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Supporting a shift in wildfire management from fighting fires to *thriving with fires*: The need for translational wildfire science

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ABSTRACT

Despite the increasing challenges wildfires are posing around the globe, and the flourishing production of high-quality wildfire scientific knowledge, the ability of fire science to impact knowledge on the ground, for people, society, economy, and the environment, in a way that facilitates change in the current wildfire management system has been limited. We believe that one reason for this limited impact is due to the fragmentation of this scientific knowledge. Therefore, we propose a Translational Wildfire Science (TWFS) as a new field of knowledge that captures the comprehensive dynamics of wildfire events, that provides information relevant, useful, and accessible to practitioners and citizens, and that facilitates the transfer of scientific knowledge into practice. The foundations of TWFS, including the main principles, the overarching characteristics, and the approach of a TWFS scientist, are presented. Finally, the next steps to be undertaken to consolidate TWFS as a new scientific field are identified.

1. Introduction

Recent years have seen a growing consensus among academics and practitioners that fire management practices that primarily focus on immediately suppressing every fire are problematic and ultimately unsustainable. Numerous papers have called for policy shift arguing that the suppression approach is often ineffective in extreme conditions, can lead to increased risk in the long-term, and often neglects and undermines the fundamental ecological role of fire in fire-adapted and fire-dependent ecosystems (Howitt, 2014; Moritz et al., 2014; North et al., 2015; Olson et al., 2015; Otero and Nielsen, 2017; Pausas and Keeley, 2019; Castellnou et al., 2019; Thompson et al., 2018).

However, despite this increasing recognition of the shortcomings of such an approach, the emphasis on fire suppression persists. A range of possible reasons to explain this persistence, includes: i) ingrained culture (Fernandes et al., 2020; Steelman and McCaffrey, 2013); ii) lack of institutional and political incentives or will (Schultz et al., 2019; Thompson et al., 2013); iii) political pressure for short-term effective measures (Cisneros et al., 2018; Fernandes et al., 2020; Ingalsbee, 2017); iv) biases of decision makers such as discounting bias (e.g., overemphasizing short-term risk reduction over longer-term considerations), status quo bias (e.g., reverting to suppressing all fires rather than allowing certain fires to burn for ecological benefits), and loss aversion bias (e.g., preferring safe options when consequences are framed as potential gains) (Calkin et al., 2015; Dillon et al., 2020; Wibbenmeyer et al., 2013; Wilson et al., 2011; Xanthopoulos et al., 2020); v) knowledge gaps around wildfire behaviour, socio-economic and ecological consequences of fires which create uncertainty when assessing alternative courses of action (Hyde et al., 2013; Venn and Calkin, 2011); and vi) the self-reinforcing mechanisms of policy failures (Busenberg, 2004).

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Many of these reasons reflect institutional barriers that are inherently challenging to address, science has an important role to play in informing development of more effective strategies. Although, a large, and growing, body of relevant fire science has developed, its impact on decision making, society, and the environment is limited (Pyne, 2017). An important question is how fire science might be structured to more effectively address real world management needs and inform policy and decision making in order to improve wildfire management outcomes (Hunter, 2016). Recent years have seen many academic and political entities (e.g., European Commission) call for Research and Development (R&D) projects that can help identify more effective wildfire management approaches and better integrate that knowledge production into on the ground wildfire management practices (Wyborn et al., 2019).

Numerous challenges face such attempts to change how science is conducted (e.g., attempts to invest in the "right" science; identify knowledge gaps; improve the knowledge transfer to the stakeholders). While the growing number of scientific disciplines examining different aspects of wildland fire management is a positive development, the ability of research to provide more holistic knowledge and solutions is limited by the fact that much of the work and findings remain within disciplinary cognitive boundaries and isolated silos (Ramirez and Belcher, 2019; Smith et al., 2016; Spiekermann et al., 2015). This creates barriers to effective use of science in a number of ways. Real world policy and management decisions are interdisciplinary and social by nature, and need to take into consideration a range of perspectives and account for the complex and dynamic nature of fires, fire-human interactions, and potential trade-offs (Depietri and Orenstein, 2020). Separately operating disciplines working to understand fire concerns in a piecemeal manner inhibit the development of scientific knowledge that can integrate the full range of complex ecological and social interactions underlying current wildfire challenges (Pyne, 2017; Pyne, 2007).

