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Perspective

Fostering Post-Fire Research Towards a More Balanced Wildfire Science Agenda to Navigate Global Environmental Change

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Abstract: As wildfires become more frequent and severe in the face of global environmental change, it becomes crucial not only to assess, prevent, and suppress them but also to manage the aftermath effectively. Given the temporal interconnections between these issues, we explored the concept of the "wildfire science loop"—a framework categorizing wildfire research into three stages: "before", "during", and "after" wildfires. Based on this partition, we performed a systematic review by linking particular topics and keywords to each stage, aiming to describe each one and quantify the volume of published research. The results from our review identified a substantial imbalance in the wildfire research landscape, with the post-fire stage being markedly underrepresented. Research focusing on the "after" stage is 1.5 times (or 46%) less prevalent than that on the "before" stage and 1.8 (or 77%) less than that on the "during" stage. This discrepancy is likely driven by a historical emphasis on prevention and suppression due to immediate societal needs. Aiming to address and overcome this imbalance, we present our perspectives regarding a strategic agenda to enhance our understanding of post-fire processes and outcomes, emphasizing the socioecological impacts of wildfires and the management of post-fire recovery in a multi-level and transdisciplinary approach. These proposals advocate integrating knowledge-driven research on burn severity and ecosystem mitigation/recovery with practical, application-driven management strategies and strategic policy development. This framework also supports a comprehensive agenda that spans short-term emergency responses to long-term adaptive management, ensuring that post-fire landscapes are better understood, managed, and restored. We emphasize the critical importance of the "after-fire" stage in breaking negative planning cycles, enhancing management practices, and implementing nature-based solutions with a vision of "building back better". Strengthening a comprehensive and balanced research agenda focused on the "after-fire" stage will also enhance our ability to close the loop of socioecological processes involved in adaptive wildfire management and improve the alignment with international agendas such as the UN's Decade on Ecosystem Restoration and the EU's Nature Restoration Law. By addressing this research imbalance, we can significantly improve our ability to restore ecosystems, enhance

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post-fire resilience, and develop adaptive wildfire management strategies that are better suited to the challenges of a rapidly changing world.

Keywords: wildfire science loop; wildfire stages; post-fire research; wildfire research agenda; adaptive wildfire management

1. The Wildfire Science Loop

Wildfire science and technology have significantly evolved over the last few decades, encompassing a wide range of themes, topics, and scientific disciplines [1,2], such as forest ecology and climate research, soil and water ecology, community risk assessment, planning and mitigation, wildfire detection and mapping technologies and atmospheric science [2]. According to the Shared Wildfire Governance (SwG) framework proposed by Tedim et al. [3], three main stages can be identified in the "wildfire science loop": before a fire outbreak, during a fire event, and after extinction takes place. These authors broadly characterized the fields of action for the "before-fire" stage as focusing on prevention, preparedness, and risk reduction through ignition prevention, hazard identification, fuel management, (emergency) planning, vulnerability assessment, community readiness, and fostering resilience by integrating local knowledge and shared governance. The "during-fire" stage emphasizes real-time crisis management, operational coordination, balancing fire suppression with community safety through effective communication, advanced fire modelling/simulation, and evacuation analysis and support. The "after-fire" stage centers on recovery and resilience, addressing losses in multiple aspects, rebuilding infrastructure to mitigate future risks, supporting ecosystem regeneration, and learning from events to inform adaptive strategies. Building on the SwG framework, we adapted and expanded the stages to encompass specific areas, research themes, and topics in wildfire science beyond identifying lines of action associated with each stage—SwG primary focus (for instance, by including fire regime/history in the "before" stage, wildfire detection in the "during" stage, and burn severity or fire effects assessment in the "after-fire" stage; Figure 1; see also Supplementary Materials Subsection S1.1 for details). Among other purposes, these stages can serve as a guiding framework to categorize the science behind preventing, understanding, predicting, and managing wildfires (Figure 1).

This partition also enables a detailed assessment of how each stage has been represented in the wildfire research landscape. Since all three stages are of high relevance for adaptive wildfire management [3], a balanced research agenda will be more aligned with broad and comprehensive policies and programs such as the UN's Decade on Ecosystem Restoration (UN-DER) and the EU's Green Deal, the EU 2030 Biodiversity Strategy, and the recently approved Nature Restoration Law (EU-NRL).

Despite the advantages of a balance across stages, we expect that the pressing need to improve wildfire management may have fostered a historical bias towards the "before" and "during" stages, with the "after" stage receiving relatively less attention in wildfire research agendas. To explore this idea and characterize the three stages of the "wildfire science loop" more rigorously, we performed a systematic literature search and exploratory bibliometric analysis to assess and compare the volume and research topics in each stage. In addition, identifying critical research disparities would more effectively guide future research investments aiming to buffer the effects of ongoing climate changes on fire regimes, with an increase in extreme and more severe fires worldwide [4–6].

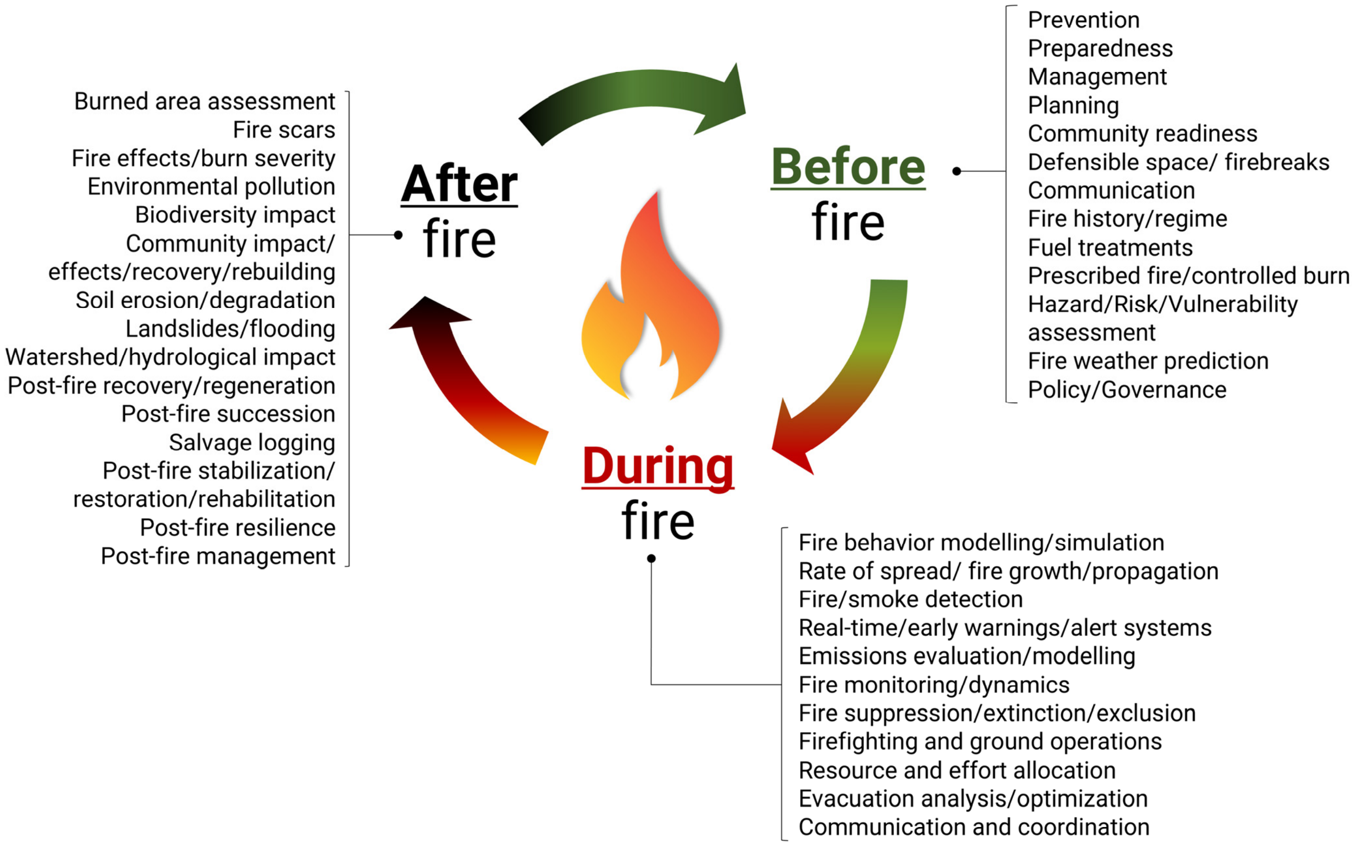

Figure 1. The "wildfire science loop" with a proposal of research themes and topics for each stage composing it.

To identify the relevant literature, we searched the Scopus and Web of Science (WoS) databases for relevant publications published from 2000 to 2023 (excluding 2024, since this was incomplete at the search date). We used both databases to reduce biases associated with each one and ensure multidisciplinary coverage [7]. To identify publications associated with each stage of wildfire research, we used three search strings that reflected distinctive topics of each stage and were adapted from the SwG framework and preliminary review work (Figure 1; see the search strings in the Supplementary Materials). We applied the search strings to the title field, the title and abstract fields, and the title, abstract, and keyword fields in each database to ensure that the choice of search field did not affect our estimates of the research volume in each stage. We combined the search results obtained for the title field search from the two databases and removed duplicates using automatic and manual title screening with the R package '*revtools*' [8]. Based on the titles, we carried out an additional manual/supervised screening to remove non-relevant publications with respect to the review's scope. Additional criteria were also employed to check the suitability of papers for each stage in cases where terms/expressions spanned two or all stages (see the screening phase in Supplementary Materials—Subsection 2.2). Finally, we employed a bibliometric analysis using the screened datasets for each stage using the R package '*bibliometrix*' [9]. Bibliometric analyses allow for the examination of large volumes of bibliographic data and the identification of key topics in a scientific field [10]. We also employed a co-occurrence network analysis to identify relationships between terms/expressions extracted from keywords of papers in each stage (see the bibliometric analysis in the Supplementary Materials).

