concepts such as co-management or co-governance, [78] and more broadly self-governance [79]. Effective resilience is more easily created and maintained by utilizing the knowledge, resources, and skills of all stakeholders to build needed adaptive capacity. The so-called *Shared Wildfire Governance* (SwG) paradigm, recently proposed by Tedim et al. [80], brings together the human, social, and ecological aspects in a meaningful and appropriate way and moves from an expert, exclusive, and top-down approach to the problem [81] to one that distributes power and harnesses the diverse knowledge, skills, and needs of different stakeholders, including through a consideration of traditional and local knowledge. Even more recently, the proposal for a *translational wildfire science* (TWS) focuses on solution-oriented research to meet stakeholder needs by actively engaging them in the research process and including follow-up evaluations to assess relevancy and timeliness. Moreover, all this is done using an interactive, open, multi-scalar, and dynamic process of integrating research from different disciplinary fields, as well as traditional and experiential knowledge [82].

## 3. Materials and Methods

Our aim is to conduct a stand-alone literature review attempting to make sense of a body of existing literature through the aggregation and interpretation of existing research [48]. Thematic synthesis provides a tested way to synthesize qualitative research in a transparent manner and achieve higher-order thematic categories [83]. The generation of new themes beyond the descriptive content of the articles is a crucial characteristic, and it should lead to the creation of a whole greater than its constituent parts. Thomas and Harden [84] outline three stages in thematic synthesis. These three stages provided the framework for the synthesis presented in his paper. Stage one involved abstract coding of the article's aim, context, and findings; stage two involved the development of 'descriptive themes'; and stage three involves the subsequent generation of 'analytical themes' leading to a synthesis of new interpretive accounts. Other scholars have used all themes from all papers to create theme clusters from which they drew their conclusions about the group of papers as a whole. Our aim is not only to identify major themes, but also to find out how prolific the scholarly contribution has been for each of them, as well as the most relevant research centres and authors and the territories that have been the target of research [48].

### *3.1. Review Focus and Elements Characterizing the Literature Review*

FAO (Food and Agriculture Organization)'s recent Forest Fire Management strategy claims that basic research on the social aspects of wildland fire is very limited. The existing literature is mainly applied research, in particular case studies of certain aspects of the social dimensions of wildland fires (wildfire's human causes and influencing factors; fire laws/policies/regulations; fire management; socio-economic impacts of wildfire risk; social awareness/vulnerability/resilience to wildfire risk, etc.).

Indigenous/local knowledge is known to be a rich resource that has been recognized and applied in several cases and that continues to be explored by FAO and others [85]. This review is focused on the many aspects of traditional fire knowledge (TFK) and its complex and sophisticated approaches to fire use. The rationale is that TKF creates opportunities for resilient and sustainable agriculture and forest management, preventing and mitigating

wildfire risk. However, the issue is contentious, and the communities analysed are very unevenly concentrated in one part of fire-dependent regions [86].

On this basis and building on the theoretical framework outlined in the previous two sections, we summarise in Table 1 a total of five elements to characterize the literature review, designed to structure the knowledge gained to date and to meet the main objective of this study.

**Table 1.** Elements to characterize the literature review.

| Issue | Purpose of This Issue |
| --- | --- |
| What is the temporal evolution and geographical distribution of publications according to author affiliation? | To know the evolution of research according to the affiliation of the first author of the work. |
| Who are the most cited authors and what are the most cited papers? | Identify the leading researchers in this field of research as well as the most cited contributions. |
| What are the main types of research carried out and their relative weighting? | Classify types of research into three categories:<br>• Concept papers and/or review;<br>• Case studies;<br>• Methodological contributions. |
| What are the territories covered in the publications analysed? | To answer the question: Are there over-analysed versus hidden territories? |
| What are the main analytical themes identified and their relative share? | To identify analytical themes in recent scholarly productions and, as a complementary approach, to address the epistemological window revealed by the systematic literature review. |

### *3.2. Inclusion and Exclusion Criteria*

Papers were included for review if they addressed traditional fire knowledge—both indigenous and local knowledge—or were involved pastoral and/or agricultural burning, and were published after 1995 in the English language. Studies were excluded if they were published before 1995, in a language other than English; if the primary concern was with impacts on air quality resulting from biomass burning, as well as health or climatic effects, soil degradation, or soil quality changes; or if the primary concern was not with traditional fire use for ecological or livelihood purposes. Studies were also excluded if they were concerned with computer simulations, numerical modelling, simulation of smoke plumes from agricultural burns or stochastic simulation, or were published in a newspaper or magazine. We limited the publication dates to the period between 1995 and 2021 (articles published in the past twenty-six years), so that we could build our review based on the recent literature considering information retrieval and synthesis in the digital age.

### *3.3. Databases and Sources: Literature Search, Screening, and Data Extraction*

Two databases—Scopus and Web of Science—were searched for both peer-reviewed and grey literature. The database retrieval was initially conducted at the end of October 2021 with a search strategy using the following search string: "Traditional Fire Knowledge", "Traditional Fire Use", "Cultural knowledge of fire", "Traditional burning", "Pastoral fire use", "Fire-use practices", "Indigenous fire knowledge", "Indigenous fire management", and "Aboriginal cultural burning". For each manuscript, preliminary relevance was determined by title and keywords. From the title, we obtained its full reference, including author, year, title, and abstract for further evaluation.

One reviewer screened the search results (Table 2) by title and abstract, and papers falling outside the criteria were excluded. The full text of the remaining papers was screened by the same reviewer to identify final papers for review; further papers were

also excluded. Excluded papers included those meeting the exclusion criteria previously specified. A second reviewer then examined the inclusion and exclusion decisions, and any disagreements were resolved through discussion.

**Table 2.** Preliminary search of references on traditional fire knowledge before exclusion criteria.

| Search String | Web of Science | Scopus |
|---|---|---|
| Traditional Fire Knowledge | 62 | 84 |
| Traditional Fire Use | 162 | 334 |
| Cultural knowledge of fire | 28 | 27 |
| Traditional burnings | 2 | 181 |
| Agricultural burnings | 4 | 998 |
| Pastoral fire use | 26 | 18 |
| Fire-use practices | 11 | 4 |
| Indigenous fire knowledge | 37 | 58 |
| Indigenous fire management | 95 | 137 |
| Aboriginal cultural burning | 2 | 3 |

Percentage of duplicated references: 15%.

