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Guiding principles for transdisciplinary and transformative fire research

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Abstract

Background Managing landscape fire is a complex challenge because it is simultaneously necessary for, and increasingly poses a risk to, societies and ecosystems worldwide. This challenge underscores the need for transformative change in the way societies live with and manage fire. While researchers have the potential to act as agents of transformative change, in practice, the ability to affect change is often constrained by siloed and biased expertise, rigid decision-making institutions, and increasingly vulnerable social-ecological systems where urgent rather than long-term solutions are prioritized. Addressing these challenges requires more holistic and equitable approaches to fire research that promote new models of transdisciplinary thinking, collaboration, and practice.

Results To advance transformative solutions to this complex fire challenge, we propose four principles for conducting transdisciplinary fire research: (1) embrace complexity, (2) promote diverse ways of knowing fire, (3) foster transformative learning, and (4) practice problem-centered research. These principles emerged from our experience as a group of early-career researchers who are embedded within and motivated by today's complex fire challenge within British Columbia (BC), Canada. In this forum piece, we first describe the four principles and then apply the principles to two case studies: (1) BC, a settler-colonial context experiencing increased size, severity, and impacts of wild-fires, and (2) our ECR discussion group, a space of collective learning and transformation. In doing so, we present a unique contribution that builds on existing efforts to develop more holistic fire research frameworks and demonstrates how application of these principles can promote transdisciplinary research and transformation towards coexistence with fire, from local to global scales.

Conclusions In this forum piece, we identify and apply four guiding principles for transdisciplinary fire research. Collectively, these principles can foster more inclusive applied fire research that matches the scope and scale of today's fire challenge and promotes transformative change towards coexisting with fire.

Keywords Fire research, Transdisciplinary, Transformative change, Social-ecological systems, Early-career researchers, British Columbia

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Resumen

Antecedentes Manejar los incendios a nivel de paisaje es un completo desafío, dado que el fuego es necesario para, y a la vez pone en riesgo, tanto a las sociedades como a los ecosistemas en todo el mundo. Este desafío subraya la necesidad de realizar un cambio transformativo en la manera que en que las sociedades viven con, y manejan los fuegos. Mientras que los investigadores tienen el potencial para actuar como agentes del cambio transformativo, en la práctica, la habilidad para inducir ese cambio está frecuentemente condicionada por el aislamiento y la experiencia sesgada, las decisiones rígidas de las instituciones, y la creciente vulnerabilidad de los sistemas socio-ecológicos donde lo urgente es priorizado por sobre las soluciones a largo plazo. El abordar estos desafíos, requiere una aproximación más holística y equitativa a la investigación en fuegos, que promueva pensamientos, colaboraciones, y prácticas transdisciplinarias.

Resultados Para avanzar en soluciones transformadoras a este desafiante complejo problema de los incendios de vegetación, proponemos cuatro principios para conducir Investigaciones transdisciplinarias en la ciencia de fuego: 1) abrazar la complejidad. 2) alentar las diversas formas de conocer el fuego. 3) Promover el conocimiento transformacional; y 4) promover la investigación centrada en el problema. Estos principios emergieron de nuestra experiencia como grupo de investigadores novatos que estamos imbuidos y motivados por el desafío que hoy presenta el tema de los incendios dentro de la Columbia Británica en Canadá. En este foro, describimos en primer lugar los cuatro principios y luego aplicamos estos principios a dos estudios de caso: 1) BC, un contexto pionero-colonial que está experimentando un incremento en el tamaño, severidad e impactos de los incendios; y 2) nuestro grupo de discusión ECR, un espacio de aprendizaje y transformación colectivo. Al hacer esto, presentamos una contribución única que se construye en base a los esfuerzos colectivos para desarrollar marcos de investigaciones en la ciencia del fuego de manera más holística y que demuestra cómo la aplicación de estos principios puede promover investigaciones transdisciplinarias y la transformación hacia la coexistencia con los fuegos desde escalas locales a global.

Conclusiones En este foro identificamos y aplicamos cuatro principios-guía para la investigación transdisciplinaria en la ciencia del fuego. Colectivamente, estos principios pueden alentar más investigaciones inclusivas en la ciencia del fuego aplicada que iguala el alcance y la escala de los desafíos actuales del tema de los incendios y promueve el cambio transformativo hacia la coexistencia con el fuego.

Introduction

Worldwide, managing landscape fire is increasingly challenging because fire is simultaneously necessary for (Lake and Christianson 2019; Millington et al. 2022) and poses a risk to (Bowman et al. 2013) societies and ecosystems. Furthermore, there are distinct but interacting challenges across local, regional, and global spatial scales (Bowman et al. 2013; Hessburg et al. 2021; Hoffman et al. 2022b). These challenges require transformative solutions that match the scope and scales of the current and future fire context (Smith et al. 2016; Higuera et al. 2019; Tedim et al. 2019; 2021; Shuman et al. 2022). In response to environmental challenges such as managing landscape fire, researchers have emerged as potential agents of transformative change (Milkoreit et al. 2015) by synthesizing knowledge, facilitating diverse collaborations, and (re)framing problems to allow for the co-creation of solutions (Pereira et al. 2020).