2. An Overview of the Three Stages of the Wildfire Science Loop

Our systematic review allowed us to explore the literature and provide a more detailed outline of the research associated with each of the three stages of the wildfire science loop. The "before-fire" stage takes place before a wildfire ignites and focuses on preparedness, prevention, management, and planning (Figure 2). The assessment and prediction of fire weather indices (e.g., [11]), fuel characterization and mapping (e.g., [12]), fuel treatments [13], land-use management schemes [14], fire history, and fire regimes [15] are framed within this stage to guide the development of strategies for reducing fire risk, increasing preparedness and recoverability [16]. Risk and vulnerability assessments enable the formulation of proactive measures and support the development of informed strategies for preventing and mitigating wildfire impacts and enhancing adaptive resilience across sectors [17].

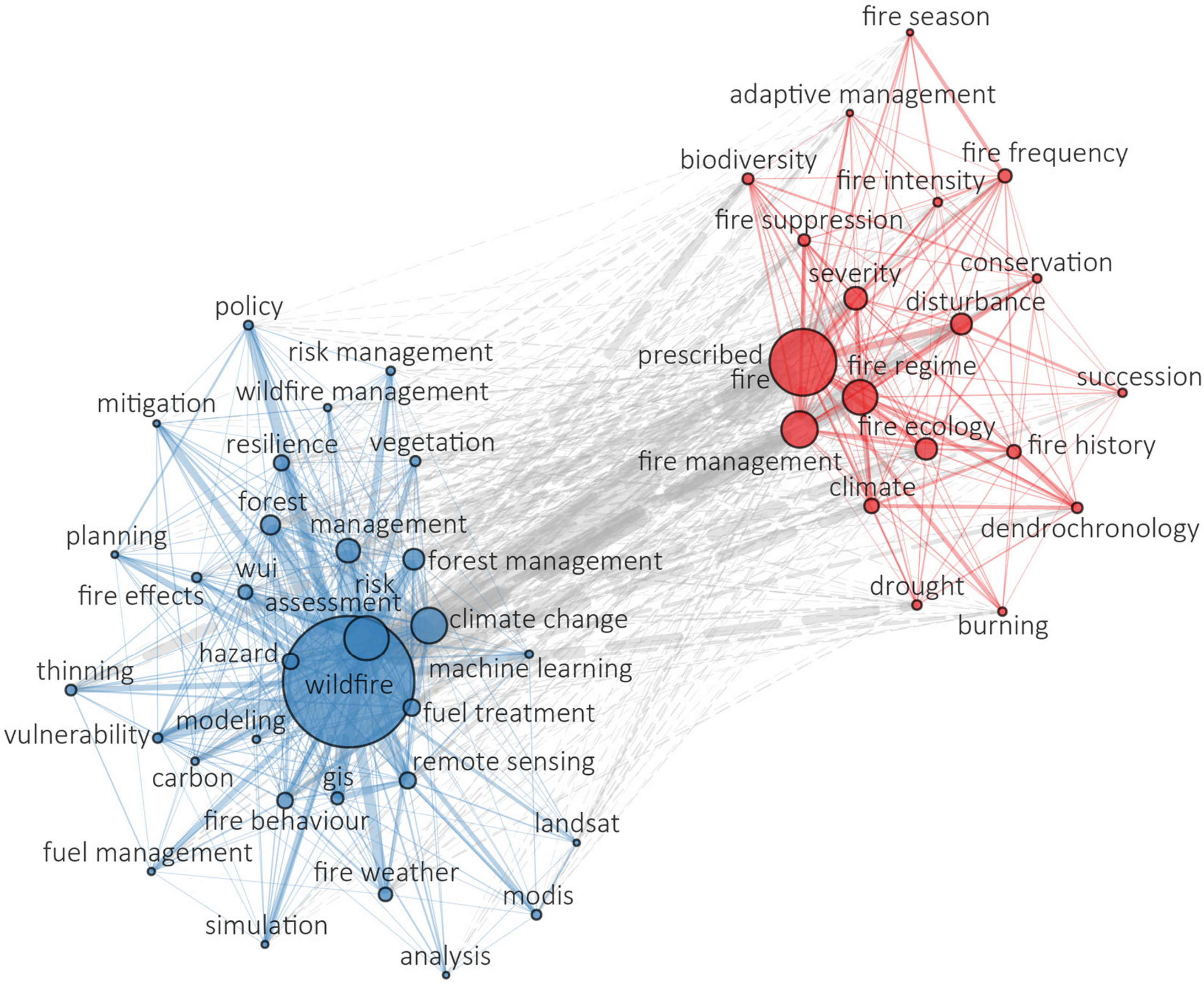

Figure 2. Keyword co-occurrence graph for the "before-fire" stage based on bibliometric analyses, highlighting terms or concepts (with node size proportional to its frequency/relevance) and associations among and between them. Colors represent clusters of frequently co-cited words/terms. For the "red" cluster, key terms indicate that this group of research is centered on adaptive/fire management and suppression, prescribed fire and its effects/consequences (e.g., severity, disturbance, biodiversity, conservation), fire history, frequency, and regime, and the climate implications of droughts from the perspective of fire ecology. The "blue" cluster focuses on wildfire risk assessment/management, hazards and vulnerability, climate change, forest and fuel management, fuel treatments, and thinning. Studies on the wildland–urban interface ("wui") appear in this cluster. Technological tools such as GIS,

remote sensing, modelling, machine learning, and simulation support the technical, methodological and future-oriented perspectives on wildfire research in the "before" stage. A relatively weak connection between the clusters might indicate that there is potential for greater integration of the knowledge of fire ecology with modern risk modelling and predictive technologies. The strongly connected position of "climate change" suggests that it is a pivotal topic connecting various aspects of wildfire science in predicting future risk, management implications, and novel fire regimes.

In this stage, the objective is to ensure that communities, agents at multiple levels, and responders are adequately prepared for wildfires of different magnitudes and circumstances. Research on the scientific, technical, and management issues surrounding the development and application of preventive measures (e.g., prescribed fires [18–24]) also takes place at this stage, but not exclusively, according to our bibliometric analysis (Figures 2 and 3). Amid pervasive climate and land-use changes, coupled with complex demographic trends [25], this stage is even more relevant, as it pre-emptively addresses the impacts of a shifting environment on wildfire risk and activity (e.g., [26–28]). This stage also emphasizes the importance of adaptive strategies supported by a factual and robust scientific backbone, policy responses, nature-based solutions (NbSs), and governance frameworks (e.g., [3,29,30]).

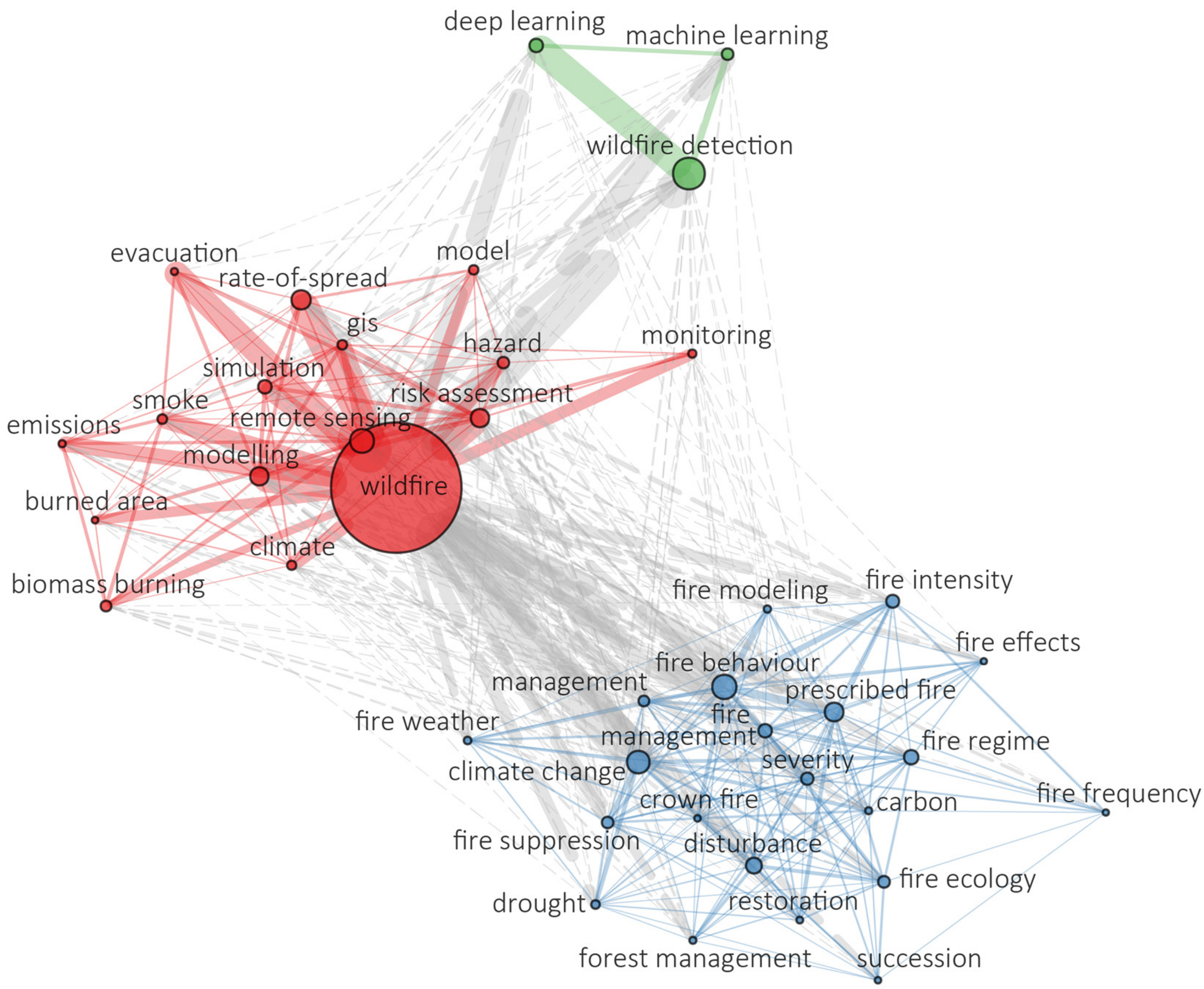

Figure 3. Keyword co-occurrence graph for the "during-fire" stage based on bibliometric analyses highlighting key terms or concepts (with node size proportional to its frequency/relevance) and associations among and between them. Colors represent clusters of frequently co-cited words/terms.