Once the final sample of 134 contributions had been defined and delimited, and before proceeding to the extraction of data for the thematic synthesis, we checked the impact of each paper according to the number of citations in Google Scholar. Google Scholar is a very powerful open access database that archives journal articles as well as "grey literature," such as conference proceedings, theses, and reports. Its extensive coverage of academic and scholarly productions convinced us of its suitability.

The process of data extraction for thematic synthesis involved coding. Conclusions and generalizations were established based on the themes and concepts that were coded. Since we worked as a team, we decided to code a few papers together before splitting the task to make sure everyone was coding the papers similarly [87]. Subsequently, two researchers coded the studies independently [88].

Similar codes were subsequently clustered together, and overlapping codes were merged. A total of 61 codes emerged from the initial stage capturing TFK approaches. The second stage involved searching for similarities and differences in the codes and the generation of new codes that grouped together codes from the initial coding. The second stage resulted in a set of related descriptive themes, which were drafted by the research team. Critical discussion of these resulted in a final set of 16 themes. The third stage involved distilling them into analytic themes, which is the most challenging but also most defining stage of qualitative synthesis (Figure 1).

### *3.4. Analysis and Interpretation of Data*

Once the data extraction process was complete, the analysis and interpretation of data was organized by combining charts, tables, and a textual description. The results were read and interpreted within the frame of the 4 analytical themes previously distilled. This accounts for most of the following reporting on the results of the review.

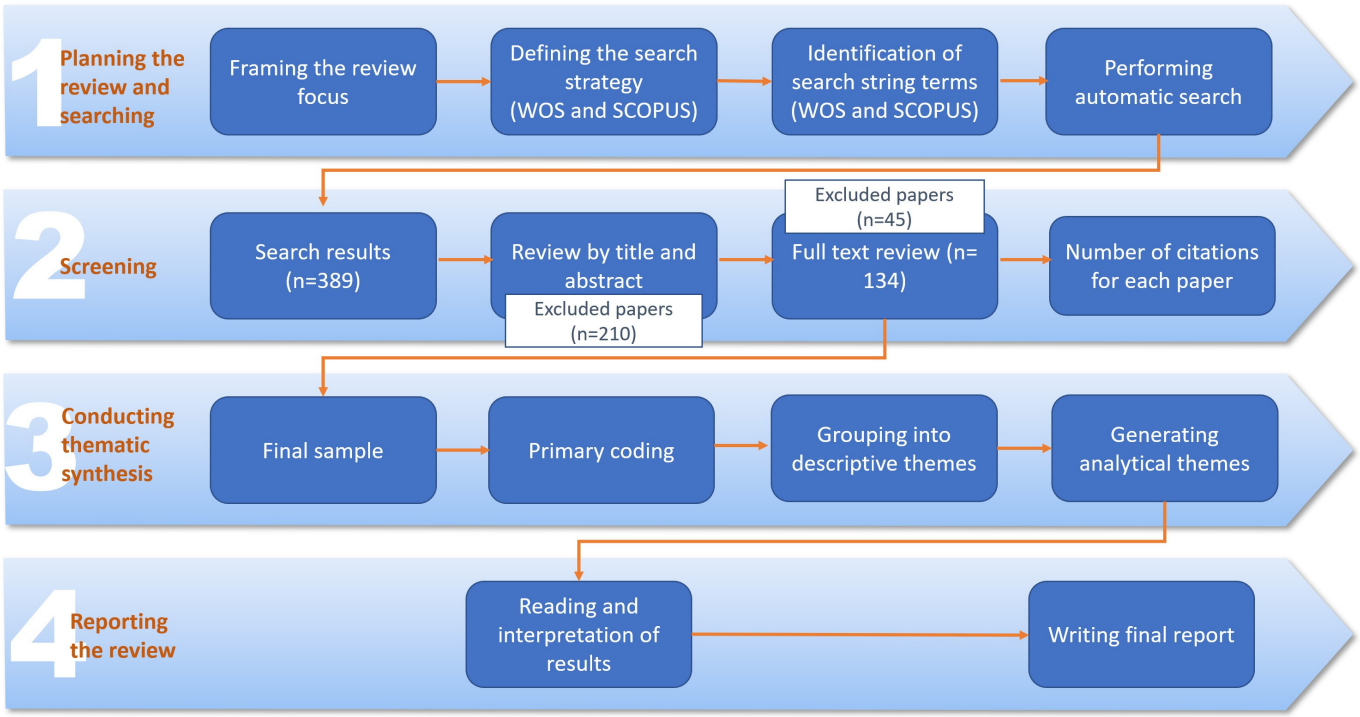


**Figure 1.** Research design.

## 4. Results

### *4.1. Evolution of Scientific Literature, Geographic Origin/Focus, and Type of Research*

As we have already mentioned above, the search process focused on the period 1995–2021 and brings together 134 studies that meet the search criteria (Appendix A). In twenty-six years, there has been a steady increase in the number of papers published on the subject, with a first turning point occurring in 2004, along with two years of exceptional growth at the end of the period in 2019 and 2021. This last year contained an impressive increase, especially if we consider that only papers published until October 2021 were included. It is apparent that researchers affiliated with Australian and US universities and/or institutions have led the research and advances made to date (Figure 2). If we look at the first author of each paper, 17 Australian universities are represented, to which should be added 6 other institutions involved in conservation or indigenous land management projects. The result is a total of 45 papers, accounting for 33.6% of the sample. In the case of the United States, the first authors of the papers belong to 16 different universities, in addition to other institutions, such as the USDA Forest Service or The Nature Conservancy. They contributed a total of 42 papers, 31.3% of the sample. In other words, 87 papers (64.9%) were headed by authors working at universities and institutions in these two countries. Far behind come Brazil with 10 studies (7.5%), Canada with 9 (6.7%), and the UK with 8 (6%). The research led by authors from the remaining ten countries only contributed 19 papers (14.2%).

As might be expected, the territories analysed replicate the same biases in both the intensity and the concentration of the spaces analysed (Figure 3). The major Australian and US think tanks have focused preferentially on their own territories (more specifically on the regions occupied by Indigenous communities that preserve a living and robust TFK), a trend that could also apply to the cases of Brazil, Canada, and Venezuela. However, the studies led by British authors (8) do not provide a single article focused on their own territory. The topo-negligence that the European continent is enduring is noteworthy, rivalled only by that suffered by most of mainland Asia and much of Africa. One paper analyses a case study in France, three in Spain, one in Sweden—focusing on the indigenous Sami community—and one in Ireland. As a distinctive feature with respect to the affiliation of the

first author of each paper, we find a significant number of papers in southern and eastern Africa, mostly associated with savannah ecosystems. It seems apparent that declining TFK has failed to attract the interest of most researchers, yet lessons from fire-adaptive communities in varied cultural settings are still to be learned.