This fragmented disciplinary focus can also contribute to a narrow interpretation of both the nature and scope of the wildfire problem and potential solutions (Fifer and Orr, 2013). Scientists often do not recognize that their particular disciplinary focus often means that the solutions they propose are themselves value ridden (Wyborn et al., 2019).

Even academics who call for change and advocate using a Coupled Human and Natural Systems approach (CHNS) (e.g., Liu et al., 2007), tend to make recommendations based on knowledge produced from their specific disciplinary perspectives and, as a result, often suggest solutions that may have counterproductive outcomes or be ineffective or impractical in the real world.

Individual academic disciplines also often have diverse and competing needs and interests, different mindsets and ways of operating, and different views of the values of scientific knowledge (Albris et al., 2020; Polk, 2014). For example, evaluation criteria for many peer-reviewed journals tend to focus on the soundness of the methods and the scientific novelty of findings, with less importance given to how the knowledge addresses real-world problems and the needs of stakeholders (Neff, 2020; Van Kerkhoff and Lebel, 2006). In addition, the unidirectional and passive knowledge transfer via articles in costly scientific journals (Enquist et al., 2017), often written with sectorial scientific language, can make it challenging for stakeholders to interpret, understand, and apply the information scientists offer.

Beyond issues with academic disciplinary silos, effective use of wildfire science is complicated by the complexity of the wildfire management system which involves numerous institutions; each with different goals, culture, bureaucratic processes, and knowledge and perspectives on fire. In addition, the experiential knowledge of individual organization members can differ from the "official knowledge" of the institution and may not be recognized or considered by institutional leadership. The type of scientific knowledge used, and how it is interpreted and applied, will depend on the mindset and competencies of the different users. Many knowledge users, particularly agencies, tend to place more value on a narrow range of more technocratic approaches while placing little attention on the critical knowledge offered by social sciences, humanities, and arts. In fire management, this tendency has led many organizations to focus on risk mapping, increasing firefighting capacity, and improving overall fire response rather than developing more holistic but less immediate solutions (e.g., creating mosaics of less flammable landscapes and developing the adaptive capacity and resilience of citizens and communities to reduce the wildfire risk).

As a final challenge it is often assumed that more and better scientific knowledge in and of itself can and should change practices and lead to better outcomes. This assumption generally overlooks the question of which scientific knowledge should be prioritized and fails to recognize that scientific knowledge is only one of many inputs into policy decision processes. Besides scientific knowledge, system transformation in a complex and rapidly changing fire environment will need to take into account a wide array of cognitive, emotional, and social resources (Cash et al., 2003; Funke, 2012; Kropp and Wagner, 2010; Ramirez and Belcher, 2019; Depietri and Orenstein, 2020). However, experienced practitioners also recognize that rigorous and relevant science is a key need in efforts to improve and support decision-making processes (Sherry et al., 2019).

It is therefore important to consider how fire science might be created and conveyed to better ensure that the generated knowledge can be used to effectively reduce wildfire risk and improve individual, social, and ecological outcomes. This is particularly critical given that the current fire management system is increasingly unable to match shifting conditions, particularly those resulting from climate change and the increased potential of extreme wildfire events (Tedim et al., 2018, 2020). The purpose of this paper is to consider what type of fire science effort would be more likely to generate the knowledge that could lead to new and effective ways of improving wildfire management. Building on approaches developed in Translational Medicine (e.g., Cohrs et al., 2015), we suggest the need to develop a Translational Wildfire Science (TWFS). We argue that such an approach is more likely to capture the complexity and dynamics of wildfire management and thereby create knowledge that is relevant, useful, and accessible to practitioners than the current fragmented system.