The "green" cluster revolves around fire detection technologies, with keywords indicating research using deep learning and machine learning to develop new ways of detecting fires early, with strong interconnections suggesting that this may be an emerging field. The "red" cluster emphasizes hazard-related aspects of wildfires, including risk assessment, fire monitoring, evacuation analyses, and smoke plumes for (often real-time) monitoring and understanding of wildfire dynamics, rate of spread, emission assessment, risk mitigation, and broader support for emergency response. Remote sensing, GIS, modelling, and simulations provide the data, tools, and technological backbone. The "blue" cluster is broader than the previous ones and includes topics such as fire modelling, fire ecology, and management. It focuses on understanding fire behavior, intensity, crowning, and ecological impacts, as well as the use of this evidence to support management strategies, such as prescribed fires and fire suppression. The keywords "climate change" and "drought" indicate a recognition of the effect of environmental factors on wildfire behavior, intensity, and frequency, as well as carbon balance and emissions.

The "during-fire" stage encompasses all scientific and technological advances contributing to effectively tackling a wildfire's active phase (i.e., this is defined as the period between ignition and extinction), where fire behavior, rate of spread, suppression, and control are often the primary goals (Figure 3). Geospatial analyses, coupled with fire indices, weather monitoring, and dynamic fire modelling and simulation (e.g., cellular automata, physically realistic, process-based, and, more recently, machine learning or deep learning models), with some operating in (near-)real time, are pivotal operational tools. These enable researchers, technical staff, civil protection agencies, and other responders to anticipate, predict, and understand fire behavior and the rate of spread (e.g., [31–34]). Optimization and simulation tools also assist in resource allocation and in deciding on evacuation needs and priorities in different scenarios or conditions (e.g., [35–37]). The optimization of resources, ground operations, communication, and tactical positioning of firefighting efforts also characterizes the "during-fire" stage (e.g., [38,39]).

Wildfire and smoke detection in real time (or near-real time) is also an active topic of development within this stage, combining advanced modelling methods (e.g., deep learning) and a plethora of distinct data sources (e.g., satellites, drones, social media/crowdsourced) (e.g., [40]). This stage is also concerned with addressing the health impacts of wildfires (e.g., [41,42]), particularly those associated with the emission of harmful gases or aerosols, which is critical for safeguarding the well-being of populations affected by wildfires and that of firefighters [43].

The "after-fire" stage takes place in the period following the extinction of a wildfire event. It concerns the science involved in assessing the full spectrum of wildfire-related impacts (at multiple dimensions and levels) and facilitating post-fire emergency stabilization, restoration, and short- to long-term recovery (Figure 4). The post-fire stage involves assessing, mapping and monitoring burned areas, the burn severity (supporting the quantification of effects in several systems of interest, such as the biota, soil microbiology, hydrologic processes, or atmospheric inputs [44]), and the overarching (socio-)ecological consequences. This assessment draws on various scientific methods, including field-based [45,46] and remotely sensed observations [47–51].

Depending on their severity, the immediate aftermath of wildfires includes an increased risk of soil erosion and degradation [52–54] and other cascading long-term effects [55,56]. The effects of subsequent or compounding disturbances related to post-fire salvage logging on soil erosion, runoff, and other parameters, such as soil organic matter or fertility (e.g., [57–60]), or climate extremes, such as droughts (e.g., [61]), are research topics of this stage. The same happens when assessing wildfire effects on ecosystem services, which also occurs in the "after" stage [62–64]. Assessments and understanding of the effects of prescribed fires on soil [65,66], water [67], and air quality [68] and vegetation and species diversity [69,70], in addition to the associated impacts on ecosystems (functions and services), communities, and society, also (partially) relate to this stage (e.g., [71]).

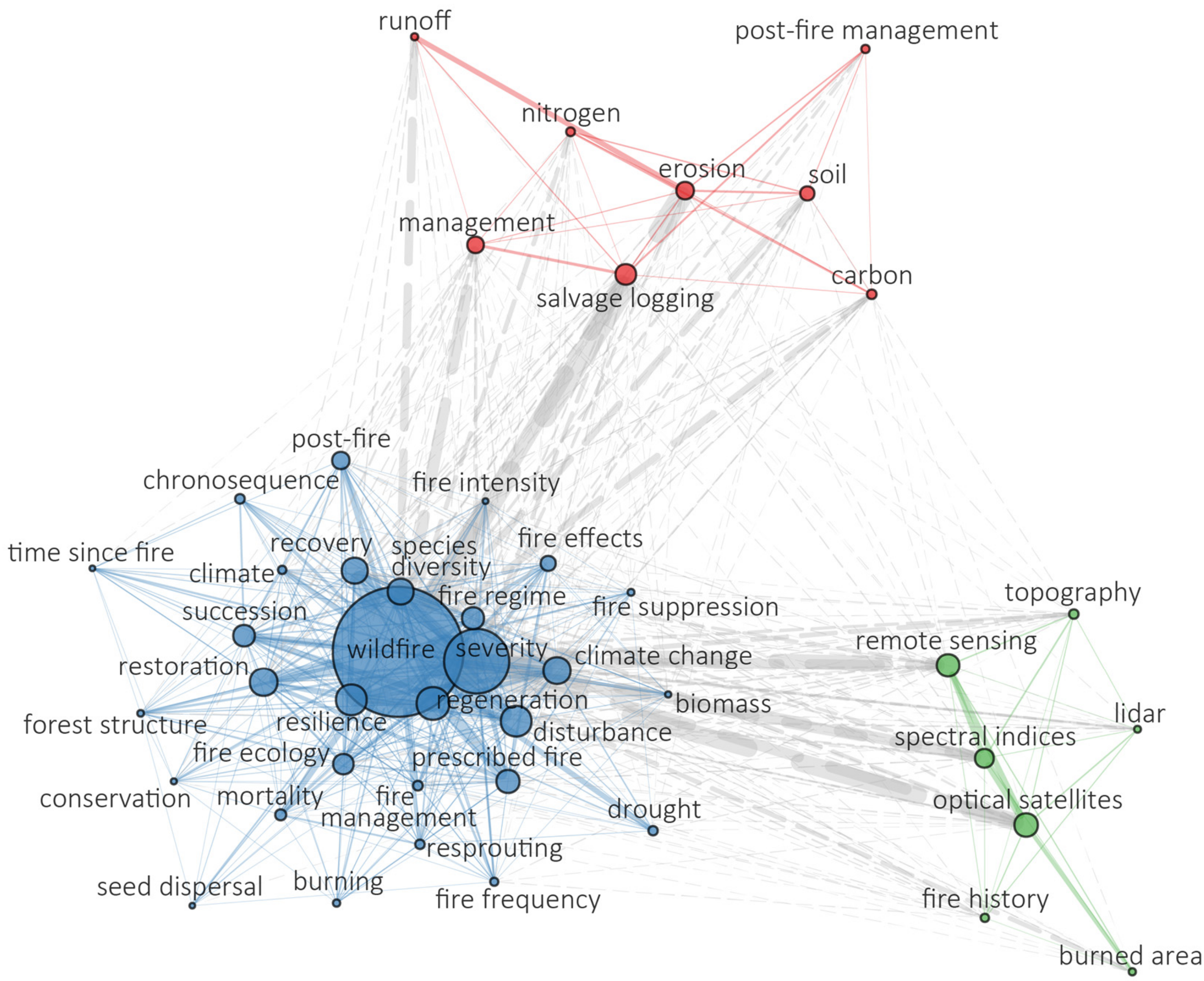

Figure 4. Keyword co-occurrence graph for the "after-fire" stage based on bibliometric analyses, highlighting key terms or concepts (with node size proportional to its frequency/relevance) and associations among and between them. Colors represent clusters of frequently co-cited words/terms. The "red" cluster focuses on studies on soil-related impacts, highlighting themes such as erosion, runoff, carbon, and nitrogen, with salvage logging being studied for its effects on soil health and nutrient cycling. Research on these topics seems to have a significant role in supporting post-fire management strategies. The "blue" cluster seems to represent the bulk of research in this stage, focusing on post-fire ecological dynamics, species recovery, and long-term environmental impacts. Central keywords include (wildfire) severity, recovery, and fire regime, with related terms such as resprouting, succession, forest structure, and regeneration, which seem to focus on how ecosystems regenerate and adapt after wildfires (relating to, e.g., species diversity, conservation, mortality, resprouting, seed dispersal as well as restoration, and resilience). Terms such as climate change and drought suggest these environmental factors' compounding effects. The "green" cluster is heavily centered on remote sensing tools and methods for evaluating and monitoring post-fire landscapes, burned areas, burn severity, ecological impacts of wildfires, and recovery. The connections with the "blue" cluster suggest that remote sensing tools are critical for understanding recovery processes and fire regime impacts.

As a response to wildfire impacts, research in the "after" stage also includes the development of soil rehabilitation and mitigation methods (e.g., [54,59,72,73]), as well as an assessment of the cost-effectiveness of such measures [74]. Biodiversity and ecological responses to post-fire ecosystems are integral to this stage, offering insights into how species (native and alien/invasive species and their interactions) and biological communities adapt, recover, or decline in the aftermath of wildfires [75,76]. This information is essential for addressing long-standing questions and theories in fire ecology, such as the "pyrodiversity–biodiversity" hypothesis [77]. Moreover, understanding post-fire recovery and its driving factors for species, communities, and ecosystems is a pivotal contribution of this stage to the grander wildfire research landscape [50,78–81]. Research in the "after-fire" stage plays a critical role in guiding communities, stakeholders, and managers and acknowledging the challenges and opportunities of adequately managing post-fire landscapes and rebuilding communities.

3. A Striking Imbalance in the "After-Fire" Stage of Research

Together, the three stages form an intricate and interconnected continuum of wildfire-related science, delivering vital knowledge for fire management, prevention, and ecological resilience. Each stage can be further disentangled into thematic clusters or sub-fields (as suggested by Figures 2–4). Despite being interconnected, each stage holds unique challenges, concepts, approaches, and scientific questions, underscoring the necessity of a multidisciplinary approach to wildfire research to support adaptive and sustainable management.

One might expect the three stages to be equally represented in the literature, reflecting a balanced research effort by the scientific community over recent decades. However, in line with our initial assumption, our exploratory bibliometric analysis revealed significant asymmetries in the volume of published research across the stages. Specifically, our results show that research related to the "after-fire" stage (with 3976 papers retrieved after screening) is 1.5 times or 46% less represented than research related to the "before-fire" stage (5802 papers) and 1.8 times or 77% less represented than research on the "during-fire" stage (7041 papers; Figure 5b).