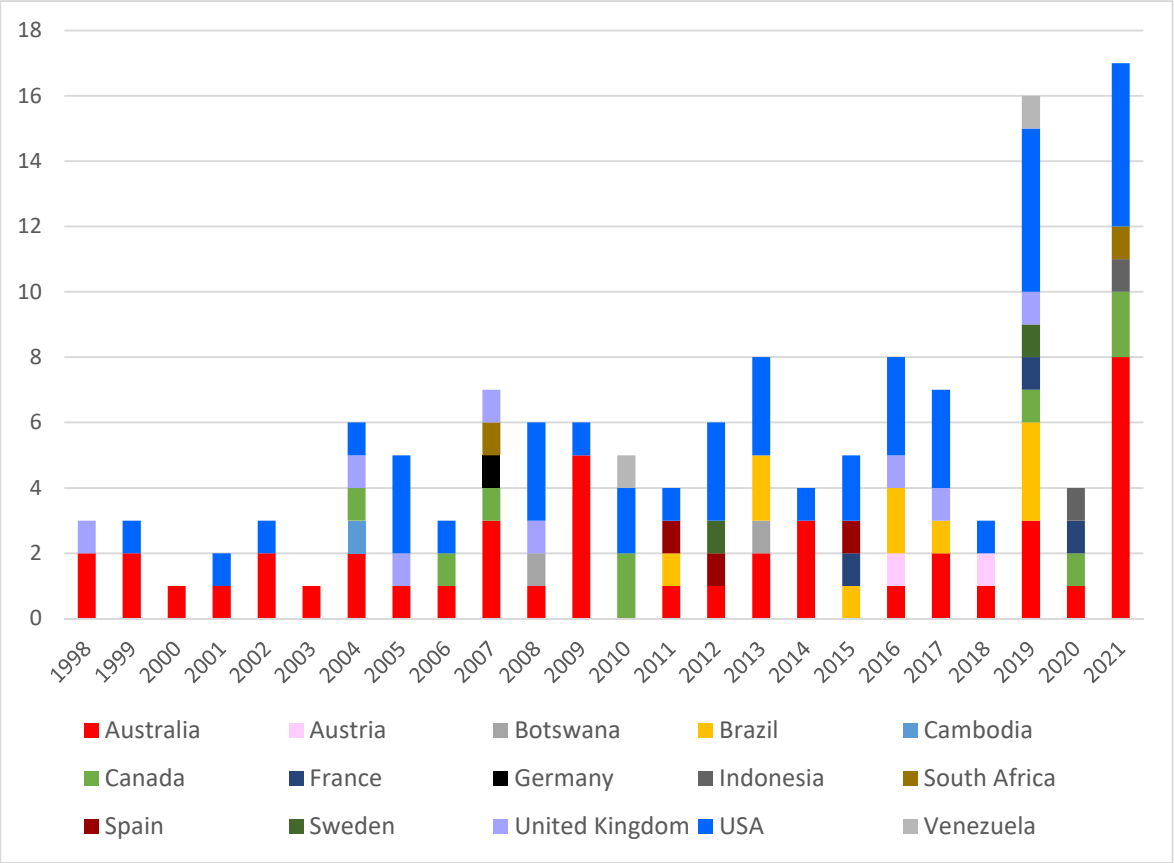


**Figure 2.** Publication figures by year according to first-author affiliation country.

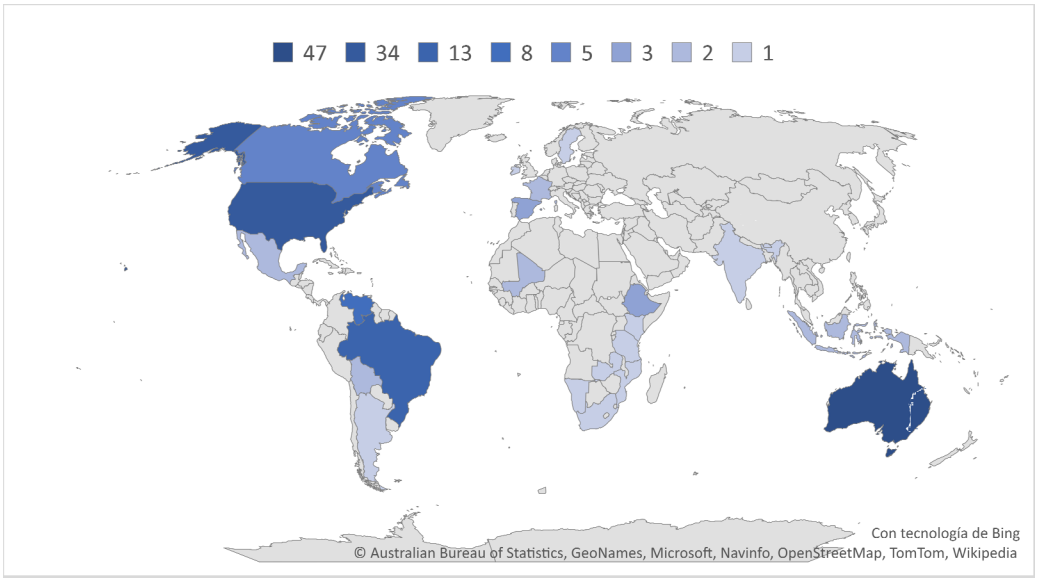


**Figure 3.** Number of papers focusing on each territory based on the contributions analysed in the sample.

Aiming to provide a first approach to the most productive first authors in relation to the topic addressed, from a quantitative, non-relational, and synthetic perspective, Table 3 shows the 24 most productive leading researchers (we focus on the first quartile by citation ratio for a total of 98 scholars) according to the citations for their papers in Google Scholar. The first authors in this quartile account for 68.5% of the total accumulated citations. Attention should be drawn, however, to the obvious fact that the time elapsed since the publication of the paper affects the possibility of accumulating more citations, so that some recent papers have not yet had time to compete. Australia, with 10 authors, and the USA, with 7, lead the list of the most productive scientists, although the case of Brazil is noteworthy, with 2 authors taking second and third place in the ranking. This fact is especially noticeable if we realize that the first publication led by a Brazilian author does not appear in the sample until 2011. Focusing on the most cited contributions, the most cited paper is that of David M.J.S. Bowman [12], with 545 citations, followed by Dean Yibarbuk et al. [16], with 427 citations, and Vânia R. Pivello [89], with 295 citations.