2. Basis for a translational approach in wildfire science

2.1. The antecedents

Recognition of the need for enhanced knowledge transfer between scientists and practitioners has led to a proliferation of recommendations "to do science differently". A range of collaborative and participatory approaches has been proposed including: interdisciplinary research (Robinson, 2008); transdisciplinary research (Curnin et al., 2015b; Curnin et al., 2015a; Hadorn et al., 2008; Ismail-Zadeh et al., 2016; Jahn et al., 2012; Klein, 2010; Lang et al., 2012; Polk, 2014); action research (Chevalier and Buckles, 2019); interactive social research (Talwar et al., 2011); mode-2 science (Gibbons, 2000; Gibbons, 1994; Nowotny et al., 2001); post-normal science (Funtowicz and Ravetz, 1993); actionable science (ACCCNRS, 2015; Kirchhoff et al., 2013; Mach et al., 2020); transformative or participatory science (Blackstok and Carter, 2007; Burke and Heynen, 2014; Lang et al., 2012; Spangenberg, 2011; Wiek et al., 2014; Wiek et al., 2012); stakeholder-driven science and user-driven science (Dilling and Lemos, 2011; McNie, 2007); knowledge exchange (Cvitanovic et al., 2015); Problem Driven Iterative Adaption (PDIA) (Andrews et al., 2013); knowledge brokering (Hukkinen, 2020; McGonigle et al., 2020; Saarela and Rinne, 2016); co-production (Djenontin and Meadow, 2018; Jasanoff et al., 1998; Lemos et al., 2018; Meadow et al., 2015; Wyborn et al., 2019); socially robust knowledge (Hernández-González and Corral, 2017; Nowotny, 2003; Nowotny et al., 2003; Nowotny et al., 2001); implementation science (Durlak, 2015) integration and implementation sciences (i2S) (Bammer, 2015, 2019); and translational research (Curry, 2008; Rubio et al., 2010).

While these approaches use different terms, they share numerous similarities in overall aims and methodology. Attempting to bridge the gap between science and practice, particularly in relation to understanding and solving increasingly complex and rapidly changing socio-environmental challenges, these approaches emphasize the need for scientists to i) work across disciplines and dissolve limiting silo-thinking; ii) work more directly with practitioners, who hold valuable traditional and experiential knowledge (Pohl, 2010); and iii) produce scientific knowledge that can benefit society (Robinson, 2008; Wyborn et al., 2019). Although each approach provides important insights, we believe that, in the wildfire domain, the translational approach presents the greatest potential to resolve or transcend weaknesses and contradictions in fire science and better inform policy and management.

2.2. The origins and recent developments of translational science

The translational science approach was first developed in the early 1990s in medicine (Curry, 2008; Rubio et al., 2010) to hasten the transmission of scientific knowledge to practitioners and the development of practical tools for diagnosis and/or treatment (Woolf, 2008). A translational approach focuses on integration of knowledge by working across disciplines and including stakeholders outside the usual academic research community, such as patients, communities, non-governmental organizations, and businesses in order to more effectively improve public health, ensure that society receives a significant return on research investment, and improve the public's regard for, and potential participation in, research (Selker and Wilkins, 2017).

The US National Institutes of Health (NIH) defines translation as "the process of turning observations in the laboratory, clinic, and community, into interventions that improve the health of individuals and populations – from diagnostics and therapeutics to medical procedures and behavioral changes" (NIH, 2020). For translational health research, Selker and Wilkins (2017) propose the following definition: a "broadly engaged team science where community members and stakeholders are integral members of the research team". In their view, such trans-disciplinary and multi-stakeholder teams will be best suited to pose appropriate research questions, conduct research, and interpret and disseminate the results.

In recent years, interest in translational science has spread beyond medicine to other scientific fields. Schlesinger (2010) proposed Translational Ecology (TE) as a means to better respond to real ecological world needs with specifically tailored solutions. It also argues for the need to make ecological science discoveries more usable in environmental management and conservation efforts by rapidly translating relevant ecological research into practice to inform and improve decision making (SWCASC, 2020). To better account for the complexity and contextual nature of ecological challenges, TE involves interdisciplinary teams of scientists, relevant practitioners, and policy-makers who jointly identify research that is "actionable" rather than purely "curiosity-driven" or theoretical (Brunson and Baker, 2016; Schlesinger, 2010) (Brunson and Baker, 2016; Enquist et al., 2017; McNie et al., 2017; Wall et al., 2017). In this way, TE is argued to better enable ecologists to "play a key role in mediating the decision-making process by designing experiments in the context of the specific objectives, so that they can evaluate proposed solutions to environmental problems more explicitly" (Hallett et al., 2017; p.585).