In addition to the relatively smaller volume of published research, our bibliometric analysis also revealed that post-fire research tends to be slightly more thematically partitioned, with more sub-areas and fewer connections (see Figure 4 vs. Figure 2, for instance). An example of a niche sub-area identified by our bibliometric analyses relates to soil research, which includes the themes of soil erosion and degradation.

The reasons for these asymmetries are likely manifold and require a more profound investigation, which would be outside this study's scope. In short, the high potential value of knowledge generated through post-fire research may not have been acknowledged by researchers, managers, and policymakers. Still, we suggest that these asymmetries are potentially driven by the intense public and political need to improve pre-fire management and preparedness for during-fire action involving, for instance, early detection, suppression, and the protection of lives and livelihoods.

In fact, adding to a strong, understandable focus on early detection of new fire events, during active fires, there is an immediate need for accurate simulations or predictions of fire spread and behavior that are capable of informing practical decisions regarding suppression and respondents' efforts (e.g., [32,39,82]). These predictions/simulations include, among other issues, assessing wildfire propagation, identifying evacuation routes, deploying firefighting resources, and protecting critical infrastructure. Models and simulations provide real-time information that is essential for these decisions [32], making them highly prioritized for funding and research. In addition, the vast economic impact of wildfires in terms of direct damages and fire suppression costs is substantial. As such, governments, military personnel, wildfire-related authorities, and insurance companies are highly interested in reducing these costs, leading to a justifiable focus on preventive planning and developing immediate response strategies.

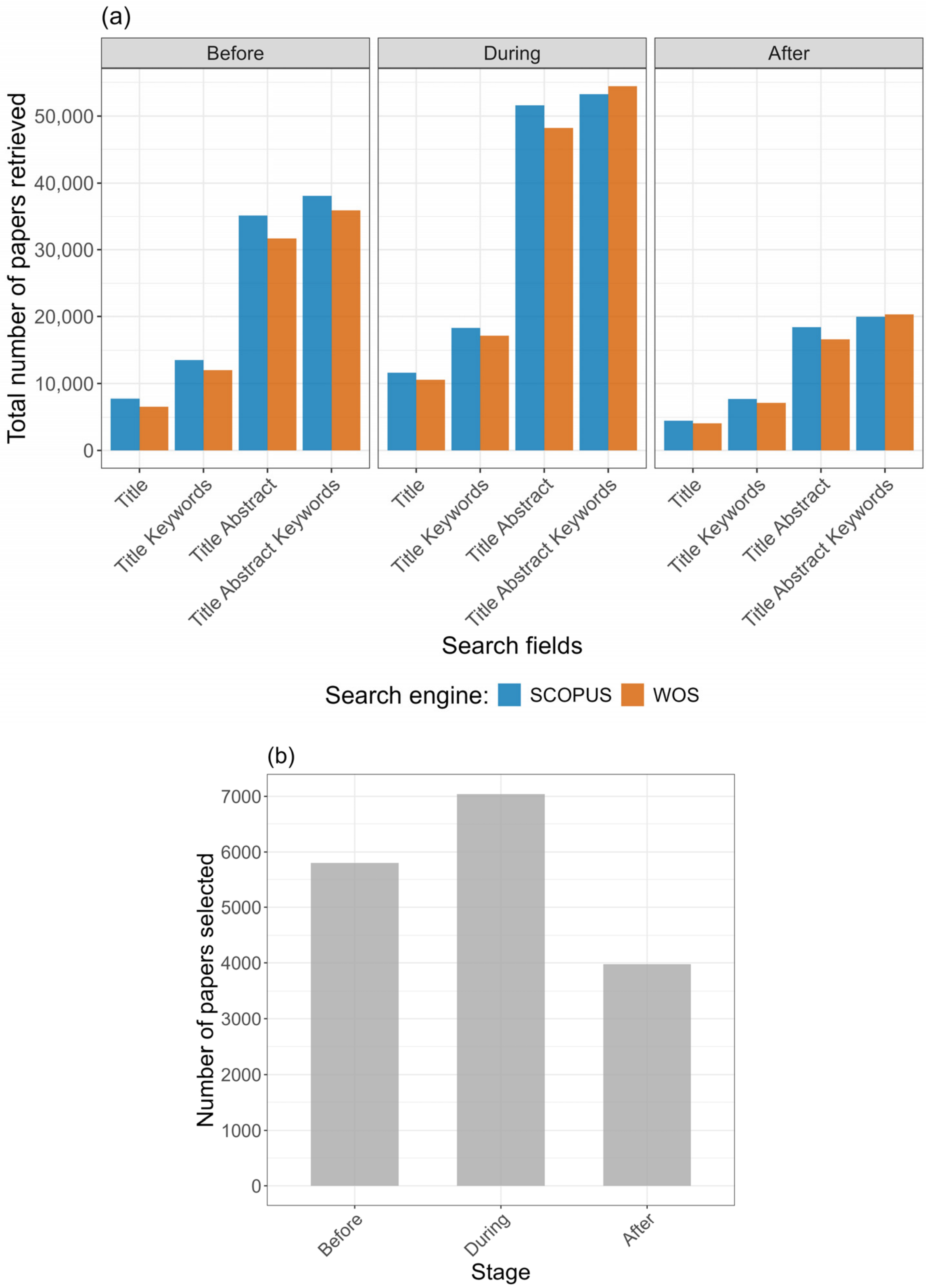

Figure 5. Results from the bibliographic database search showing (**a**) the total number of research papers found for each stage of the "wildfire science loop" and (**b**) the number of eligible papers following the screening stage to remove duplicate records and non-relevant papers considering the scope of this review.

Policies typically prioritize immediate, direct, and visible impacts, such as risk reduction and fire suppression, due to their direct consequences for public safety (e.g., [83]), thereby tipping the investment scale towards the "before-fire" and "during-fire" stages. In addition, active wildfires capture significant media and public attention. As a result, there is usually (and, for obvious reasons, justifiable) urgency for fire suppression and public safety during the active phase. Wildfire science history and the necessity of developing scientific resources and tools to model, simulate, and operationally tackle wildfires may also justify why the "during-fire" stage is proportionally more represented in scientific papers. At this stage is where/when scientific developments related to, e.g., real-time wildfire detection (e.g., [84–86]), fire behavior modelling and simulation (e.g., [87–90]), fire–weather analysis [91–93], tactical planning (e.g., [39,94,95]), and evacuation route optimization [35–37] take place. These developments are inherently interdisciplinary, drawing on vast and diverse research communities, contributing to the "during-fire" stage's significant critical mass. These specialized communities include, for instance, physicists and mathematicians advancing the understanding of wildfire dynamics; computer scientists developing wildfire alert systems, simulators or detection algorithms; wildfire scientists conducting experimental and applied studies; electronics engineers designing sensors, networks and communication protocols; and climatologists and Earth-systems scientists examining fire–weather interactions and climate change impacts. The potentially lower interdisciplinarity, critical mass, and representation of broad research communities (e.g., physicists, climatologists, mathematicians, and computer scientists) in the "after-fire" stage may also help to explain the lower volume of published research in this area. Despite their relevance, these issues deserve an in-depth assessment outside the scope of this perspective paper.

Beyond historical reasons, the mediatic exposure and focus on fire suppression and managing crisis scenarios may also have the potential side effect of funnelling more resources to the "during-fire" stage. This is primarily and understandably due to the urgent need for effective responses that directly impact public safety and protect property during these critical moments. Conversely, post-fire recovery processes, which are more protracted and less dramatic (exceptions exist), do not usually attract the same level of social attention, funding, or political prioritization, which may contribute to fewer resources being allocated, comparatively fewer research initiatives being proposed, and less scientific production [52,96].

Moreover, because post-fire research typically deals with longer-term (socio-)ecological impacts and recovery processes, it may receive fewer resources and support. This effect may be enhanced by the often short-lived research funding cycles and the tendency to prioritize projects with shorter timeframes, yielding faster results and higher publication volume. The long-term nature of post-fire research also makes it potentially less attractive to researchers seeking more immediate academic and professional recognition and impact. Benefits from post-fire research and its applications, such as decreased short-term risks (e.g., floods), faster recovery, ecosystem restoration, and long-term resilience building, are realized over extended periods, making it potentially less attractive for immediate funding and policy support. In line with these issues, post-fire research requires long-term (socio-)ecological monitoring [97] to understand and guide recovery processes, which is resource-intensive and time-consuming.

Lastly, the complexity of environmental and ecological responses to wildfires, including soil loss and recovery, vegetation regrowth, and biodiversity changes, demands extensive and interdisciplinary studies that are often very challenging to establish. On the other hand, the variability in post-fire responses and recovery due to factors such as climate, soil attributes, vegetation composition and structure, and human land use adds complexity to this research field, making it challenging to generalize findings (e.g., [50,98–100]).

This inherent complexity and these demands for interdisciplinarity may create barriers to establishing a shared framework and mutual comprehension among diverse experts. Coordinating effective collaboration across various fields, such as wildfire science, ecology, hydrology, soil science, and social sciences (among others), presents significant challenges in forging and steering knowledge networks of specialists and a common ground for communication and analysis tools. Our bibliometric analysis supports these connectivity issues in post-fire research (Figure 4) and calls for more integration among experts across different domains.

4. The Added Value of Reinforcing Post-Fire Research

Rebalancing wildfire science is crucial and can be achieved by increasing research investment in the "after-fire" stage. This investment would enable post-fire research to deliver a more detailed and nuanced understanding of post-fire environments, address critical aspects such as burn severity and recovery trajectories, and support the development of experimental setups for testing and refining post-fire stabilization, mitigation, or recovery methods—all of which are essential to overcoming ecosystem restoration challenges [47,48,50].

Reinforcing the post-fire research agenda would make a decisive contribution that aligns with global and regional environmental policies and programs. Initiatives such as the UN's Decade on Ecosystem Restoration, the EU's Green Deal, the 2030 Biodiversity Strategy, and the recently approved EU's Nature Restoration Law will all benefit from the insights yielded by robust post-fire research.