**Table 3.** Leading researchers in the field by most cited contributions.

| First Author | Affiliation | Papers | Citations | Citation Ratio |
|---|---|---|---|---|
| Yibarbuk, D. | Northern Territory University, Australia | 1 | 427 | 427 |
| Pivello, V.R. | Universidade de São Paulo, Brazil | 1 | 295 | 295 |
| Durigan, G. | Instituto de Pesquisas Ambientais, Brazil | 1 | 248 | 248 |
| Angassa, A. | Botswana University of Agriculture and Natural Resources | 1 | 244 | 244 |
| Kimmerer, R.W. | State University of New York, USA | 1 | 228 | 228 |
| Laris, P. | California State University, USA | 2 | 454 | 227 |
| Berkes, F. | University of Manitoba, Canada | 1 | 211 | 211 |
| Chalmers, N. | Rhodes University, South Africa | 1 | 177 | 177 |
| Bowman, D.M.J.S. | University of Tasmania, Australia | 5 | 822 | 164.4 |
| Gott, B. | Monash University, Australia | 1 | 122 | 122 |
| Mathews, A.S. | University of California, USA | 2 | 228 | 114 |
| Ockwell, D.G. | University of Sussex, UK | 1 | 114 | 114 |
| Wohling, M. | Charles Darwin University, Australia | 1 | 111 | 111 |
| Lake, F.K. | USDA Forest Service, USA | 1 | 103 | 103 |
| Huffman, M.R. | The Nature Conservancy, USA | 1 | 101 | 101 |
| Murphy, B.P. | Charles Darwin University, Australia | 1 | 101 | 101 |
| Mistry, J. | Royal Holloway University of London, UK | 4 | 399 | 99.8 |
| Eriksen, C. | University of Wollongong, Australia | 2 | 199 | 99.5 |
| Whitehead, P.J. | Department of Natural Resources Northern Territory, Australia | 2 | 191 | 95.5 |
| Burrows, N.D. | Science and Conservation Division, Australia | 1 | 95 | 95 |
| Griffiths, T. | Australian National University, Australia | 1 | 95 | 95 |
| Fitzsimons, J. | Deakin University, Australia | 1 | 81 | 81 |
| Butz, R.J. | Humboldt State University, USA | 1 | 78 | 78 |
| Mason, L. | University of Washington, USA | 1 | 78 | 78 |

The types of research widely embraced by the authors in our sample were classified into three broad categories (Figure 4). The *case studies* stand out by a large majority (71.4%), are evenly distributed among the papers led by researchers from different countries, and

have lasted over time. *Concept papers and/or reviews* account for 24% of all the literature analysed, with key contributions made primarily by Australian, American, and Canadian researchers. This category includes such relevant contributions as that of Michael R. Coughlan [46] reviewing some of the most salient and persistent theoretical propositions and hypotheses concerning the role of humans in historical fire ecology and discussing this history in light of current research agendas, or the previously mentioned paper of Nikolakis and Roberts [29], building a conceptual model on indigenous fire management from the literature. Another fundamental contribution in this group is that of Huffman [47], based on the hypothesis that traditional social-ecological fire systems around the world include common elements of traditional fire knowledge (TFK) and the proposal for classification into TFK systems, including typologies of agroecological type, pre- and post-industrial anthropogenic fire regimes, and viability status. The third category includes the *methodological contributions*, which account for a modest 4.5%. Papers in this category only appear from 2008 onwards, but since 2017 the number of studies has increased significantly.

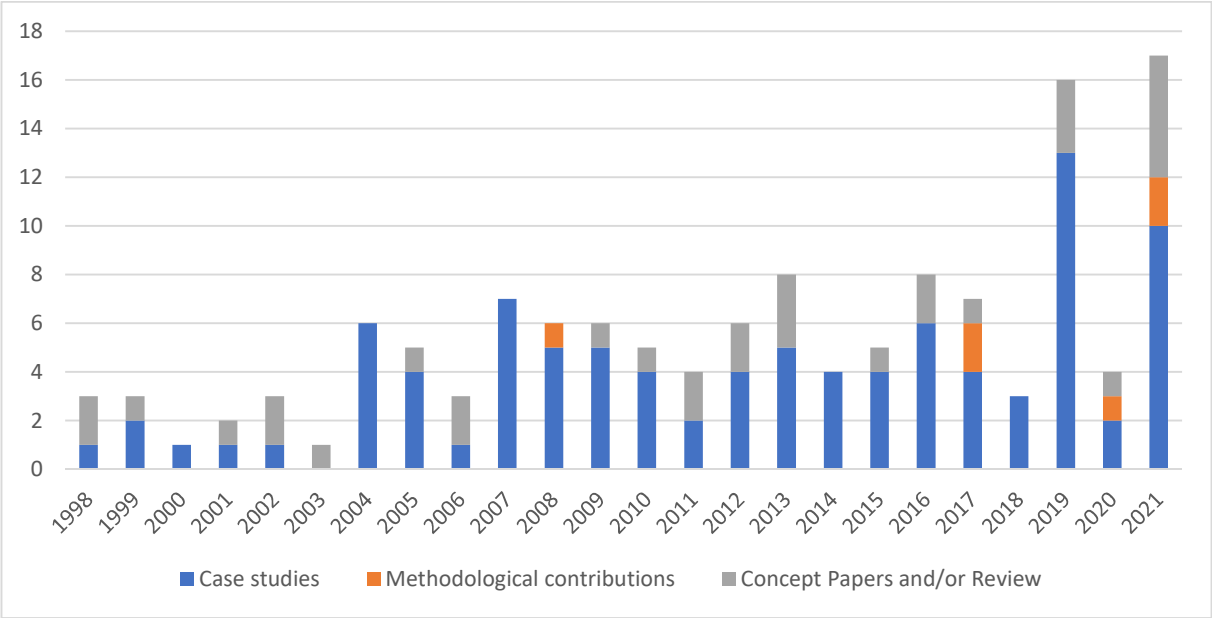


**Figure 4.** Types of research by year of publication.

To conclude this section, we would like to point out the characteristics and evolution of the methodologies used in the different studies (Figure 5). Papers using *mixed methods/participatory action research* (*PAR*) (30.8%) and *quantitative methodologies* (30%) were clearly more prevalent. *Literature reviews* made up 24% of the sample, and *qualitative methods* accounted for only 15% of the papers. Analysis of the data reveals that, although mixed methods were not present until 2001, since then their share has grown steadily to become almost dominant since 2016. The new era in the conceptualization and utilization of integrated approaches across the social and behavioural sciences [90] seems to have spread and gained a foothold in wildland fire science since the first decade of the 21st century. Scholars argue that mixed-methods research is a powerful tool in building and enhancing a wildfire science that has policy relevance, retains analytical depth, and is acceptable to risk managers. Wildfire science will benefit from mixed-methods research to illuminate how socio-cultural processes are central to environmental attitudes and preparedness behaviour, as well as to ecosystem management strategies for adaptation and mitigation [91].