Recognizing that "farmers like learning from farmers", agricultural researchers have also begun applying translational research principles to address the fact that basic research appeared to have failed to improve crop sustainability (Passioura, 2020). Here, scientists and farmers work together to consider all factors that may influence farm system productivity and sustainability, and the health and aesthetics of the landscape. This translational approach enables researchers to translate basic scientific discoveries into improved agricultural productivity.

The focus of these translational efforts—on conducting science in a manner more likely to develop knowledge that will inform development of effective solutions to real-world problems—fits well with the current need for wildfire research that is better able to address current wildfire challenges. Indeed, recent use of these methods to understand effective wildfire smoke interventions (Baghdikian, 2020) highlights the potential value of these methods for improving future fire outcomes. The focus on valuing and engaging knowledge bases of both academic and non-academic actors also is more likely to contribute to the identification of novel solutions and better enable system transformation.

3. Translational wildfire science

The term translational wildfire science was first used as part of a health research project initiated by the US Environmental Protection Agency to assess different health interventions for wildfire smoke (Baghdikian, 2020). Using a translational science design, the project focuses on solution-oriented research to meet stakeholders needs by actively engaging them in the research process and inclusion of follow-up evaluations to assess relevancy and timeliness. The TWFS described in this paper addresses all the characteristics considered by Baghdikian (2020) but proposes applying them not just in health research but as part of an overall scientific field that can provide an overarching trans-disciplinary and policy-relevant approach on how to think about and implement a holistic wildfire research process.

As fire science, as currently practiced, is unlikely to contribute as much as it could to meet the rapidly evolving fire management challenges of the moment, the goal of TWFS is to facilitate development of scientific knowledge that is better able to address real-world problems and produce outcomes adapted to being used on the ground, and in the process, help shift the focus from fighting fire to thriving with fire (Tedim et al., 2020). By focusing on understanding each wildfire phase and how all the phases interact in an integrated way, TWFS is better positioned to improving wildfire outcomes.

Using an interactive, open, multi-scalar, and dynamic process of integrating research from different disciplinary fields (e.g., natural sciences, engineering, social sciences), as well as traditional and experiential knowledge, TWFS is better able to optimize the understanding of all dimensions of the wildfire system—biophysical to social—in order to identify feasible solutions that can be tailored to specific contexts, meet practitioner needs, and improve both short and long-term wildfire outcomes. Pulling from commonalities across existing translational endeavours, we identify a set of principles, overarching characteristics, and desired traits of TWFS scientists.

3.1. The principles

Informed by general science-policy literature, but drawing primarily from translational research literature, we propose four interrelated principles that can guide the design and implementation of research that characterize a TWFS as a new scientific discipline.

1st principle:*TWFS identifies and responds to different types of needs and values of actors, including citizens and decision or policy makers.*

This fundamental principle of TWFS determines that the scientific process is designed around real-world needs of practitioners rather than theoretical needs of academics or the desire for ready-made solutions. This principle recognizes that the scientific knowledge mode is only one of the many perspectives from which to study and understand wildfire problems and outcomes. Involving different actors throughout the research process ensures that scientific work addresses the knowledge needs of actors whom it is intended to benefit. TWFS recognizes that expertise comes in many forms, including the traditional fire knowledge (TFK) of indigenous and rural communities (Huffman, 2013), as well as experiential and operational knowledge. This means that a critical and prominent element for effective TWFS is listening, learning, and communicating with end-users (Brunson and Baker, 2016) to identify research needs and, ultimately, develop and deliver knowledge and products that can be readily used and implemented.