Considering the high relevance of knowledge produced in all three stages of the "wildfire science loop", we underline that fostering a robust, sustained agenda of post-fire research should not involve disinvestment in the other two stages (i.e., the "before-fire" and the "during-fire" stages). All three stages are strongly interconnected and essential for effectively addressing the challenges of altered fire regimes, particularly in an increasingly dynamic and rapidly changing world. These interconnections occur not only across time but also through the relationships established between actors and processes within and across the different stages. Building on these premises, we advocate for greater attention and investment in research focused on the 'after-fire' stage, with benefits to enhance and rebalance the generation and application of knowledge across the entire wildfire cycle (Figure 6).

Given this interdependence of the different stages of the wildfire science loop, the underrepresentation of post-fire research presents a substantial gap in our collective knowledge, potentially hindering effective long-term adaptive wildfire management.

Overlooking the critical insights from post-fire research could hinder our ability to improve pre-fire strategies and plans to reduce landscape fire hazards and enhance wildfire suppression effectiveness. This happens because post-fire research informs both landscape-scale management and restoration actions—such as the conversion of land to less fire-prone cover types and structures, establishing fuelbreaks, area-wide fuel treatments, and policies to address land abandonment—and stand-level management, including monitoring natural regeneration and converting to more fire-resistant and resilient species [101]. Post-fire research aligned with critical knowledge needs will enable better interventions and priorities, identify critical situations for community support, identify emergency soil stabilization needs, foster restoration treatments and their adequate, timely, and efficient application, and assess ecological risks linked to, for example, the spread of fire-adapted invasive species. Promoting post-fire research also paves the way for a deeper understanding of recovery processes and dynamics (e.g., [50,80,99,102]), clarifying when and where active restoration is required (e.g., [103–106]).

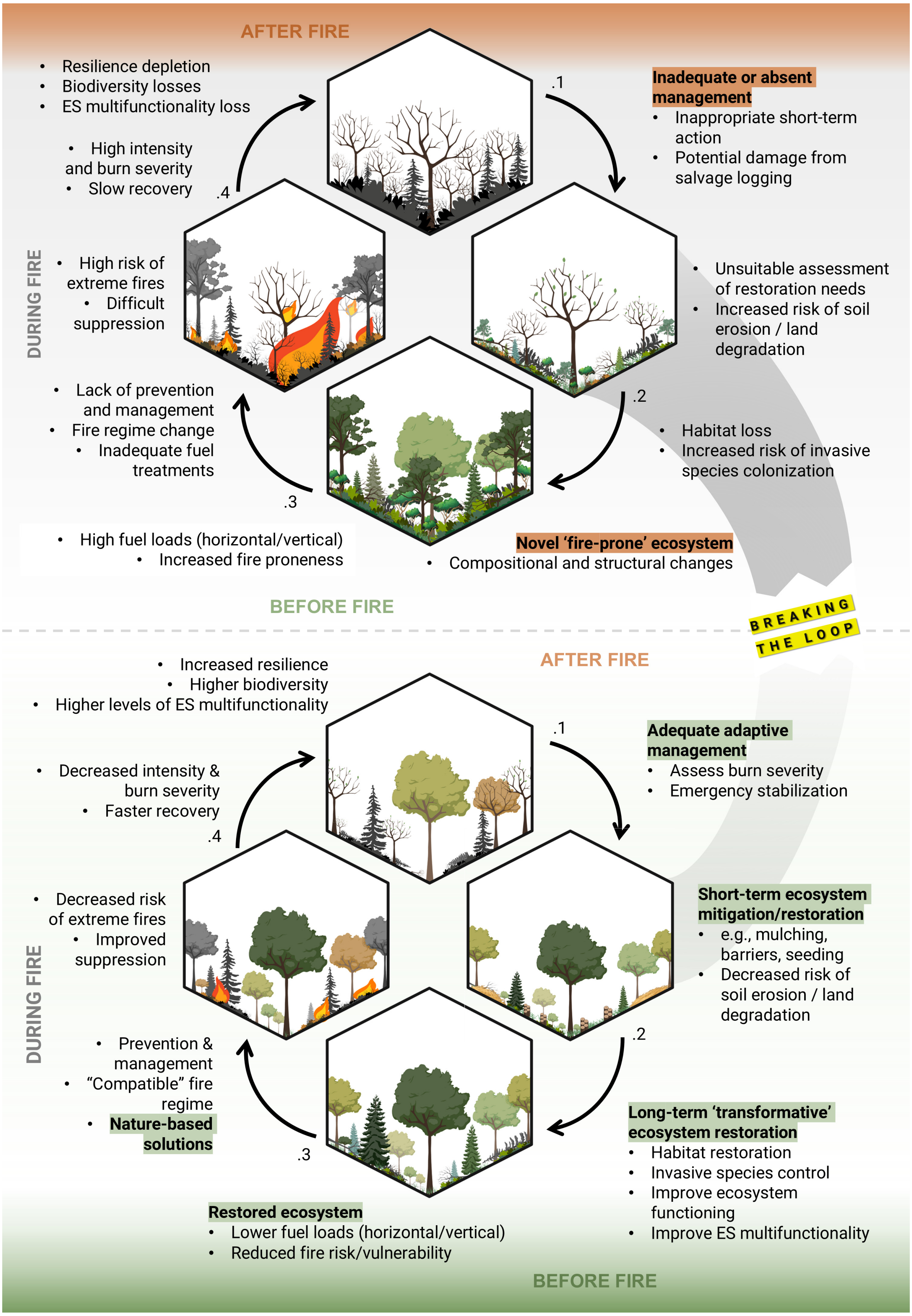

Figure 6. Combining multiple solutions for an improved and integrated post-fire research agenda can help strengthen the connections to the other stages involved in wildfire research and management,

thereby contributing to "breaking the loop" of conditions that steer ecosystems into fire-prone dynamics. Such cyclical trajectories are often observed in Mediterranean systems, with high fuel loads and widespread invasion by non-native (often fire-adapted) species. Engaging resources, stakeholders, and communities to conduct transformative actions immediately after wildfires can set the scene for a virtuous cycle of improvement, starting with improved severity characterization and post-fire stabilization/mitigation actions and extending to ecosystem restoration, sustainable and fire-smart forestry, risk reduction, and implementation of short- to long-term nature-based solutions (ESs—Ecosystem Services).

Engaging resources, stakeholders, and communities in transformative actions immediately following wildfires is also crucial (Figure 6). This process should begin with improved protocols for a more comprehensive burn severity characterization (see, e.g., the SeverusPT Project; URL: https://severus.pt/en/ (accessed on 22 January 2025), URL: https://doi.org/10.54499/PCIF/RPG/0170/2019 (accessed on 22 January 2025)) to accurately assess the impacts on nature and the benefits/services for people [48,50,62–64]. Subsequent steps include post-fire mitigation, efforts to stabilize the post-fire environmental conditions of burned areas, promotion of ecosystem restoration to prevent secondary hazards (e.g., floods, land degradation), and the enhancement of recovery.

Sustainable forest management practices and risk reduction measures are also essential for establishing adequate fire regimes that balance production goals with biodiversity and ecosystem service delivery (e.g., climate and water regulation, soil protection, and recreation opportunities). Short- to long-term nature-based solutions (e.g., [107]) can also be implemented to establish a robust framework for continuous improvement. We argue that by systematically addressing these issues, we can initiate, from the "after-fire" stage, a virtuous cycle of improved environmental and ecological resistance, recovery, and resilience that effectively learns from past lessons (Figure 6).

5. Scope of an Expanded Post-Fire Research Agenda

5.1. A Bottom-Up and Multi-Level Approach

Fostering a comprehensive post-fire research agenda that closes the loop across all stages involved in the adaptive management of wildfires can decisively contribute to developing more integrated responses, improving risk assessment tools, devising mitigation and recovery strategies, and setting up structures to help safeguard and rebuild communities (Figures 6 and 7).

As outlined above, a robust agenda addressing the "post-fire research imbalance" will deliver valuable knowledge to improve wildfire governance in a changing world. However, putting such an agenda into practice will require targeted efforts to promote and support post-fire research through long-term funding, interdisciplinary collaboration, and increased awareness of the critical role of post-fire research in comprehensive wildfire management and ecosystem restoration.

Here, we propose a general outline of such a post-fire research agenda, highlighting the range of knowledge production and applications at the relevant governance levels (Figure 7). We recognize the importance of data and knowledge gathered at different moments of "post-fire landscapes" (Figure 8), from short-term assessments of wildfire impacts and their applications to emergency mitigation/restoration and medium- to long-term assessments of post-fire recovery and their applications to long-term adaptive management of burned areas. Integrating the knowledge and experience gained from both time frames at a strategic level can support more robust policy and management instruments to deliver landscapes and communities that are more adapted and resilient to changing fire regimes.