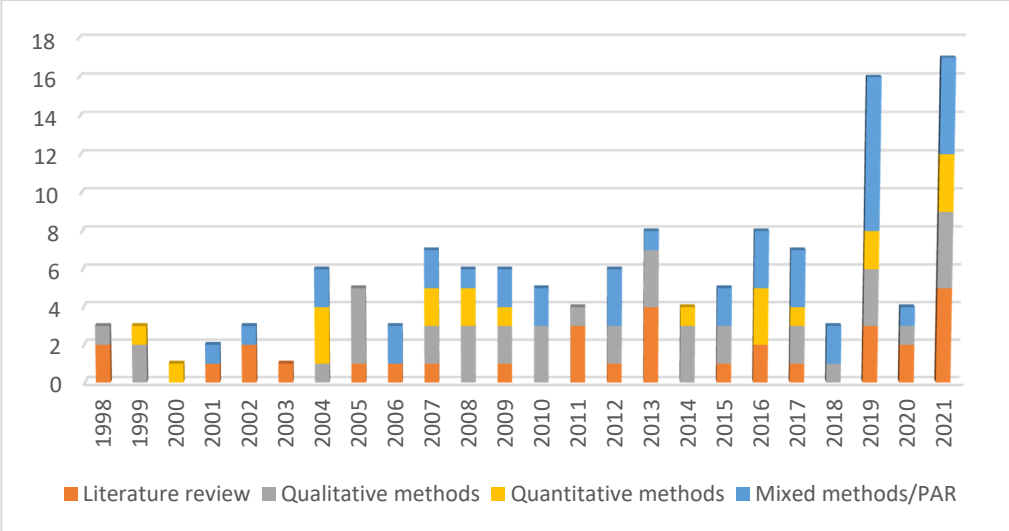


**Figure 5.** Research methodology by year of publication.

### *4.2. Analytical Themes*

The thematic synthesis identified four analytical themes in the 134 papers analysed. (1) *TFK within fire ecology global research field*: from palaeoecology and eco-history to the effects of fire on fire-dependent species, fire-dependent ecosystems, and cultural landscapes, pyrogeography, and transdisciplinary ecology; (2) *The role of TFK in integrated fire management*: the emergence and visibility of the benefits and consequences of integrating TFK into fire management, from conservationist perspectives to the new ethos of eco-efficiency and environmental economics; (3) *Governance*: traditional fire knowledge and fire management in contested institutional contexts, the exploration of distributive ecological conflicts arising from shifting power relations between Indigenous populations and Western societies, rural communities and urban populations; (4) *TFK within global fire management research needs* (Table 4).

**Table 4.** Breakdown of descriptive themes, main analytical themes, and their relative share.

| Number of Papers | Share | Analytical Themes | Descriptive Themes |
|---|---|---|---|
| **23** | **17.2%** | **TFK within fire ecology global research field** | Interrelation between fire ecology and TFK<br>Cultural landscapes/fire/patch mosaic burning<br>Effects of fire on targeted species/sustainable livelihoods<br>Pyrogeography and transdisciplinary fire ecology |
| **50** | **37.3%** | **The role of TFK in integrated fire management** | Co-benefits of integrating TFK<br>Ethical issues of appropriation and integration of TFK (mainly indigenous fire knowledge)<br>TFK integration considering its current viability status<br>Building community resilience |
| **37** | **27.6%** | **Governance** | Mitigating cross-cultural conflict<br>Governance and leadership models<br>Mapping good practices<br>Disaster risk reduction and TFK |
| **24** | **17.9%** | **TFK within global fire management research needs** | Encouraging ethno-ecological/ethnographic research<br>Recognizing, collecting, and revitalizing traditional fire knowledge<br>Solving problems and tensions between TFK and science<br>Supporting participatory action research |

#### 4.2.1. TFK within Fire Ecology Global Research Field

Over the last decades, fire ecology has become a global research field drawing on diverse, international, and interdisciplinary expertise to outline the generalizable properties of fire-adaptive communities in varied settings where cultural knowledge of fire is rich and diverse [92]. Indeed, even today large numbers of people use fire as a tool to sustain their livelihoods in ways that have been passed down through many generations [47]. Different contributions challenge the hypothesis that local traditional knowledge has been responsible for significant ecosystem decline and, conversely, emphasise that local communities have adapted their fire management practices to the changed ecological, economic, and social circumstances [93].

Although wildfire has been central to the ecological dynamics in different regions, the role of humans in this dynamic is not well known [94]. However, a number of case studies have proven that some local communities possess predictive knowledge of the ecological consequences of burning, including attention to the subtle needs of target organisms and the application of diverse fire regimes [95].

The relationship between biodiversity conservation and the cultural practices of local communities regarding land and resource use has been scrutinised through the lens of cultural landscapes, which provides a mechanism to understand how multiple objectives are central to sustainable forest management in landscapes that conserve heritage values and support the livelihood needs of local people [96]. Many studies focus on the creation of a mosaic of patches with different fire histories that could be used to create firebreaks that reduce the risk of undesired wildfires while also protecting fire-sensitive vegetation. The process of gradually burning off the target vegetation creates a seasonal mosaic of habitat patches that increases the potential of the landscape for a variety of seasonal land uses [14,71,97–102].

The effects of the cultural use of fire on many activities and species have also provided a wealth of work and references, from those focusing on the acquisition and production of knowledge pertaining to the ecology of anthropogenic fire, the burning calendar, group hunting strategies, and ceremonial aspects of the hunt [103] to the complexity of indigenous knowledge about fungi harvesting and associated burning to enhance mushroom populations [25] or the practice of cultural burning used to enhance culturally important species for basket weaving [104]. Other cultural uses of fire include clearing vegetation for agriculture, improving forage for domestic animals, controlling pests, reducing predator attacks, easing travel and communication over long distances, etc.

In this context, Bowman and Murphy introduced in 2011 the concept of pyrogeography as an integrative, multidisciplinary perspective on landscape fire, its ecological effects, and its relationships with human societies [57]. Pyrogeography displays a clear commitment to understanding the interrelationships between cultures and their environment. The concept meets the challenge of answering fascinating questions about the potential co-evolution of fire, life, and human cultures, and attempts to transcend the idea that landscape fires should be considered 'biologically constructed'. The success of the concept has been indisputable in current research agendas [46,47,105].