Transformative change is often described as a proactive or intentional shift towards a new or more desirable set of conditions (Chaffin et al. 2016). Enabling transformative change requires dismantling inequitable decision-making pathways and including new voices and perspectives (Reyers et al. 2018). In fire research, multiple forms of fire knowledge are needed to develop outcomes that are more attuned

to the needs of diverse ecosystems and peoples (Moritz et al. 2014; McWethy et al. 2019; Tedim et al. 2021). To this end, fire research is expanding to incorporate and bridge diverse knowledges (Carmenta et al. 2011; Roos et al. 2016; Smith et al. 2016) and to advocate for co-created, evidence-based solutions to help guide fire management (Hiers et al. 2020; Prichard et al. 2021; Tedim et al. 2021). This is especially true in places that are grappling with colonial histories and ongoing legacies of fire suppression and exclusion (Thomassin et al. 2019; Weir et al. 2022). These more holistic and equitable approaches to fire research are critical for supporting pathways towards coexistence with fire.

Over the last several decades, fire researchers have proposed new research frameworks that transcend disciplinary boundaries to help enable transformative change (Carmenta et al. 2011; Bowman et al. 2013; Roos et al. 2016; Coughlan and Petty 2012; Williamson et al. 2016; D'Evelyn et al. 2022; Shuman et al. 2022). For example, pyrogeography, which combines biology, atmospheric sciences, social sciences, and other primarily natural sciences fields, seeks to understand the impacts of fire at broad spatial and temporal scales and the relationship between fire and human societies (Krawchuk et al. 2009; Bowman et al. 2013; Roos et al. 2014; Bowman and Murphy 2011). Other frameworks, such

as “translational wildfire science,” align more closely with the social sciences and aim to better connect research to policy and practice (Tedim et al. 2021). Recent emphases on action-oriented and co-produced transdisciplinary research (Pereira et al. 2020) focus on topics such as human health intersectionalities (D’Evelyn et al. 2022) or on processes such as enhancing innovation and investment in research and partnerships (Shuman et al. 2022). A commonality between the above frameworks is the bridging of natural and social science methodologies and connecting research to practice so that research can help overcome constraints that contribute to today’s challenges of managing fire.

There are three main factors that continue to constrain fire researchers’ ability to affect change in practice: (1) siloed and biased expertise, (2) rigid decision-making institutions, and (3) increasingly vulnerable social-ecological systems. First, research processes are still largely shaped by certain forms of knowledge that are validated by academic systems such as paywalled journals and colonial institutions such as elite universities (Trisos et al. 2021). Systematic power imbalances between different types of knowledge are often embedded in research and decision-making in siloed ways that are challenging to overcome (Lemos and Agrawal 2006; Reimer and Eriksen 2018). For example, biophysical science is often more respected in government decision-making than Indigenous or local practitioner knowledge (Lake et al. 2018), especially in high-risk contexts (Weir et al. 2022). Second, more ‘powerful’ forms of knowledge have become institutionalized, reinforcing entrenched views of fire and existing power relations, and leading to a rigid ‘command-and-control’ approach to fire management that perpetuates inequities in decision-making processes (Carmenta et al. 2011; Roos et al. 2016; Smith et al. 2016). As a result, efforts to ‘integrate’ (Bohensky and Maru 2011) local and Indigenous knowledges into colonial systems without sharing decision-making authority can amount to appropriation, such as researchers or managers that extract or utilize place-based knowledge of cultural burning without consent (Mistry and Berardi 2016; Nikolakis and Roberts 2021; Hoffman et al. 2022a; Sousa et al. 2022). Finally, while the increasing vulnerability of social-ecological systems due to growing negative impacts from fire and climate change (Vink et al. 2013; Hessburg et al. 2021) can, in cases, catalyze transformative change, these impacts often lead to prioritizing immediate and reactive, rather than forward-looking, research and management.

In this forum piece, we respond to recent calls for a “new kind of transdisciplinarity” (Pereira et al. 2020, 162) by arguing that transformative change in fire research requires new models of transdisciplinary thinking, collaboration, and practice (Zscheischler and Rogga 2015; Andharia 2020). To advance this transformative change, here we propose and apply four principles for transdisciplinary fire

research. We write as a group of early-career researchers (ECRs), defined here as graduate students and postdoctoral researchers, from diverse disciplinary and professional backgrounds. These four principles have emerged from our experiences as ECRs based in British Columbia (BC), Canada, as well as attention to existing fire research frameworks and recommendations for transdisciplinary research more broadly. Despite calls for a greater diversity of perspectives in shaping a new approach to transdisciplinary fire research, ECRs have been less well-represented in the development and application of new research frameworks (Stoof and Kettridge 2022). Our ECR group was motivated to work on transformative solutions through research by the catastrophic impacts of fire in BC in 2017 and 2018, which have continued and worsened since. In non-fire contexts, other early-career scholars have contributed to more holistic research frameworks (Jeanson et al. 2020; Aubry-Wake et al. 2020), and we aim to reflect those successes in a fire research context through this forum piece.