2nd principle:*TWFS has a systems approach toward the problem.*

This principle advocates and addresses wildfire as an integrated and autonomous scientific subject with its own scientific discipline. For the production of wildfire knowledge to provide the most actionable insights on wildfire problems it needs to take into account all knowledge dimensions (ecological, social, physical, political). A system approach is needed to identify critical linkages with different parts and components of the system and feedback loops. This principle guides the understanding of interconnections of all elements of the wildfire system to have a holistic view of the wildfire reality.

3rd principle: *TWFS engages in multi/cross/trans disciplinary work.*

TWFS is boundary crossing. This principle addresses the scientific tendency to work in silos and privilege certain disciplines over others. TWFS ensures that attention is paid not only to the fields of fire behaviour, fuel and fire management, fire ecology, and remote sensing, that tend to dominate current wildfires scenarios, but to the full range of scientific disciplines that can provide insight into all parts of the system; during all phases (before, during, after an event) and at multiple scales (from local to national). This principle refers to the need to integrate disciplinary research and build a comprehensive academic understanding of wildfire phenomenon. This different approach will also require a different kind of training: translational fire scientists will need to develop and apply holistic multidisciplinary competencies and skills, including more concerted focus on communication skills, and an expanded range of literacies from data literacy to policy and political processes (Cuthbert and Barnacle, 2021).

4th principle:*TWFS includes the identification and evaluation of effective interventions (including procedures, behaviors, and policies).*

Feedback loops, rapid iteration, and evaluation are key processes underlying this principle in recognition that there are significant limitations to what can be understood from relatively abstract, artificial, and controlled world of science and the often-unpredictable outcomes of real-world implementation. Hence, it is important to build in plans to continuously track outcomes and potential causalities of any given activity, identify short- and long-term impacts, (Funnell and Rogers, 2011; Maletsky et al., 2018), and assess the role of fire science on decision-making (Ferguson et al., 2016; Hunter, 2016).

Monitoring and evaluation help to ensure that unintended adverse outcomes are identified and addressed at early stages of implementation; it also can help increase adoption of effective practices, reflecting lessons from diffusion of innovations that have shown how new practices are more readily adopted when their efficacy is observable. Continuous evaluation needs to occur during all steps of the research process, from the identification of the problem to operational results.

3.2. TWFS overarching characteristics

Along with the four general principles that guide the TWFS process, we have also identified a number of overarching characteristics of TWFS, informed by a typology proposed by McNie et al. (2017).

Knowledge production is *outcome-oriented*. TWFS aims at producing and disseminating high quality innovative research that attempts to identify and evaluate realistic solutions for real-world wildfire problems. It is interested in the sustainability of long-term implementation in diverse settings, by engaging in more interactive processes throughout knowledge production.

Scaling is another key characteristic. Although, ideally, research findings developed for a given scale can be applied to a narrower or finer scale (downscaling) or a broader or coarser one (upscaling), this is often not feasible as scale can influence outcomes, and different scales may require different solutions. TWFS aims to develop and test hypotheses and interventions tailored for the target scale of the specific wildfire issue of concern.

TWFS supports the establishment of *heterogeneous social networks*, not only across academic disciplines but also between diverse individuals (researchers, practitioners, and citizens) from diverse institutions, who may each operate at different scales—global to local. More heterogeneous networks are more likely to bring a variety of perspectives and knowledge to the table (McNie et al., 2017), which in turn is more likely to lead to innovative and socially acceptable solutions. Long-term commitments to collaborative and trust-building partnerships also can help to reduce barriers to the use of wildfire science in decision making.

TWFS also places high value on building social capital. Trust and relationships, both key elements of social capital, can play a key role in facilitating use of knowledge in organizational and political settings as well as ensuring the sustainability of the work (Levin and Cross, 2004). Research has established that trust is central for people, organizations, and agencies to engage and collaborate effectively in ways that elicit transformative processes (Paton and Buergelt, 2019; Seebauer and Babcicky, 2018). Statistical analyses have confirmed that the "softest" sides of social capital (bonding and connection) can significantly contribute to innovative knowledge co-production (Charatsari et al., 2020).

3.3. The mindset of TWFS scientists

Not everyone who does TWFS needs to be a translational scientist, but there is a need for a cadre of scientists with certain skill-sets to guide such efforts. Examining literature on translational scientist profiles (Gilliland et al., 2019; Schwartz et al., 2017), we identified several key attributes particularly relevant to TWFS.