Only a year later, Michael R. Coughlan and Aaron M. Petty argued for a new proposal that moves beyond historical ecology and environmental history [106], namely a transdisciplinary fire ecology, and discussed how the study of fire ecology can benefit from paying attention to the role of humans in three thematic areas: (1) human agency and decision processes; (2) the knowledge and practice of landscape fire; and (3) socioecological dynamics inherent in the history of social systems of production and distribution [45].

#### 4.2.2. The Role of TFK in Integrated Fire Management

Most scholars attribute the ecological integrity of ecosystems to the continued human occupation and maintenance of traditional fire management practices. However, the maintenance of the biodiversity requires intensive, skilled management that can be best achieved by developing co-operative programmes with Indigenous/local communities [16]. Yet, fire

use has often been a source of conflicts with state bureaucracies [107] and legislation [108]. Whenever possible, traditional knowledge should be incorporated into messages and activities [30]. Integrating traditional knowledge (TK) into fuel treatments can improve ongoing adaptive management [74]. Incorporating TFK in adaptive co-management can help create ecosystems that are more resilient to fire and pervasive stressors such as invasive plants, provided that current conditions and the manner in which they differ from historical conditions are contextualized [18]. Conversely, criminalizing the agricultural/pastoral use of fire without understanding the needs of subsistence farmers or providing alternatives can only lead to failure or clandestine resource management, because people will set what they perceive as needed fires [37].

Regrettably, for a long time, the role of TFK on the landscape has been either overlooked or discounted within environmental studies, and there is very little formalised academic knowledge available that could be utilised to inform prescribed burning practices in some regions [109]. To learn from TFK land management, (a) formal knowledge needs to be generated based on past regional burning practices, and (b) understanding needs to be developed as to whether past burning practices could lead to effective hazard management and biodiversity outcomes within contemporary landscapes [109]. Bardsley et al. assert that the integration of TFK knowledge into effective environmental management will only be possible if the injustices of past exclusions of the importance of indigenous biocultural practices are recognised. In other cases, mismatches between policy, science, and local realities have curtailed the success of fire risk strategies in different regions [110].

The meagre amount of work focusing on Western countries also shows a critical livelihood-supporting practice steeped in social and ecological value but threatened by stringent regulation and shifting public opinion. The proposal to preserve this practice (in Ireland) is to establish more formal linkages between fire use practitioners and fire services, public land managers, and regulators to promote appropriate use of traditional fire within modern legal and best practice frameworks [34].

A relatively new incentive that could help local communities prevent fires in fire-sensitive vegetation is payment for ecological services. The West Arnhem Land Fire Abatement (WALFA) model is a fire abatement programme which has resulted in significantly reduced greenhouse gas emissions, with the involvement of Indigenous communities being a key element to optimize social and biodiversity benefits [20]. Other experiences in Northern Australia [23,111] and Central Brazil also frame Indigenous peoples in diverse ecological settings as having the responsibility to offset global carbon budgets through landscape-scale management of fire for biodiversity conservation and fire suppression based on the presumed positive value of non-alteration of tropical landscapes [112]. However, other scholars argue that the complexities of community-owned solutions for fire management are being lost as well as undermined by continued efforts on fire suppression and firefighting and emerging approaches to incorporate indigenous fire management into market- and incentive-based mechanisms for climate change mitigation [28].

The new ethos of eco-efficiency and environmental economics seems to have replaced the purely conservationist perspective, while issues of environmental justice and changing power relations are barely addressed in the literature. Nevertheless, some criticisms have emerged contrasting the traditional philosophically coherent political economy grounded in detailed earth sciences and topological networks of economic practices with the economic doctrines of the neoliberal era, which advocate the reimposition of order on the wild climate by means of a comprehensive financialization [63]. Other authors question whether national policies will adequately recognise the special needs and potential contributions of such communities and call for an equitable distribution of tangible rewards, while protecting the cultural and related benefits of customary fire use [19]. Ethical issues also arise dealing with the integration of local fire knowledge and Western fire management. The process risks imposing a Western bias in interpretation, leading to local ecological knowledge becoming subservient to Western paradigms [113]. Local knowledge and science can complement

one another, but Chalmers and Fabricius advise against integrating them in a way that co-opts local knowledge for scientific purposes [58].

Another key issue is the viability status of TFK [47]. Mary Huffman differentiates between four categories of current TFK status: robust, declining, rejuvenating, or historical. Myers argue that in many places, traditional uses of fire are either (1) persisting in an environment of increasing population growth and the current level of burning is outstripping the maintenance capacity of the ecosystem or (2) being reduced through fire prevention efforts, suppression, and changing land uses that no longer require or are intolerant of fire. Current burning practices may or may not be at odds with conservation goals [30,60]. Furthermore, the emergence of the new risk areas and shifting fire regimes is of course being contentiously debated [114].

The recovery and assessment of traditional knowledge and the cocreation of new local knowledge for enhancing resilience has also become a topic of discussion [115]. Researchers and managers have embraced traditional phenological knowledge to support the adaptive management of social-ecological systems vulnerable to changes in climate and fire regimes as an approach for improving natural resource stewardship in the face of uncertainty and complex environmental problems [116,117]. Research models whereby local communities and scientists work together to inform adaptive natural and cultural resource management have been tested and the scholars behind the study claim that such transdisciplinary and collaborative research strengthens informed conservation decision making and the social-ecological resilience of communities [117].

#### 4.2.3. Governance

Eriksen argues that local power relations are preventing local communities from adopting burning regimes that would be more environmentally sustainable and more in line with present-day farming systems. A mismatch between official fire policies and actual local fire practices—a discord based on a gap in existing knowledge of, and a lack of informed literature on, the importance of fire for socio-economic and environmental survival in fire-dependent ecosystems [118], as well as the mental models of communities exposed to environmental change [119]—is blamed for this. As a result, interstitial spaces become theatres for performances of domination and resistance, leading to contradictory and inconsistent approaches to fire management [67].

Authors involved in the field of the political ecology of fire have tackled these problems, dealing with contested processes of boundary making [67] and the knowledge production and social constructions shaping the institutional culture [66], as well as with the production and translation of knowledge within public institutions in a way that leads to a more nuanced understanding of the various forms of obscurity and ignorance which accompany official knowledge claims [44].