Below, we first describe the four transdisciplinary principles and describe their relevance to the fire context. We then apply the principles to two case studies: (1) British Columbia (BC), Canada, a settler-colonial context experiencing increased size, severity, and impacts of wildfires, and (2) our ECR discussion group, a space of collective learning and transformation. We demonstrate how application of these principles can promote transdisciplinary research and transformation towards coexistence with fire, from local to global scales. In doing so, we present a unique contribution that builds on existing efforts to develop more holistic fire research frameworks and offers a suite of tangible yet flexible principles with broad applicability to the many diverse fire contexts worldwide. In this piece, we use the term “fire research” to encompass landscape fire (including wildfire, cultural fire, and prescribed fire) to avoid problematic assumptions associated with the term *wildfire* (Dods 2002; Hoffman et al. 2022a; Bento-Gonçalves and Vieira 2020) and to extend beyond disciplinary associations with “fire science” to reflect the transdisciplinary perspective needed.

Four principles for transdisciplinary fire research

Although a universally accepted definition of transdisciplinarity remains elusive (Jahn et al. 2012; Leavy 2016), there are several key tenets from the literature on transdisciplinarity that we draw from which are applicable to fire research. These tenets include: leveraging diverse methodologies to address complexity (Leavy 2016), embracing diverse forms of knowledge (Zscheischler and Rogga 2015), questioning disciplinary assumptions and encouraging reflexivity (Rosenfield 1992), and fostering collaborations outside of academia, especially with practitioners and communities, through knowledge co-development (Roysen and Cruz 2020). These tenets are

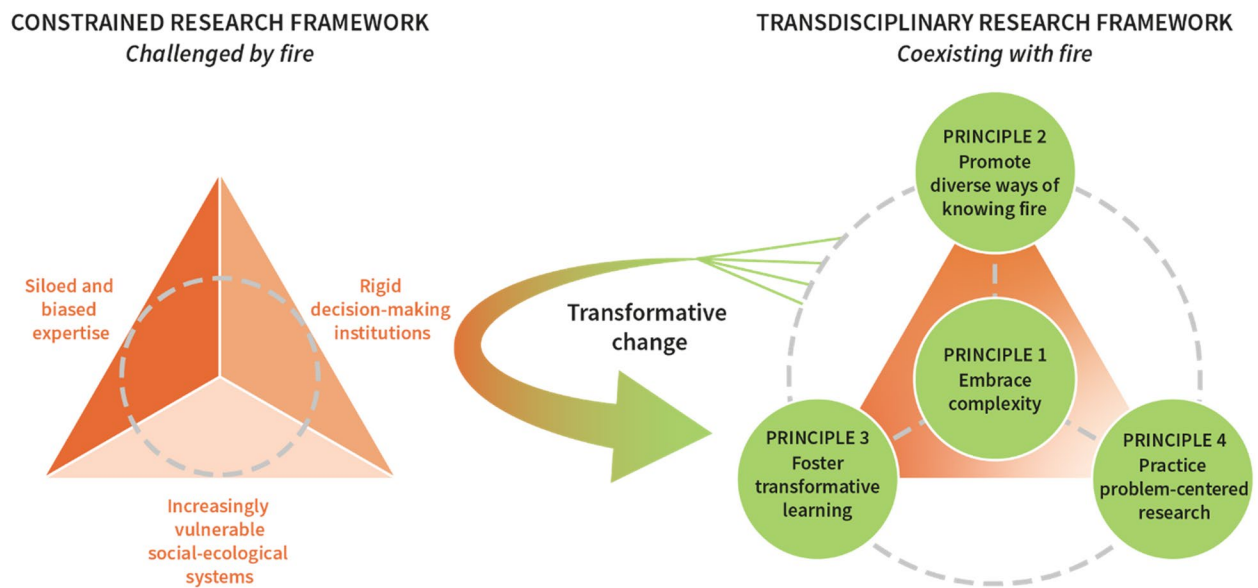


Fig. 1 Four guiding principles for transdisciplinary fire research that can motivate transformative change towards coexisting with fire. Transformative change is needed to move from a research paradigm that is constrained in practice (left, dashed circle) by three factors: siloed and biased expertise, rigid decision-making institutions, and increasingly vulnerable social-ecological systems. The four guiding principles for transdisciplinary fire research, embrace complexity (Principle 1), promote diverse ways of knowing fire (Principle 2), foster transformative learning (Principle 3), and practice problem-centered research (Principle 4), offer a research paradigm (right, dashed circle) that breaks free of those constraints. Given the complexity of managing landscape fire today, Principle 1 is a core principle that enables the other three

Table 1 Descriptions of the proposed four guiding principles for transdisciplinary fire research

Guiding principle	Description
Principle 1: Embrace complexity	Understand landscapes as complex social-ecological systems
Principle 2: Promote diverse ways of knowing fire	Employ methodologies and collaborations that uplift diverse ways of knowing to counter persistent power imbalances
Principle 3: Foster transformative learning	Develop research and educational models that foster experiential, reflexive, and collective learning to critically evaluate disciplinary assumptions
Principle 4: Practice problem-centered research	Design flexible research that engages diverse collaborators and matches the scope of a collectively defined problem

particularly salient in contexts where siloed expertise, rigid decision-making institutions, and increasingly vulnerable social-ecological systems can limit opportunities for inclusive, forward-thinking, and connected research and practice (Trisos et al. 2021).