A Translational scientist is prepared to design research around the real-world problem and not the other way-around. He/She is a boundary crosser who can naturally and easily interface with other actors, communicate across disciplines and interest areas, and translate the terminology and concepts of different wildfire domains into a language that can be understood by all (Gilliland et al., 2019). These scientists are outcome-oriented, acknowledging how the problem emerged and working strategically to address it by identifying barriers that limit access to scientific findings and services and creating new tools, services, and processes that serve to facilitate equitable access and opportunity to engage with the knowledge production process.

TWFS scientists need to have broad horizontal expertise, not just the deep disciplinary knowledge of their area of work but also a basic understanding of key knowledge and processes from other fields that provide insight into understanding wildfire outcomes, from fire behaviour to fire ecology, from individual to organizational behaviour, and from individual to societal levels. The TWFS scientists also need some understanding of how policy decisions are made in order to effectively engage practitioners, decision-makers, and citizens. Recognizing that complex problems often require multifaceted solutions, the scientists seek to enhance interdisciplinary and multidisciplinary collaboration for research, practice, and stakeholder engagement.

Given the importance of being able to effectively communicate with individuals and stakeholders with diverse social, cultural, economic, and scientific backgrounds, development of communication skills is crucial for TWFS scientists. They should be versed in a range of ways, beyond traditional peer-reviewed publications and conference presentations, of communicating scientific ideas and research findings among and between a broad and diverse audience. The skilled communicator excels not only at delivering the message in speech and in print, but also at listening and responding to the needs of their stakeholders.

Finally, a TWFS scientist needs to be a critical systems thinker, someone who seeks to identify and understand the dynamic interactions and interdependencies among a complex array of individual and societal concerns (e.g., spiritual, political, cultural, economic, ecological), and how these factors may influence outcomes and processes in interdependent systems over time (Buergelt et al., 2017; Buergelt and Paton, 2014).

4. Operationalizing TWFS: an exemplification using wildfire causes and motives domain applied to Portugal

To provide a hypothetical sense of how a TWFS approach would differ from current scientific practices, we draw from experience with an ongoing project in Portugal as an emblematic example. Over the last decades Portugal has been experiencing increasingly frequent and severe wildfires as well as increasing extreme wildfire events (Tedim et al. 2018). Despite its small surface area (92,212 km^2), Portugal has the highest number of fire ignitions per year in Europe. Most of these ignitions are human caused, with natural causes <1%. Between 1980 and 2019, 713,805 fires were recorded (San-Miguel-Ayanz et al., 2020), 37.8% of the European Union total for that period. With 1488 fires per million inhabitants (Beighley and Hyde, 2018), Portugal also has the highest density of wildfire ignitions among the European Union Members-States. This high number of ignitions can make it challenging to respond to all fire occurrences, since the suppression system for the country is only capable of handling 200 ignitions per day (Ribeiro et al., 2020). To date, the highest number of daily ignitions occurred in October 2017, with more than 500 events in one day (San-Miguel-Ayanz et al., 2020).

Ignitions are of particular concern in the Central Region of Portugal with large, continuous areas of *Eucalyptus globulus* lucrative plantations for the important pulp and paper industry. This means that any single ignition has the potential to cause a highly damaging wildfire. In 2017 the region experienced its most disastrous fire season ever, with 112 fatalities and more than 500,000 ha of burned area (San-Miguel-Ayanz et al., 2020). The amount of damage and the heavy toll of lives were aggravated by the continuity of forest cover, and lack of active management on privately owned plantations. Given this situation, understanding different reasons for ignitions, as well as their relative contribution, is of high interest to the Portuguese government. However, there is little specific knowledge on the topic. Between 2001 and 2017, only 27% of the ignition causes of wildfires in Portugal have been identified (Beighley and Hyde, 2018). This lack of knowledge of different sources of human ignitions, and their motivations, is a key obstacle to designing and implementing efficacious measures for decreasing unplanned human ignitions. The problem has traditionally tended to be defined and managed by fire and emergency response agencies who see the problem as one where all human ignitions are inherently malicious with a management focus on how to better identify and prosecute fire starters. Identification of fire causes is generally based on individual fire reports, filled often in the hectic post-fire aftermath with motives guessed or assumed rather than actually investigated (Camia et al., 2013). This unsystematic and ad hoc approach raises questions about the reliability and validity of what numbers there are, undermining their usefulness and trustworthiness.