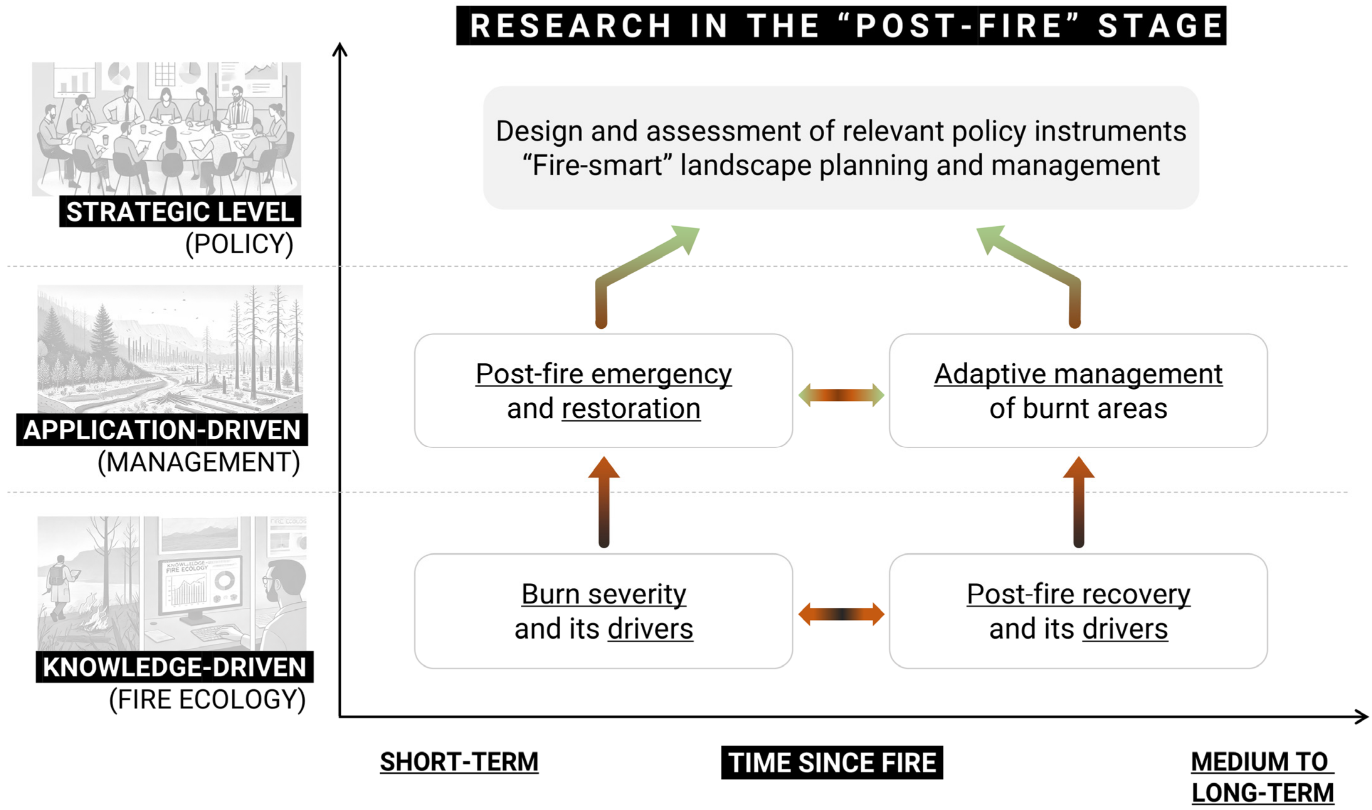

Figure 7. Framework and scope of an expanded post-fire research agenda, from knowledge-driven research to applications in the management and strategic/policy arenas.

The proposed framework for fostering a robust post-fire research agenda (Figure 7) reinforces the need for an integrated, multi-level, and transdisciplinary approach, emphasizing the interconnectedness of wildfire research, its practical applications, and the 'science–policy–people' interface. At the "knowledge-driven" level, research on fire ecology is foundational, focusing on understanding burn severity, resistance, resilience, and the underlying drivers immediately after a wildfire. This stage involves assessing the immediate impacts of wildfires on ecosystems, which informs subsequent stages of intervention. The insights from this research feed directly into the "application-driven" level, where practical management and mitigation strategies are/should be fully developed and implemented. The short- to medium-term actions include emergency and stabilization response and restoration efforts to mitigate immediate damage and prevent further land degradation, biodiversity loss, and decreased ecosystem functioning. As time progresses, these efforts should evolve into adaptive management practices that are continuously refined based on ongoing monitoring and feedback from the recovery process. The "strategic policy" level represents the culmination of these efforts, where scientific knowledge and practical experiences are synthesized into policy recommendations and landscape management strategies that are tackled in different governance spheres. These policies and technical recommendations are essential for guiding long-term planning and ensuring that landscapes and communities are resilient to future wildfires. In this regard, the design and assessment of "fire-smart" policies that integrate research and practical management insights are critical for sustainable landscape planning (e.g., [29,107]).

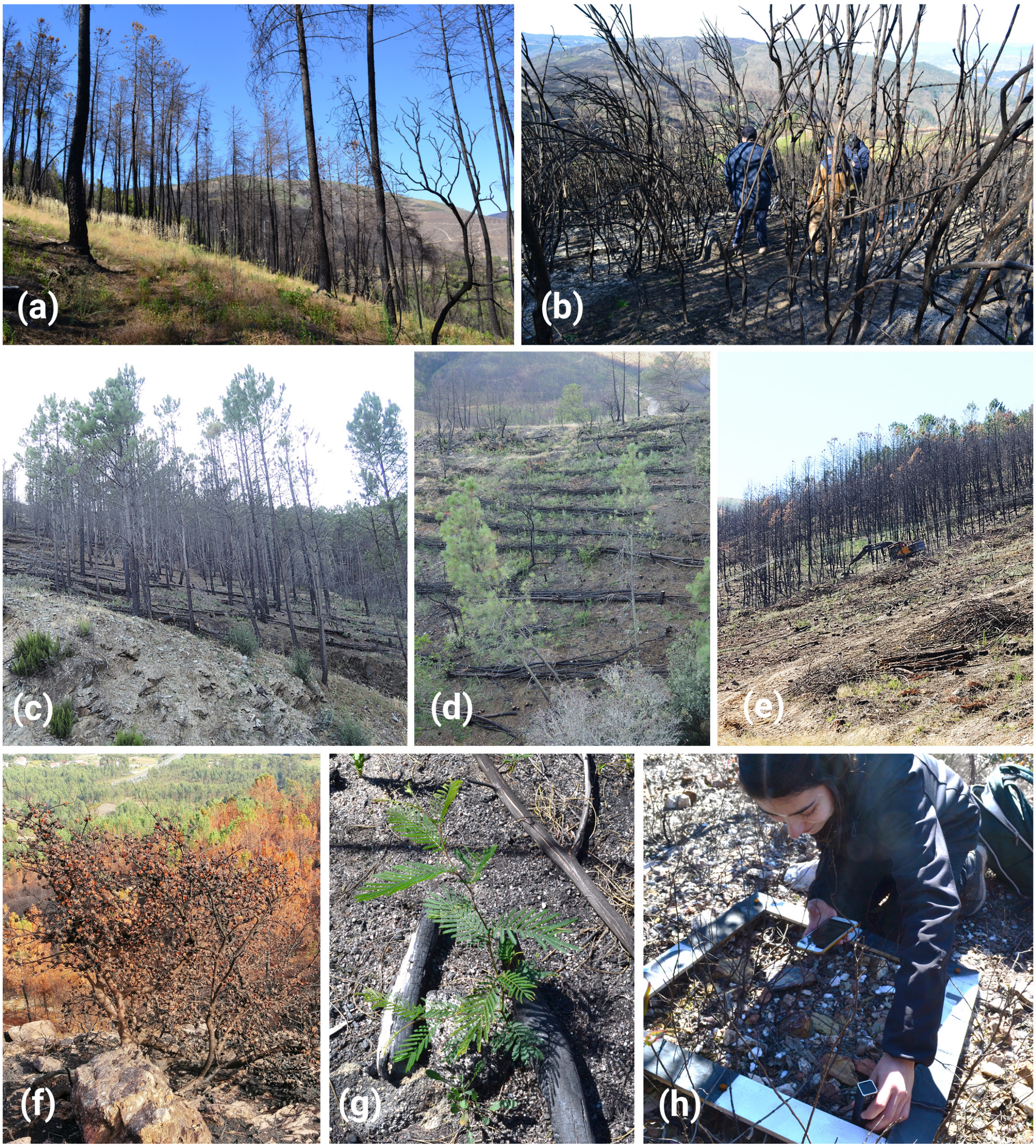

Figure 8. Examples of some priorities in a reinforced post-fire research agenda: (**a**,**b**) two burned plots assessed using the Composite Burn Index—assessing, mapping, and understanding burn severity, recovery and resilience, and their drivers is of central importance to post-fire research; (**c**,**d**) two plots in the Estrela mountain range (central Portugal) in which an intervention occurred—fostering the development and adequate application of stabilization, mitigation and ecosystem recovery methods is critical to avoid further land degradation; (**e**) salvage logging in burned areas in Estrela mountain range—understanding and managing the pros and cons of this still-common practice and its beneficial or detrimental impacts on ecosystem functioning and biodiversity is pivotal for post-fire management (**f**,**g**) a burned *Hakea decurrens* shrub and an *Acacia dealbata* seedling, two fire-adapted species thriving in post-fire environments—assessing and understanding the effects of wildfires on biological invasions and their combined (often synergistic) effects with climate and land-use changes is vital to address, manage or recover post-fire ecosystems; (**h**) a student analyzing the effect of applying a consortium of natively grown cyanobacteria and microalgae to foster the rehabilitation of post-burned soils with a portable spectrometer—an example illustrating the challenge of developing existing and novel treatments to potentiate soil and vegetation recovery. Photo credit: ©Ana Paula Portela (**a**,**b**) and ©João Gonçalves (**c**–**h**).

5.2. Assessing Post-Fire Impacts and Recovery

To support the development of effective post-fire management strategies, it is crucial to measure the multifaceted socioecological effects of wildfires. **Standardized protocols and robust data collection** are vital for accurately assessing these impacts, with primary data on burn severity estimates being essential. In this regard, satellite remote sensing is crucial, offering synoptic and consistent geospatial data on burn severity and ecosystem recovery [47,48,50,98]. Together with readily updated and high-resolution satellite products on vegetation composition and structure, these data can contribute to assessing recovery trajectories (from soil to biota), fuel characteristics, biomass status, and post-fire fuel accumulation trends. Despite its tremendous advances, future research in **satellite remote sensing** should focus on developing/improving globally validated burned area, severity and recovery products and expanding efforts to underrepresented tropical and subtropical ecosystems. Leveraging high-resolution imagery, advanced sensor integration (combining, e.g., SAR, optical, hyperspectral, thermal or LiDAR), AI-based algorithms and geospatial cloud computing infrastructure is also essential to enhance fire detection and post-fire mapping, especially in challenging tropical regions [51].

Beyond impacts on nature, the **socioeconomic footprint of wildfires** is substantial (e.g., [108]), and more data are needed to address the effects on different communities and account for relevant social and environmental justice issues [109]. Along these lines, there is growing recognition that post-fire recovery involves not only physical or ecological aspects but also a complex web of social, economic, and cultural dynamics. Despite previous syntheses (e.g., [110]), social science research on post-fire community recovery and resilience remains limited, particularly in underrepresented geographies beyond North America and Australia, and lacks integration of traditional, local and Indigenous knowledge and practices [2]. Moreover, a recent review by [111] highlights the need to integrate the perspectives, memories, and cultural practices of forest users and professionals, as well as the historical interactions between people, fires, and forests, to enrich wildfire research and inform socially relevant fire management policies which can also extend to post-fire perceptions and its legacy effects.