Here, we build on the tenets of transdisciplinarity, existing fire research frameworks (Bowman et al. 2013; Tedim et al. 2021; Shuman et al. 2022), and the collective learnings in our ECR group, to identify four guiding principles for transdisciplinary fire research (Fig. 1; Table 1). Because of the inherent complexity of landscape fire, embracing complexity is a core principle (Principle 1) that can promote diverse ways of knowing (Principle 2), foster transformative learning (Principle 3), and enable the practice of problem-centered research (Principle 4).

Below, we describe each principle and highlight its relevance to fire research. Although we discuss each principle separately, we emphasize the powerful transformative change — from being challenged by fire to coexisting with fire — which can occur through applying these principles collectively.

Principle 1: embrace complexity

The increasing scale and complexity of modern environmental challenges have motivated researchers and practitioners to study and manage landscapes as complex systems. The concept of complexity arises both from resilience theories (Holling 2001) as well as environmental humanities, feminist science, technology studies, and Indigenous studies scholarship (Cronon 1996;

Armstrong 2009; Haraway 2016; Kanngieser and Todd 2020). The focus on complex landscapes and social-ecological systems, characterized by impacts, feedbacks, and dynamic human-environment relations at multiple spatial and temporal scales (Holling 2001; Liu et al. 2007; Schlüter et al. 2019), contrasts ‘command-and-control’ approaches to fire that are based on optimizing landscapes for resource production (Folke 2006; Holling and Meffe 1996). For example, in Western North America, fire-adapted ecosystems that were historically shaped by interacting processes of Indigenous fire and land stewardship, lightning ignitions, forest management, climate, topography, and fuels (Hessburg et al. 2019; Lake and Christianson 2019) have been altered through top-down approaches to landscape management that aimed to suppress and exclude fire.

Understanding landscapes as complex social-ecological systems is the starting principle (Principle 1) that enables researchers and decision-makers to engage with fire management on those landscapes as a complex practice. Re-envisioning fire as a social-ecological process in complex systems can also help shift research and management towards a more collaborative and integrated approach that acknowledges managing fire is as much a social challenge as an ecological one by developing new and shared understandings of challenges and solution pathways (Moritz et al. 2014; Fischer et al. 2016; Smith et al. 2016; Dunn et al. 2020; Vigna et al. 2021). This approach enables transdisciplinary problem-solving and solutions that come from multiple perspectives and recognizes the role of decision-making power in shaping knowledge-sharing, research, and practice.

Principle 2: promote diverse ways of knowing fire

Effectively managing complex social-ecological systems requires transparent, accountable, and equitable decision-making processes that are guided by diverse peoples and knowledges: from local and Indigenous ways of knowing to academic and practitioner knowledge (Davis 2009; Lam et al. 2020). Given the global prevalence of fire and fire-adapted ecosystems, many cultures around the world have adapted to living with and actively managing fire (van Vliet et al. 2012; Huffman 2013; Smith and Mistry 2021). Through long-standing use of fire as a livelihood tool and cultural practice, many Indigenous and local peoples have developed strong traditional, place-based fire knowledge and practices (Huffman 2013; Lake and Christianson 2019; Millington et al. 2022). However, Indigenous peoples and knowledges have historically been — and in many cases continue to be — excluded from both research and decision-making related to fire. In response, fire researchers increasingly argue that addressing these persistent epistemic power imbalances

must involve processes that strengthen the decision-making power of those marginalized from the dominant fire discourse (Steelman 2016; Kelly et al. 2019; Tedim et al. 2021; Devisscher et al. 2019).

Principle 2 emphasizes the need for transdisciplinary fire research to be grounded in ethical methodologies and collaborations (Goldstein and Kennedy 2022) that center and promote diverse ways of knowing fire and simultaneously counter biased management systems that are largely grounded in western scientific-based knowledge (Zscheischler and Rogga 2015). In doing so, fire research must also explicitly counteract extractive approaches to research that seek to ‘integrate’ Indigenous knowledge or practices of fire into dominant management systems (Bohensky and Maru 2011). ‘Integration’ can dilute or distill Indigenous knowledge systems into disciplinary silos or discrete ‘data’ that are disconnected from the peoples, cultures, languages, and lands in which they are embedded (Steffensen 2020). Indigenous scholars emphasize that Indigenous communities must be the ones to lead the reclamation and revitalization of their knowledges and cultures (Zahara 2020; Dickson-Hoyle et al. 2022); decolonial (Smith 2021) or anticolonial (Martinez et al. 2023; Liboiron 2021) research practices that actively seek to overcome systems of oppression can support these aims.

Principle 3: foster transformative learning

In contexts characterized by rapid social-ecological change, intentional forms of collective learning across knowledge systems can help catalyze transformation. *Social learning* refers to learning and knowledge generation through social interaction in networks that can produce shared frameworks for understanding complex problems (Reed et al. 2010; McCarthy et al. 2011). Extending this concept, *transformative learning* involves collective processes of critically examining assumptions, values and ways of thinking, and results in shifts in both individual and collective understanding of problems as well as in wider institutional structures (Pahl-Wostl 2009; Löf 2010). In the context of research, training, and education, transformative learning that is inclusive of multiple perspectives and builds competencies in systems thinking can foster more meaningful collaboration towards problem-solving and system-wide change (Burns 2011; Frisk and Larson 2011; Crockett et al. 2013; Ahmed et al. 2017).