A traditional science approach to this problem would be to develop more standardized investigation procedures, such as the Method of Physical Evidences (NWCG, 2016; Porrero Rodrìguez, 2001). While such work is needed to provide a more accurate numerical understanding of the different ignition sources, it can do little to identify how to reduce ignitions most effectively as it pays little attention to understanding the broader context that might be contributing to unauthorized fire starts. A broader TWFS approach would start with a broader effort to better understand human ignitions by working with diverse stakeholders and disciplines to define the problem and eventually identify targeted solutions. The approach would involve actors from diverse sectors and relevant jurisdictions and regions to jointly identify the potential issues to investigate (which may or may not be as simple as improving investigative procedures) and to harness their related resources to gather and analyze needed data.

Rather than relying on quickly done reports where motives are inferred, this approach better ensures that any improvements to national wildfire statistics are based on empirical rather than assumed motivations and also helps identify potential ways to target efforts to change behaviour and reduce ignitions. The process is more likely to produce a systematic qualitative and quantitative analysis across communities and a comprehensive, holistic and in-depth understanding of how individual (e.g., interpretations and actions based on beliefs, values and emotion) and contextual (e.g., natural and built environment, culture, society, religion/spirituality, economy, technology, politics) factors interact to contribute to fire ignitions. This more comprehensive understanding is more likely to provide insights that can inform development of targeted and effective solutions across sectors and jurisdictions.

Table 1 provides a hypothetical comparison of how a traditional science and TWFS might differently approach understanding the causes and motivations of fire outbreaks and how to address them in Portugal. This hypothesized example is informed by an ongoing project with the Portuguese National Guard, the national gendarmerie force charged of identifying the causes and motives of wildfires, who realized the need to work together with scientific community to more properly fulfil its task. This project is going to involve several actors (including citizens) and experts with different scientific expertise.

Table 1 presents the steps and explains how the problems in wildfire causes and motives investigation could be addressed differently with each approach, demonstrating the potential added value that an intersectorial collaboration would provide to address the gap in knowledge by using a more holistic assessment to co-create and co-implement research and, by so doing, to develop solutions more likely to address the needs of the territory and its stakeholders.

5. Conclusion

Given the increasing societal challenges posed by wildfires and climate change, there is a need to reconsider how wildfire science might be conducted and disseminated to ensure it can be more effectively used to inform future wildfire management efforts. Building on several proposed approaches for improving science use, this paper argues that a translational approach is best positioned to foster the scientific knowledge most likely to improve future outcomes. Counter to current wildfire science that is produced in disciplinary silos that traditionally have limited interactions, TWFS would provide a more holistic, problem-based field focused on solving real-world wildfire problems by: i) integrating scientific knowledge from different domains, ii) including consideration of experiential and traditional knowledge alongside scientific knowledge, and iii) involving a range of non-scientist actors throughout the research process to ensure that it addresses the real world needs of diverse stakeholders.

This paper is only a first step toward potential creation of a new research field. By outlining the potential advantages of such a process and TWFS principles, general characteristics, and the competences of ideal TWFS scientists, we hope that it can initiate the conversation necessary to foster concrete action. Although we have provided an example for a specific problem of how such an effort might differ from current research approaches, it is only a hypothetical illustration that needs to be tested overtime. Potential next steps could include: i) develop a TWFS agenda/framework summarizing what knowledge must be created; ii) propose tools and methods to facilitate the translational processes; iii) develop a framework to monitor and evaluate the translational process as early as possible; and iv) design how this approach will be homogeneously conveyed in graduate courses throughout the globe.

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Table 1
Comparative approach to wildfire causes and motives domain in Portugal using traditional science and TWFS.