Despite the aforementioned gaps, research and syntheses on the effects of wildfires on soil and water properties embody one of the most substantial and well-represented areas of post-fire investigation, including, among other aspects, the modelling/prediction of run-off and erosion, effects on soil organic matter, water repellency, soil stability and its biological responses as well as water quality [2]. Despite substantial research in these areas, significant challenges and gaps remain to be addressed. For instance, further research is needed to connect erosion studies across scales, from small plots to catchments, while considering diverse soil types and soil burn severity levels [112]. As for post-fire erosion modelling, future research should address geographic gaps in the application of such models (specifically in countries with fewer resources), develop adaptable post-fire infiltration models, calibrate cover factors to burn severity levels and address its varying impacts, incorporate diverse mitigation measures, and conduct structural uncertainty analyses to enhance model performance/accuracy assessments and the communication of results [113]. Regarding modelling post-wildfire hydrological effects and response, [114] stresses that future research should expand model applications to underrepresented regions such as South America, Africa, Asia, the tropics, and arid/dry subhumid climates. The same authors also stress the need to incorporate comprehensive streamflow and subsurface processes, develop remote sensing parameterization methods, include subsurface hydrologic states in analyses, conduct intercomparison studies with robust metrics and link vegetation regrowth with hydrologic models.

Assessing the effects of wildfires on **Ecosystem Services** (ESs) also remains critically relevant. In this matter, a recent review highlights that future research should address the bias toward negative wildfire impacts in ESs, incorporate scale-dependent dynamics and underrepresented intermediate services, explore regional and long-term variability, and adopt comprehensive frameworks that consider the full suite of ESs to better manage and assess wildfire–ES relationships [64].

To tackle the aforementioned challenges, multidisciplinary research on post-fire impacts and recovery will continue to be essential for informing policies and interventions that support affected populations, facilitating the rebuilding of economies, and managing insurance and compensation mechanisms.

5.3. Post-Fire Effects on Species and Biological Communities

Fire disturbances act as a filter by selecting species that are adapted and more resilient to fire-prone ecosystems, and they may even require fire as part of their life cycle. In contrast, high-severity fires may negatively affect other species, destroying habitats, reducing food availability, and making it more difficult for certain species to find shelter and resources [115]. As such, understanding **fire selection effects** on species is also enhanced by better characterizing post-fire environments and burn severity (e.g., [116]). Despite substantial knowledge accumulation and syntheses, more **replicated, landscape-scale studies** are needed on fire's effects on terrestrial animal communities (particularly lizards and amphibians), along with research on community assemblage composition in underrepresented habitats (e.g., montane, alpine, boreal, tropical, wetlands) while also exploring its influence on alpha diversity and assemblages across diverse taxa, ecoregions, and geographic locations [117]. Research gaps also exist regarding wildfire effects on invertebrate species. For this group, Ref. [118] suggests prioritizing systematic surveys in understudied, fire-prone ecosystems, expanding species distribution data, and investing in taxonomic research to identify unknown species. In addition, future research should also focus on long-term invertebrate recovery, **plant–invertebrate interactions** influencing fire intensity, and the effects of different/novel fire regimes, fuel reduction, mosaic burning, pyrodiversity and recolonization trajectories. Overall, research on wildfires' ecological impacts and recovery needs more focus on long-term assessments, mixed-severity patterns, underrepresented taxa and ecosystem/habitat types, and the combined effects of thinning and prescribed fire to better understand species dynamics, diversity, habitat use, and ecosystem responses [119]. These efforts are expected to enhance our ability to understand wildfire impacts comprehensively and to develop effective strategies for long-term monitoring and ecosystem restoration.

Beyond the species-level implications of post-fire research, it is crucial to consider the varying degrees of an ecosystem's sensitivity and adaptability to fire, reflecting its deep evolutionary role in natural history [120]. Ecosystems can be categorized as fire-dependent, fire-sensitive, and fire-independent, each with distinct fire-related characteristics and responses [121]. Accordingly, post-fire management strategies must be tailored to each ecosystem's specific attributes and state, e.g., by re-introducing fire in fire-adapted landscapes with a recent history of fire exclusion [122] or managing high-intensity fires in sensitive ecosystems. This effort requires the development of flexible **post-fire monitoring frameworks** with adjustable indicators that reflect each ecosystem type's unique conditions and recovery processes. Such a nuanced approach ensures that management efforts are effective and sensitive to the ecological dynamics at play, fostering the restoration and long-term "health" of diverse landscapes. Improving and expanding post-fire research will contribute to these efforts.

Fostering post-fire research can also critically enhance our understanding of **invasive species dynamics** by identifying opportunistic species (e.g., species with high growth rates or fire-adapted traits) [123] and how these species exploit and modify fire-disturbed ecosystems. In the aftermath of wildfires, invasive species often profit due to decreased competition, altered nutrient cycles, light availability, and the creation of open niches that favor their growth and reproduction, especially if modified fire regimes occur [124]. While considerable progress has been made so far, more research and syntheses are required to widely assess wildfire impacts on native and invasive species by developing community-level metrics to evaluate and compare fire impacts on and between these two species groups, monitoring temporal dynamics at wider timeframes, focus on underrepresented fire-prone habitats, and integrate **species traits, environmental factors, and fire characteristics** better and more comprehensively [125]. Advancing post-fire research will enhance our understanding and the ability to predict the complex interactions between fire events and invasive species, enabling more dynamic and adaptive management of landscapes.

5.4. Prescribed Burning and Its Post-Fire Effects

Prescribed fires (in the context of the "after-fire" stage) are usually conducted to achieve a specific burn severity level, ensuring that the risk of uncontrolled wildfires and other adverse impacts is avoided. In this sense, fostering post-fire research is pivotal to optimizing the employment of prescribed fires [18–20] and assessing its effects regarding wildfire activity and severity. For instance, insights regarding the interplay between soil physicochemical attributes, vegetation cover, and thermal dynamics support predicting the impact of burns on soil ecosystems and structure, guiding the timing and intensity of prescribed fires to prevent detrimental effects such as nutrient depletion [24,65]. Studying the seed bank's reaction to fire also enlightens the management of burn schedules to promote native species and avoid the regrowth and spread of invasive species (e.g., [124]). Knowledge of **species' after-fire recovery and recolonization** contributes to prescribed fire timing and minimizing impacts on biodiversity and vegetation [126]. Moreover, evaluating how varying fire intensities and the spatiotemporal allocation of prescribed burns [21] influence ecosystem services (e.g., carbon storage and water purification) can help to find a balance between reducing wildfire risk and maintaining these critical services [62–64].

While considerable progress and synthesis have been made on the effects of prescribed burns on soil properties, challenges remain ahead. More specifically, [65] emphasizes that future research should address the **spatial variability of prescribed fire**, considering differences in soil properties, vegetation, and topography to optimize these practices for specific environments. The same authors also highlight that key factors such as fire residence time, seasonality, and intervals between burns must be studied to avoid adverse effects, as annual burning can harm soil properties, while periodic burns (every 2–6 years) can improve nutrient cycling and biological properties. Moreover, implementing a robust post-fire research agenda should look for a better understanding of how prescribed fires affect soil properties and contribute to restoring fire-adapted ecosystems, enhancing biodiversity, and reducing wildfire risks. Strengthening the collaboration between researchers and land managers to identify and disseminate best practices for effective burns is also key.

As for the hydrological effects of prescribed fire, Ref. [127] summarized future challenges and research priorities, including the need for wider geographic and environmental representativity (beyond the US and Mediterranean Europe) and the immediate implementation of post-fire management actions following prescribed fires. Moreover, the same authors highlighted that future studies should extend beyond two to three years, include catchment-scale assessments, and evaluate key physical, chemical and biological soil and water parameters and features of recovered vegetation while also experimentally assessing the effects of repeated fire applications. Although challenging, addressing these aspects alongside enhanced sharing of data, research outcomes and guidelines is expected to significantly advance research and practical efforts in applying prescribed fire.

On another note, addressing the **societal perception of prescribed fire** practices and their barriers (e.g., informational, practical, social, and regulatory) (e.g., [128,129]) is also crucial to broadly integrating them. For instance, by leveraging advanced modelling techniques to forecast smoke plume dispersion from prescribed burns, managers and technicians can strategically plan these actions to mitigate air quality deterioration. The same rationale applies to assessing the effects on water quality (e.g., [67,130]) and tackling potential disservices. Actions such as these safeguard public health and may foster community support by demonstrating a commitment to forecasting, understanding, and minimizing risks and negative impacts [41,131,132]. Fontúrbel, Carrera, Vega and Fernández [66] state that the lack of **long-term, integrated, and interdisciplinary post-fire studies** limits our understanding of the impact of prescribed burning on soil health, underscoring the need for extended research. An integrative approach coupled with tools such as remote sensing and long-term field observations to monitor post-fire landscapes is paramount.

5.5. Post-Fire Stabilization and Ecosystem Restoration—From Spatial Prioritization to Implementing Adequate Treatments

Understanding the dynamics of ecosystem recovery, resistance, and resilience following wildfires is paramount. Research shows that **post-fire management** decisions and treatments (e.g., mulching, barriers, seeding) can significantly influence the trajectory and speed of ecological recovery, impacting not only wildlife habitats and plant regeneration but also soil condition and stability [54,73].

Enhancing post-fire research can significantly bolster ecosystem restoration efforts, leveraging the inherently interdisciplinary nature of this field to develop 'high-precision' restoration methods [106]. For example, employing GIS and remote sensing techniques for detailed burn severity mapping [51] offers a powerful tool for **strategically selecting and prioritizing restoration sites** (e.g., [103–105]). This methodology facilitates a systematic approach to intervention and enables consistent monitoring of recovery and post-fire restoration over time, providing valuable feedback for adaptive management strategies. For this matter, very high-resolution imagery from **Unoccupied Aerial Vehicles** (UAVs) can enhance post-fire monitoring by collecting detailed optical and thermal data. However, to fully profit from these technologies, advancing algorithms for AI-based mapping and aerial path planning specific to wildfire monitoring remain crucial challenges [133]. Moreover, while remotely sensed Earth observations (e.g., satellites, airplanes, drones) offer significant benefits, **field-based or in situ observations** remain essential for validating and calibrating post-fire severity and recovery indices (e.g., [134,135]). Addressing these challenges requires deeper collaboration among experts in remote sensing, vegetation science, and fire ecology to develop more robust methods that effectively bridge scales and integrate diverse approaches. Fostering the post-fire research agenda can promote a multidisciplinary platform for such collaborative efforts and allow the continuous development and refinement of existing mitigation, restoration, and monitoring methods.