Promoting transdisciplinary approaches to fire research requires the development of research and educational models that foster experiential and collaborative learning while empowering learners, from students to professionals, to critically question dominant systems and problem boundaries to lead change (Burns 2011; Ahmed

et al. 2017). Fostering transformative learning — leading to alternative ways of thinking and understanding, building competencies in systems thinking and collaboration, and empowering learners to confront complex challenges — will prepare learners to become problem-solvers, ‘change agents,’ and leaders (Burns 2011; Laszlo 2012). An emphasis on transformative learning also underscores the need for fire researchers and managers, particularly those trained in biophysical sciences, to interact with critical studies such as geography and humanities, as well as qualitative methodologies, to incorporate practices such as reflexivity, and to question disciplinary assumptions and siloes. Just as reflexive and mutual learning is central to collaborative research and transdisciplinary approaches, transformative learning is increasingly recognized as a key component of addressing complex challenges (Principle 1) such as managing landscape fire (Muro and Jeffrey 2008; Löf 2010; Dickson-Hoyle et al. 2021). Researchers that critically analyze dominant ways of thinking in fire research can further learn from and enable the promotion of diverse ways of knowing fire (Principle 2) and apply their learning by practicing problem-centered research (Principle 4).

Principle 4: practice problem-centered research

A fundamental principle of transdisciplinarity is designing research to match the scope of a defined problem, and not being constrained by disciplinary boundaries (Krimsky 2000; Leavy 2016). Like action-oriented research, problem-centered research — research characterized by collective or collaborative work and a flexible research design (Wickson et al. 2006; Leavy 2016) — allows for a diversity of theories, epistemologies, and methods that fit the problem space. Collective research is most successful when collaborators bring a range of values, attitudes, beliefs, and methods that are respectful of the contribution of others (Laszlo 2012), with flexible and iterative research design spaces allowing for more “responsive problem-solving” (Russell et al. 2008, 461). This principle complements Principle 3 by providing a central focus — addressing a specific problem — to motivate an ongoing collaboration around which transformative learning can occur.

In the context of fire, problem-centered research promotes the value of bringing together, rather than continuing to silo, disciplines, in order to better address the complex dimensions of fire across broader physical, biological, and cultural paradigms (Stoof and Kettridge 2022). While participatory collaborations in fire management can be subject to biases and conflict (Otero et al. 2018), intentionally creating spaces to consider, reflect,

and situate around a shared “problem” can provide more collective outcomes (Devisscher et al. 2019). Further, centering research on the problem space of fire can lead to innovative collaborations. For example, the merging of art and science has helped to draw attention to the emotional and embodied lived realities of experiencing and using fire on the land (Eriksen and Ballard 2020; Colavito et al. 2020). Centering complex problems that require both individual and collective action also speaks to the critical importance of engaging with relational, embodied, and experiential ways of knowing and living with fire (Principle 2). Further, this approach highlights how better understanding emotional relations can form the basis for action (Nightingale et al. 2022), help people reconcile themselves as part of the problem they are experiencing (Bryan 2020), and imbue leaders with long-term commitment and evolving thinking to tackle complex problems (Laszlo 2012).

Effective problem-centered research also requires engaging directly with communities who have been impacted by or are at risk of fire (Mistry et al. 2016). Community-based or participatory action research can simultaneously enhance ethical and more diverse collaborations that affect change through research (Leavy 2016) and allow space for knowledge co-development outside academia (Roysen and Cruz 2020), an important process to allow for Principle 2 to occur. Community-based fire research is one pathway for strengthening transdisciplinary problem-centered research, situating research around a given community in a way that respects the unique circumstances and relationships that people have with fire (Brenkert-Smith et al. 2017; Paveglio et al. 2018; Copes-Gerbitz et al. 2021; Dickson-Hoyle et al. 2022).

Applying the principles to two case studies

To highlight the need and relevance of these four principles and how they can be leveraged in tandem for more holistic fire research, below we apply the principles to two case studies: (1) the complex fire context in BC, Canada, and (2) our ECR wildfire discussion group. For case study 1, we first discuss the history, drivers, and current state of the modern fire challenge in BC and then demonstrate how applying the four principles could guide transformative change in fire management and foster coexistence with fire. In case study 2, we describe the formation of our ECR group, how the four principles both emerged from and were modelled within our collective processes of coming together in response to the complex fire challenges in BC, and how this has promoted transdisciplinary and transformative research and practice within our group.