The conflict between scientists on the one hand and land managers in general [53,99,120] on the other became a cross-cultural conflict scalable to different regions and countries [55], a problem of epistemic supremacy which should be reversed in order to achieve greater cognitive justice in conservation areas and ensure that conservation aims are achieved [52]. Therefore, the mitigation of cross-cultural conflicts has become a pressing and inescapable need [72,121]. Taking a diachronic view over the past 20th century, Vinyeta has unveiled the United States Forest Service's discursive evolution from using racist logic discrediting, downplaying, and erasing Indigenous peoples and knowledge to a new scientific discourse in the face of changing social contexts [56]. In the same vein, Marks-Block and Tripp argue that fire suppression developed from a white supremacist settler colonial culture that effectively denigrated indigenous prescribed burning to protect timber and houses on stolen native lands [122]. However, now, where governments and communities have acknowledged the benefits of prescribed fire, interagency partnerships have developed and supported diverse modes and innovative mechanisms to expand prescribed fire.

Scale is another factor to be aware of. Ray et al. [123] maintain that some disagreements came from reliance on generalized national narratives at the expense of place-based science.

Therefore, they argue that, in some cases, conflicts between traditional ecological knowledge and conventional resource management, rather than indicating a dead end, can enable us to identify topics requiring in-depth, place-based research.

In the absence of institutional clarity dealing with governance and leadership models, established networks and interpersonal factors could be a first step—e.g., for the revival of indigenous fire management, the implementation of IFM activities, etc.—but they are highly contingent and depend upon routine persuasive labour and fragile intercultural diplomacy [72,124]. Moreover, in situations of cultural violence, hidden environmental knowledge is not easily made visible unless adequate conditions are created for it to emerge. Thus, some authors argue for the need of conservation engaging with the well-being agendas of Indigenous people, in particular, with the construction of their life plans [52].

Supporting grassroots movements that defend Indigenous-led restoration of Indigenous lands, knowledges, and cultures, different action-oriented frameworks have been proposed, such as "walking on two legs", an method of indigenous fire stewardship for fire-adapted landscapes [70]. Models of community-based fire management that meets local landowners' interests in property protection [125], new developments of intercultural governance creating spaces for continual multi-stakeholder conversations about fire management [68], or collaborative bushfire management [126] have been tested, mostly as 'decolonising experiments'.

Whatever the case may be, documents and proposals for collaboration are viewed by locals as a basis for their engagement in contemporary management on their own terms. Consistent with the conclusions of Hill et al. [127] that the integration of traditional and Western knowledge systems is best achieved through governance or co-governance, different local stakeholders clearly expressed a desire to be 'at the table' in future management negotiations, rather than having their documented knowledge being incorporated by others [128].

Mapping good practices of governance dealing with the recognition and incorporation of traditional ecological knowledge in contemporary community-based adaptive fire-dependant ecosystem management [55] has been the focus of several studies. The following have been recorded: consultation and organization of burnings conducted between formal agricultural organizations and local administrations in France [39]; participatory geographic information systems (PGIS) as organizational platforms for the integration of traditional and scientific knowledge in contemporary fire and fuel management [73]; or an traditional ecological knowledge (TEK) framework integrating efforts among resource managers, tribal representatives, scientists, and a tribal youth intern program to conduct ecological restoration [128]. Overcoming the gaps derived from different experiences and historical worldviews and building mutual trust and respect are the main challenges when integrating multiple perspectives through the "intercultural interface" [69].

Debates about disaster risk reduction and TFK are embedded within the United Nations Sendai Framework 2015–2030 for disaster risk reduction (DRR), which reaffirms the role of indigenous and local knowledge (IK) in complementing and contributing to more effective DRR [9]. The Sendai Framework is being linked to, and worked on, in the context of the Sustainable Development Goals (SDGs) [129].

#### 4.2.4. TFK within Global Fire Management Research Needs

Although research needs arise on a global scale, concerning processes of socio-ecological change, answers have to be found at the relevant local scale. The term "glocal management" in the sense of "think globally, act locally" fits perfectly the coupling between TFK and global fire management research needs. At the local community level is where the fires are ignited (by people mainly); fires escape containment, but fires can be initially attacked most effectively. This is also the level at which the fire use and the balance of impacts can be effectively combined. Community-based fire management (CBFiM) and multifaceted TFK have been combined and refined over time and places, and are a valuable foundation upon which integrated fire management can be articulated and then promoted up into

jurisdictions at other scales [129]. Efforts to record, characterise and evaluate CBFiM and TFK continue, and their value has been discussed [47,130].

Research interest in ethnographic research is illustrated in cases as diverse as the relationship between toponymy and fire dynamics in boreal ecosystems occupied by the Sami people [131] or the exploration of the role of fire in cultural landscapes in the boreal forest of Canada [132].

In the same vein, recognizing, collecting, and revitalizing traditional fire knowledge is one of the most fertile and promising strands of research [59,101,133–137]. This issue has been a source of controversy in the past. Customary use of fire by Indigenous peoples was a contentious issue. Equally contentious was the proposition that attempts should be made to support and re-establish customary practice. Some dismissed Aboriginal practice as little more than culturally endorsed pyromania, and consequences for land, vegetation, and wildlife management as incidental and unintended outcomes [17]. Moreover, obstacles are often encountered to recovering and redeploying a defunct fire-based production strategy, e.g., reluctance by Indigenous people to embrace old production strategies that have been supplanted by new ones [138].

Solving problems and tensions between TFK and science is another repeated concern that almost inevitably ends up resorting to the invocation of participatory approaches and processes for facilitating stakeholder engagement in fire management policy and practice [139]. However, attempts to combine local and technical/scientific fire knowledge entangle different understandings of what a "traditional" fire regime was and should be, and often prioritize technical/scientific views supported by funding bodies [24].

Supporting participatory action research has become a further dominant topic which draws the consensus of almost every expert and has produced a wealth of research papers [54,71,76,132] as well as some tools to share knowledge and guide the management of natural and cultural resources such as a fire and seasons calendar to lead cultural burning, share cross-cultural knowledge, and increase awareness of local cultural fire management [140].

## 5. Discussion and Conclusions

Based on contributions such as building fire-adaptive communities living on a flammable planet [92], supporting Fire Smart Territories [141], and fostering resilient landscapes to prevent catastrophic forest fires [142], it appears clear that we are facing a new paradigm that is committed to going beyond strictly biophysical viewpoints and calling for the integration of complementary visions of landscapes and the communities living there, with their legacy of knowledge and subjective dimensions [143]. All this is unfolding in an international context in which risk reduction proposals are aligned with adaptation and resilience objectives. The Sendai Framework for Disaster Risk Reduction 2015–2030 developed as the successor instrument to the Hyogo Framework for Action (HFA) 2005–2015: Building the Resilience of Nations and Communities to Disasters.