Steps	Traditional science (Linear and "siloes")	Translational wildfire science (Ongoing co-creating cycle and interactive exchange between actors)
WILDFIRE GOVERNANCE	Top-down, exclusive, directive protocols. Weaknesses in the current post-fire investigation of the origin of the fire related with wildfire control organization and resources. Focus on increased prosecution of fire starters.	Recognizes and values both ground up and top-down protocols and systems. Focuses on learning and implementing participatory governance systems and processes and adaptive management. Revision of protocols based on empirical and, experiential findings to facilitate shared governance of the ignition problem Development of protocols tailored to different real problems. Enhance fire culture and governance
WILDFIRE PROBLEM: Who defines the specifics of the human ignition problem.	Fire response agencies (National Guard in Portugal) define the problem from their perspective with a focus on identifying ignition causes and inferring motives that are uploaded in the national wildfire database in order to inform policies and support research. Assumes that only fire managers set fires for positive reasons. Wildfire evaluation based on: - the number of occurrences and burned area; - the percentage of fires investigated and the percentage of unknown causes.	Researchers co-work with diverse actors (e.g., fire agencies, local government, landholders, organizations, and community members), within and across jurisdictions, to co-define the problem and continuously share knowledge regarding the causes and motives. Improved understanding of ignition sources and motivations enabling improved wildfire statistics and more targeted ignition prevention measures Continual evaluation Co-evaluating systems and procedures to constantly adapt the operational system of identifying wildfire causes and motives and addressing them. Potential metrics: Decreases in unauthorized ignitions; Fire behaviour and severity parameters; socio-economic and ecological impacts; level of satisfaction of stakeholders and communities with the new procedures.
WILDFIRE PROBLEM: Perception of fire	Culturally perpetuated perception of wildfire as a threat that needs to be fought. Restrictive wildfire legal framework (criminalization of fire use as a tool for land management). discourages alternative views.	Recognition that fire is not always a threat but can have an array of impacts, some of which are beneficial. Co-constructing knowledges and understanding about fire risks and benefits, and refining research designs. Identify continuum of motivations for fire setting and potential actions to foster more appropriate behaviour. Development of ways to understand trade-offs between the negative impacts and the benefits in a systematic way. Improve legal frameworks and fire culture

(continued on next page)

Table 1 (*continued*)

Steps	Traditional science (Linear and "siloes")	Translational wildfire science (Ongoing co-creating cycle and interactive exchange between actors)
FIELDS OF RESEARCH TO IMPROVE ACTIONS: examples	Need to improve and validate methods to identify ignition causes and increase accuracy of wildfire database. Improving data gathering on causes of human ignitions with a focus on quantitative data and modelling. Emphasis on numbers that can summarize the different ways humans start fires in a given region (time of occurrence, pattern of concentration, time of return). Communities are not seen as a data source but a problem for managers to fix.	Need to improve and validate methods to identify ignition causes and increase accuracy of wildfire database. Utilising participatory research approaches to build long-term collaborations between actors and enable *citizen science* to help identify and address ignition causes and motives. Qualitative/Quantitative research to understand: - roles of different actors on preventing or igniting fire outbreaks including range of reasons to start fires in a given region; -current traditional fire knowledge; -potential impacts of fire criminalization; -existing relationship/communication status between the local populations and fire agencies and how this may influence unauthorized ignitions; -relationship/communication status between fire agencies at local and national levels. Identify-alternative methods that may be more effective in reducing unauthorized ignitions. Develop policies and outreach programs tailored to needs of different stakeholders including citizens and the specificities of the territories. Help build community capacity to limit unauthorized and unwanted ignitions by co-creating, co-implementing and co-evaluating research with different actors including communities, Co-evaluate outputs Create new research questions
DISCIPLINARY INTERACTIONS	Predominantly a government domain, using knowledge from forestry, statistics.	Anthropology, Ethnology, Criminology, Sociology, Psychology, Forestry, Geography Law production and implementation Statistics Communication and Extension

represent any official USDA or U.S. Government determination or policy.

Author statement

All the authors have read and approved the current version of the manuscript.

Declaration of Competing Interest

The authors declare that there is no conflict of interests.

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