Case 1: the complex fire challenge in British Columbia, Canada

Fire is an integral process to numerous cultural and ecological communities across BCs ~94 million hectares. Broadly across BC, major ecosystem types adapted to fire include northern boreal forests that sustain moderately frequent crown fire (100-150 year mean interval), interior sub-boreal to dry mixed-conifer forests that sustain frequent mixed-severity (crown and surface) fires (10-100 year mean interval), grasslands and open conifer forests maintained by very frequent low-severity fire (4-50 year mean interval), and coastal temperate forests that can sustain large wildfires (200-250 year mean interval) under extreme droughts (BC Forest Service and BC Environment 1995; Taylor et al. 2022). Fire also was, and, in many cases still is, an essential component of land management and culture for many Indigenous Nations. Both intentional and lightning-ignited fires are a part of Indigenous fire stewardship, which incorporates year-round practices of stewarding and benefiting from fire-affected landscapes (Hoffman et al. 2022a). Cultural burning, an intentional type of landscape fire, has been conducted by Indigenous peoples across BC for millennia for diverse purposes, including managing preferred food species, promoting wildlife habitat, reducing risk of negative impacts from uncontrolled fires, and to fulfill an obligation to care for the land (Turner et al. 2000; Gottesfeld 1994; Lake and Christianson 2019; Lewis et al. 2018; Dickson-Hoyle et al. 2022; Xwisten Nation et al. 2018; Christianson et al. 2022). This burning was spatiotemporally heterogeneous and, combined with lightning ignitions, created a patchwork mosaic of ecosystem structure and composition (Copes-Gerbitz et al. 2023; Hoffman et al. 2017) that limited impacts of subsequent fires (Brookes et al. 2021; Baron et al. 2022).

However, colonization from the mid-1800s shifted decision-making authority away from Indigenous peoples to a centralized provincial government, whose priority has largely been controlling fire through exclusion and suppression (Tymstra et al. 2020; Copes-Gerbitz et al. 2022, b,c). Today, despite ongoing assertions of rights, title, and jurisdiction by Indigenous Nations, the provincial Ministry of Forests and the British Columbia Wildfire Service continue to claim primary decision-making authority over forests and fire on so-called Crown land, respectively (Copes-Gerbitz et al. 2022b). This past century of excluding and suppressing both lightning-ignited fire and Indigenous fire and land stewardship practices, coupled with climate change, is driving increasing fire size and severity and associated impacts to societies and ecosystems (Fig. 2) (Abbott and Chapman 2018; Hanes et al. 2019; Coogan et al. 2019; Baron et al. 2022).

Prior to 2023, the three most widespread fire seasons since 1912 in BC were 2017, 2018, and 2021, which collectively burned 3.4 million hectares, prompted the evacuation of approximately 70,000 people (Government of British Columbia 2021), caused weeks of air quality advisories within and beyond Canada, and cost over US \$3.5 billion in direct fire suppression alone (Copes-Gerbitz et al. 2022b). The 2023 fire season broke the record for area burned in both BC and Canada, with the full scope of impacts continuing to emerge. With climate change, fire seasons of this magnitude are expected to worsen and increasingly overwhelm fire suppression efforts (Stocks and Martell 2016; Wotton et al. 2017; Tymstra et al. 2020). The legacies of colonial fire exclusion and suppression, which caused a build-up of hazardous fuels, as well as the interconnected challenges of climate change (Wotton et al. 2017; Kirchmeier-Young et al. 2019), forest disturbances such as pests and pathogen outbreaks (Parker et al. 2006; Hessburg et al. 2019), flooding disasters (Gillett et al. 2022), and the need to uphold and center Indigenous sovereignty (Zahara 2020; Hoffman et al. 2022a) all contribute to the complexity of the modern fire challenge in BC.

The 2017 fire season prompted calls for transformative change in the way that BC manages fire. These calls came from a range of groups, including Indigenous Nations (Verhaeghe et al. 2019; Sharp and Krebs 2018; Dickson-Hoyle and John 2021), government-sponsored commissions (Abbott and Chapman 2018), and researchers and forest professionals (Daniels et al. 2020). These calls also reflected a shift in public and policy dialogue calling for new approaches to fire research and management (Canadian Council of Forest Ministers 2016; Coogan et al. 2020; Sankey 2018; Johnston et al. 2020). Many resulting recommendations center on increasing the decision-making authority of Indigenous and local communities. Progress is slowly being made in certain areas, particularly in terms of recognizing the value of Indigenous and local knowledges. However, fire and landscape management in BC largely remain siloed and rigidly institutionalized (Copes-Gerbitz et al. 2022b) and locked into a complex policy and legislative system that require excluding fire from the landscape to prioritize timber values (Sutherland et al. 2023). Rigid and siloed institutions prevent a comprehensive understanding of the complex social-ecological nature of the fire challenge, constraining decision-making institutions to make incremental rather than transformative change (Copes-Gerbitz et al. 2022b; Sutherland et al. 2023). These institutional realities exacerbate the vulnerabilities of social-ecological systems in BC that are simultaneously navigating other disasters, economic pressures, and climate change (Coogan et al.