Despite substantial advances in post-fire stabilization and restoration treatments, there is a pressing need for long-term studies and well-designed metrics to fully understand their impact on ecosystem recovery. To identify more effective rehabilitation strategies, research should focus on evaluating the **synergistic effects of combined treatments** (e.g., seeding, mulching, erosion barriers, chemical and microbiological). Additionally, defining and adopting improved success metrics that extend beyond vegetative cover to encompass ecosystem recovery and biodiversity is essential for achieving comprehensive restoration goals [136]. In this regard, a recent review goes even further, emphasizing the need for increased monitoring and research efforts (particularly in underrepresented regions in Africa) and advocating for the establishment of multidimensional indicators of recovery and restoration encompassing environmental, economic, social, cultural, aesthetic, management, infrastructure, and educational goals [137].

Complementarily to the aforementioned points, [138] emphasizes that future research on post-fire treatments should prioritize expanding the geographical scope of studies (beyond the US and Mediterranean Europe), enhancing data collection and monitoring of post-fire conditions, integrating advanced modelling tools and hydraulic assessments, and developing comprehensive evaluations of erosion, nutrient loss, and wildfire countermeasures, with a strong emphasis on assessing soil burn severity as an initial step. On the other hand, advocating and raising awareness for the adequate use of post-fire stabilization and restoration treatments is paramount, as the successful implementation of such measures centers on integrating science, policy, governance, and adequate funding. As such, addressing post-fire recovery must be approached through an interdisciplinary lens, which requires policies that prioritize fire protection, ensure timely and efficient application of post-fire treatments, implement economic valuation tools to demonstrate the tangible benefits of measures, and foster research to understand and enhance their effectiveness [138].

5.6. Understanding and Adapting to Novel Fire Regimes Under Climate Change

Fire regimes are often and primarily described in terms of burned area, frequency, seasonality, and ignition sources (e.g., [139]), frequently lacking a description of **the patterns and trends of burn severity**. In this regard, the benefits of incorporating burn severity measures may be critical for improving the regionalization and description of fire regimes, given that this is a critical driver of post-fire recovery [50,80]. Assessing current trends in severity is also crucial for mapping hotspots where ecosystem degradation and potential regime shifts may happen due to poor ecosystem functioning and resilience [47]. For instance, changes in ecosystem functioning related to carbon dynamics can transform forests from carbon sinks to carbon sources [140], further disrupting the balance of the global carbon cycle. Post-fire research focusing on these carbon flux dynamics can thus contribute to delineating strategies aimed at climate change mitigation. Moreover, in the face of **changing fire regimes**, it is also essential to assess how ecosystem functioning is modified by wildfires [47,48], understand the limits to vegetation recovery [102], and identify how faunal communities resist, adapt, recover, or perish [75,77,141,142]. This knowledge is fundamental in developing conservation strategies that ensure the long-term sustainability of 'post-fire ecosystems' and the multitude of services provided [23,62–64]. Given that **climate change** is a significant driver behind novel fire regimes with rising economic and societal impacts across national boundaries (as recognized by the 2023 IPCC Synthesis Report [6]), we argue that understanding, monitoring, and adapting to its effects in the context of adaptive wildfire management is paramount (e.g., [143]). As such, given this fast and unparalleled change context, there is a pressing need to understand fire regimes across spatial and temporal scales and their past-to-present dynamics. Such an endeavor can profit from the integration of **historical fire data**, such as fire return intervals and human impacts, with contemporary metrics, including burned area, fire severity and seasonality (from remotely sensed data sources), while leveraging models to explore feedbacks and nonlinear interactions between fire, vegetation, trophic levels, and belowground systems [97]. Moreover, integrating fire histories into models and incorporating archaeological and paleoecological research can reveal the ecological and evolutionary effects of changing fire regimes and provide valuable insights into the human dimension of fire for addressing future adaptation [97].

5.7. Adaptive Management—Harnessing Change in the Post-Fire Period for a More Resilient Future

Sustainable or integrated fire management seeks to optimize strategies for reducing the impact of wildfires in a way that is compatible with the maintenance or improvement of biodiversity and ecosystem services [144]. On the other hand, the adaptive management of natural resources and ecosystems focuses on monitoring the outcomes of management actions and making adjustments based on the results while accounting for uncertainty and change in an iterative learning process. **Adaptive and sustainable management** may be particularly beneficial in the after-fire stage to involve multiple communities and agents (e.g., land managers and forest producers, NGOs, hiker associations, and mushroom pickers) to co-design strategies based on lessons learned from recent wildfires [145,146].

Post-fire environments (may) offer **opportunities for transformative change** (also known as "seeds of change"), better management cycles, and improved practices to adapt to increasing wildfire risks and global fire regime changes. In this sense, nature-based solutions (NbSs) offer many measures to integrate into adaptive management [29]. Promoting collaboration and co-design in a socioecological and interdisciplinary approach is critical for implementing NbSs supported by stakeholders, ensuring their efficacy, and aligning with societal and ecological goals [107]. Effective post-fire research and monitoring provide the necessary feedback to refine NbS management practices to mitigate future fire risks while supporting local communities and fostering biodiversity.

Finally, **adaptive management** is fundamental for overseeing and adapting landscapes in a **changing climate** where extreme climatic events (e.g., heatwaves and droughts) modify fuel conditions and enhance fire-proneness [147]. As such, understanding the interplay between climate change and modifications in the fire regime, especially in terms of burned area, frequency, timing or seasonality, and burn severity, is a crucial contribution from post-fire research that needs to be deepened. In this regard, [148] highlights that post-fire management strategies should emphasize protecting large trees and fire refugia, anticipating fuel accumulation, restoring fire–vegetation feedbacks, differentiating between climate- and dispersal-driven transitions to non-forest, and aligning species composition with novel fire regimes and climate. The same authors also emphasize that a comprehensive post-fire landscape evaluation, spatial prioritization and prescription should guide the application of these strategies. Overall, post-fire research and management contributions that effectively seize opportunities in the after-fire stage are anticipated to enhance ecosystem resilience, reduce vulnerability, and support adaptation to future climates.

6. Limitations and Advantages of Classifying Wildfire Research Across Stages

As previously noted, wildfire stages are deeply interconnected, making the classification of specific research topics or applied issues within the proposed "wildfire science loop" particularly challenging. This issue is especially true for broad, overarching topics such as fire weather, which require additional criteria to determine the suitability of research papers for a given stage based on their context and objectives. For instance, if fire weather is discussed in the context of guiding prescribed fires, forecasting medium- to long-term wildfire activity or seasonality, or addressing issues related to prevention, preparedness, planning, or climate change, then studies are categorized in the "before" stage [11,91–93]. However, if fire weather is used to anticipate (e.g., early warning systems), simulate, or predict an active wildfire's behavior, rate of spread, or emissions, then research would be attributed to the "during" stage [149–151]. Similarly, if fire weather is used to assess the behavior, rate of spread, or emissions of a particular fire event, region, or fire season (i.e., post hoc or "forensic evaluation" and validation of fire weather indices), this is also attributed to the "during" stage because these studies emphasize active wildfires and their conditions [150,152]. Finally, if (post-)fire weather is used to evaluate impacts in the aftermath of a wildfire, such as soil erosion, burn severity, or ecosystem recovery/regeneration, such a study would be classified in the "after-fire" stage [153–155] (see Supplementary Materials—Section 2 for more information and other examples). Moreover, despite our rigorous and iterative approach to define and improve search strings, it is possible that we missed relevant papers for the "after-fire" stage. However, the number of these is unlikely to close the gap between this stage and the others.

While acknowledging these caveats, we argue that the proposed "wildfire science loop" still provides a valuable framework for understanding and addressing the complex, interconnected dynamics of wildfire events, their governance issues, and related scientific domains. As such, the proposed classification approach can assist in comprehensively evaluating existing research niches beyond our exploratory bibliometric analysis, highlighting areas of concentration or underrepresentation across the continuum, identifying critical knowledge gaps, and providing a practical lens for integrating science and factual evidence into wildfire management and policy.

7. Final Remarks

Investigating post-fire conditions and assessing (socio-)ecological recovery and resilience enhances our broader understanding of subsequent wildfires, closing the loop of socioecological processes and dynamics involved in wildfires. For instance, detailed insights regarding burn severity and recovery drivers help to elucidate and monitor fuel regeneration and re-accumulation, which is fundamental for refining fire simulation and informing risk assessment. This straightforward example illustrates how a vast post-fire research agenda can provide the insights needed for a holistic and integrated approach that encompasses all relevant dimensions to understand connected phenomena.

In addition, harnessing the opportunities that the post-fire "social–scientific–political landscape" presents may prevent or repair planning or management errors and steer ecosystems into more resilient and biodiverse trajectories. Timing is of the essence, and while subjects are still in the public sphere of debate, it may be the best opportunity to act by "striking while the iron is hot". Aligning with these ideas, the United Nations has argued for a new "Fire-Ready Formula" that recognizes the vital role of ecosystem restoration, through which we can minimize the risk of extreme wildfires by enhancing preparedness and "building back better" in the aftermath of wildfires.

On the other hand, addressing the imbalance across the stages of the "wildfire science loop" is essential, in our opinion, as each stage feeds into the next. Thus, a call to balance research efforts and cross-sectoral funding allocations will contribute to bridging this discrepancy and fostering a more integrated approach to wildfire science.

Finally, we argue that in the face of global environmental changes with worldwide modifications in fire regimes, it is not merely beneficial but essential to foster post-fire research. Such an endeavor will tackle asymmetries across wildfire stages (i.e., before, during, and after) and improve the political alignment with conservation and restoration agendas—such as the UN Decade on Ecosystem Restoration and EU Nature Restoration Law—with benefits for preserving and repairing ecosystems, protecting human life, regulating ecological fire regimes, and stabilizing our global environment.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/fire8020051/s1, supplementary material .zip—which includes details on the systematic literature review: 1. search strings for each wildfire stage; 2. screening phase; 3. bibliometric analysis (check the .docx file provided) and the full database with bibliographic records, categorized by each wildfire stage (.xlsx file).

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