However, unfortunately, the proven failure of focusing exclusively on traditional fire exclusion strategies or a war on fire [80] lacks a proven track record of promising fire-resilient landscape strategies: how to operationalize the theoretical construct is still an on-going challenge [144].

Now, what is the role of TFK in new approaches to fire-resilient territories? All experts agree that TFK is a basic input in fire impact prevention, reduction, and mitigation strategies. Those local fire-adaptive communities derive knowledge of how to manage the land from multiple sources and perspectives, and they retain traditions of place-based knowledge and practices related to fire [92]. Effective resilience is more easily created and maintained by utilizing the knowledge, resources, and skills of all stakeholders to build the needed adaptive capacity. Indeed, even today we still see many communities in which TFK keeps its viability with a robust status, and a slight and gradual change in perspective has occurred since the 1990s, influencing a shift in environmental discourse and policy making toward an intercultural fire management approach. Fire ecology as well as the

management of fire by rural communities have been incorporated into what is now referred to as "integral fire management" [52,71,145,146].

Following the course of both the evolution of scientific paradigms and their subsequent progressive enforcement by practitioners, a growing number of scholars have addressed the identification, collection, and revitalization of TFK, albeit focusing almost exclusively on indigenous fire knowledge.

One school of thought argues that the concept of tradition is part of a Eurocentric vocabulary that is framed within a cultural essentialism and that derives from colonial creations (politics of tradition), thus championing the idea that decolonizing the social sciences leads to a clash between local histories and overarching paradigms [147]. In a similar vein, other scholars argue for an understanding of collaborations between Aboriginal peoples and management agencies as 'decolonizing experiments'. This means paying attention to the open-ended character of collaborative initiatives, whether and how they materially improve the position of Indigenous peoples, as well as whether and how they give rise to new resources and strategies for the creation of other decolonizing futures [126]. Some scholars argue that where indigenous communities have established burning infrastructure, authorities should consider the devolution of decision making and land repatriation to accelerate prescribed fire expansion [122]. Be that as it may, efforts to identify, collect, and rekindle this indigenous knowledge in contexts of collaboration and new models of governance are noteworthy. They are illustrated by the wealth of the literature that was collected and analysed.

Instead, local fire knowledge in developed regions or, to use the term coined by Seijo and Gray [42], pre-industrial anthropogenic fire regimes (PIAFRs) has been neglected or side-lined in the mainstream research, as can be easily inferred from the number of papers that address it (7 out of 134) in the sample. Admittedly, our sample has the limitations of being restricted to English-language contributions collected in the Web of Science and Scopus databases, which means that we are missing out on the potential knowledge produced in other languages. However, assuming the inherent weaknesses of this decision, we consider that the state of the art on traditional fire knowledge within the international scientific community is significantly represented by the selection made. The exclusion of local fire knowledge from mainstream scientific productions that are recognized and exchanged among leading researchers is unavoidable.

Among the possible causes of this unjustifiable oblivion could be its declining viability status. Most of the cases are defined as those in which TFK still exists within members of a given culture, but in which demographic, economic, political, land use, or other changes threaten its continued viability [47]. In many European regions, bottom-up changes, such as a demographic decline leading to the deterioration of cooperative labour networks, may negatively affect both the transmission of fire-use knowledge and the physical capacity to control fire spread [148]. Furthermore, where opportunities to practice fire use become constrained from the top down, for example governmental policies enforcing fire exclusion and suppression, cultural knowledge of fire ecology also risks degradation. Studies of fire suppression history and social memory in Mexico [149] found that local peoples had 'forgotten' not only the fact that their ancestors used landscape fire, but that fire was ever a part of the forest ecology. Similar impacts have been reported in Alberta [150] and seem plausible in the United States, given the success of the Smokey Bear campaign and its ideological proxies [151]—this even though responses in Spain and the USA have demonstrated, for as long as a century, that prohibition and sanctions for using fire in systems in which people depend upon it for utilitarian purposes is largely futile and often counterproductive [37,152].

Today, strict fire suppression policies have been modified, yet other threats are emerging. We find a fine example of this in France, where in the 1980s the pastoral services of the Pyrenean massif carried out pragmatic experiments to reintegrate traditional fire practices into the register of pastoral management tools. This process was relatively long, running from the 1980s to the 2000s [39]. Today, the entry of new stakeholders (development organi-

zations, tourists and second-home residents, hunters, permanent non-agricultural residents, environmental associations, fire brigades, etc.) and new regulations (national or European, notably concerning air quality) has considerably complicated the scheme.

In the meantime, rural depopulation and the abandonment of pastoral practices in mountain areas have triggered deep changes in the landscape, resulting in the accumulation of lignified fuels and an increased risk of fires—a sensitive issue in southern areas of the European continent. Climate and land use changes led to an increased prevalence of megafires in Mediterranean-type climate regions, with experts now calling for a shift in focus from fire suppression to mitigation, prevention, and preparation. A paradigm change is being hampered by strong risk aversion motivated by social and political expectations and pressures, including societal unacceptance of prescribed fire [153].

In short, practices based on traditional fire knowledge (TFK) in the forest ecosystems of the Mediterranean mountains exhibit a level of sophistication that deserves further attention from scientific researchers, foresters, and environmental managers. Attempting to exclude fire from ecosystems that can be "fire adapted", may be overlooking some promising leads as to how to manage and conserve such ecosystems in the future [33]. The same approach could be extended to many other territories that have not been analysed so far.

Finally, we can argue that the conducted thematic synthesis analysis has allowed us to unveil an epistemological window proving the existing gap in current research on local fire knowledge among non-Indigenous populations. Our first recommendation is therefore to promote a broader interest in the identification and systematic collection of local fire knowledge, especially in the territories most exposed and vulnerable to forest fires and where the TFK can contribute to the building of fire-resilient territories. Second, it would be necessary to conduct the scientific validation of the fire management strategies and uses articulated by TFK practitioners in each territory. Third, the barriers and enablers (including cultural, social, organizational, economic, technological, and political) should be identified to support and/or revitalize TFK. Fourth, a framework should be built where community-based management methodologies can be pooled, shared, and discussed.

The ultimate goal would be to contribute to achieve an integrated fire management strategy to engage in more agile and adaptive wildfire problem solving and operating from a Shared Wildfire Governance (SwG) perspective [80].

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## Appendix A Data for Bibliometric Analysis

Publications included in the literature review (N = 134):

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