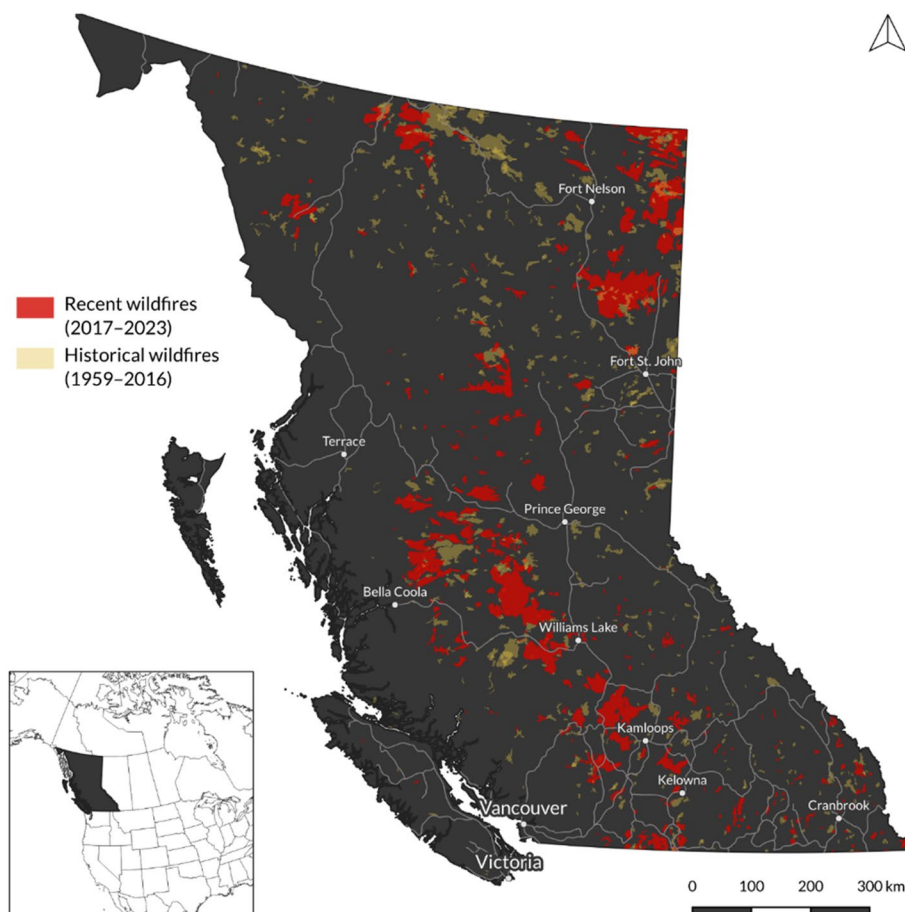


Fig. 2 Recent (red; 2017–2023) and historical (yellow; 1959–2016) wildfire events (≥ 1000 ha) in British Columbia. Deeper yellow indicates overlap between historical wildfire events (re-burns). The vast majority has only experienced one wildfire event, with re-burns being extremely rare due to the efficacy of fire suppression in this time period. Of the land area burned since 1959, approximately 58% burned in the 7 years (inclusive) between 2017 and 2023. This map does not include prescribed or cultural fires. Gray lines represent major road networks. Fire perimeter data from the BC Wildfire Service (<https://catalogue.data.gov.bc.ca/dataset/fire-perimeters-historical>)

2019). BC is therefore an ideal case study in which to apply principles for transdisciplinary fire research and reflect on how these can guide transformative change.

Transdisciplinary fire research needs for BC

Recent catastrophic fire seasons in BC underpin the urgency of action and the need for a clearly defined research agenda that matches the scale of complexity (Principle 1; Sankey 2018) and is responsive to the rapidly evolving fire problem (Principle 4). Furthermore, meaningful and transformative change requires systematically dismantling policy and decision-making constraints that limit transformative learning (Principle 3) by reinforcing entrenched perspectives (Sutherland et al. 2023). For example, fire research in BC has been dominated by biophysical research that stresses the importance of managing forests for heterogeneity (Campbell et al. 2009) or climate resilience (Mahony et al. 2018) or on developing

technical solutions to enhance the efficacy of fire detection and suppression (Coogan et al. 2020). This research has recently motivated spatial planning frameworks and guidelines that prioritize physical hazard reduction, quantitative assessments of risk, and considering diverse forest structures and successional stages (BC Forest Practices Board 2023) as well as policy change (such as the Forest Statutes Amendment Act 2021). While important, the strong focus on this type of research reflects a perception that managing fire is a purely biophysical, ecological, and technical challenge, rather than a complex social-ecological one.

In contrast, community-led or social science research that offers perspectives from Indigenous and local communities (Labossière and McGee 2017; Lewis et al. 2018; Nikolakis and Ross 2022), and that examines issues such as public health (Bowman et al. 2018), governance (Hagerman et al. 2010; Copes-Gerbitz et al. 2022b; Sutherland

et al. 2023; Asiyandi and Davidsen 2023), and equity (Reimer and Eriksen 2018), is undervalued and not well-represented in management spheres. Furthermore, unlike in the USA (such as through the 15 government-sponsored, regional Joint Fire Science Exchanges¹), there is little emphasis in BC on establishing and supporting transdisciplinary research networks and boundary spanning between Indigenous and western science and management (Hoffman et al.: Boundary spanners catalyze prescribed and cultural fire in Western Canada, in review). As such, there is a need to address the persistent imbalance in the types of knowledge that are used for decision-making (Principle 2).

Applying the four principles for transdisciplinary research directly addresses these issues by offering *processes* to guide research, rather than specific research questions. In BC, research is beginning to influence management through these processes at local scales, where diverse knowledges, tangible problems, and unique spaces for transformative learning exist. For example, many Indigenous Nations, building on knowledges and practices transmitted since time immemorial, are leading their own research to advance community priorities and policy change following recent fire events (Verhaeghe et al. 2019; Sharp and Krebs 2018; Dickson-Hoyle and John 2021). This approach contrasts with efforts to ‘integrate’ Indigenous knowledge into colonial management institutions (Bohensky and Maru 2011; Hoffman et al. 2022a). Similarly, Community Forests in BC are a local governance structure and social network that bring together local and Indigenous peoples to guide decision-making on forestry and fire through respectful dialogue, trust building, and reflexivity; collaborative research is helping to support these processes (Devisscher et al. 2021; Dickson-Hoyle et al. 2023; Siegner et al. 2023).

The above examples demonstrate the value of research that responds directly to needs and problems and how new models of research are informing changes in fire management at local and regional scales. However, to date, work at provincial scales is constrained by path-dependent and rigid institutions (Méndez et al. 2019) that do not value diverse forms of knowledge and are not rapidly evolving to meet the increasing vulnerability of BC’s fire-dependent systems. Implementing the four transdisciplinary research principles in BC could enable the necessary scaling up of transdisciplinary research. This could include informing efforts by the BC government (e.g., the Ministry of Forests and BC Wildfire Service) and the Forest Professionals BC (who collectively set standards

for “expertise”) to build on locally developed solutions and enable transformative learning to occur (Butler and Goldstein 2010). It could also include complementing biophysical and technical research with more social science research, supported by long-term funding for more connected research extension networks. Furthermore, implementing these principles will help ensure that BC’s emerging and future generations of researchers and practitioners are equipped to cope with uncertainty and change: key features of fostering more resilient social-ecological systems (Higuera et al. 2019; Folke 2016).

Case 2: our early-career research group as agents of transformative change

ECRs are uniquely positioned to lead and engage in transdisciplinary research because we are the first generation of scholars experiencing negative effects of climate change during our early years of scholarship (Jeanson et al. 2020; Hickman et al. 2021). Because of this, ECRs often focus on applied problems and embrace diverse forms of knowledge, learning, and collaborations (Lim et al. 2017; Aubry-Wake et al. 2020; Jeanson et al. 2020), especially when we complement academic training with professional experience. Many ECRs today are also seeking out training in decolonizing research methodologies, which challenge the assumed hegemony of western science, value other forms of knowledge, and explicitly recognize the historical and political drivers of environmental problems (Smith 2008, 2021; Cram and Mertens 2015). In fire research, there is a growing movement towards fostering ECR groups, such as the European PyroLife project,² which are equipped to promote transformation through research (Stoof and Kettridge 2022).

Our group of ECRs formed in 2018 after two back-to-back record-breaking fire seasons in BC, driven by our motivations to process and discuss how our research could contribute to possible transformative solutions. Through this focus on an applied problem, we identify as agents of change (Milkoreit et al. 2015) who are actively seeking to shift the status quo of fire research and management. Over 5 years, our group self-organized regular meetings to review academic literature and postfire reviews and collectively reflect on our individual engagement in community meetings, academic conferences, collaborative research, and professional work. Our self-organization as ECRs participating in ‘experiential education’ (Godwin and Ferrarese 2014), outside of our formal advising and academic requirements, and our emphasis on cultivating a supportive and caring space, is a micro-scale example of a ‘transformative space’ (Pereira et al.

¹ https://www.firescience.gov/JFSP_exchanges.cfm

² <https://pyrofire.lessonsonfire.eu/>

2020), a ‘transformation lab’ (Scoones et al. 2020), or ‘slow scholarship’ (Mountz et al. 2015). Our group is an example of how a short-term, emergent, and collective action can help foster transdisciplinary thinking and change the trajectory of our individual and collective contributions to fire research. This process coalesced into a collective goal of advancing transdisciplinary fire research in BC, where much of our research is situated. It was through this process, and towards this goal, that we identified the above four principles for transdisciplinary fire research, which can guide other early and later-career researchers to also participate as agents of change.

Transdisciplinary fire research for ECRs

As flexible learners in the formative years of our scholarship (Jeanson et al. 2020; Aubry-Wake et al. 2020; Stoof and Kettridge 2022), ECRs often have greater opportunities to employ a range of methodologies to embrace complexity, work collaboratively with diverse knowledge holders on specific problems, and foster spaces for transformative learning to take place (Leavy 2016). Within our ECR group, our individual and collective application of the four principles of transdisciplinary fire research has transformed the way we undertake our research (Pereira et al. 2020; Scoones et al. 2020; Mountz et al. 2015). We have intentionally taken time to learn the value of different disciplines from one another, broaden our methodological skillsets, ground our research in place, and expand our individual and collective ability to address complex problems.

For example, our methodological expertise ranges from qualitative inquiry and participatory action research (Dickson-Hoyle and John 2021; Copes-Gerbitz et al. 2021; Burr 2022), to mapping and modeling (Baron et al. 2022; Crowley et al. 2019a, b, 2022; Kitchens et al. 2022), to field-based forest assessments (Copes-Gerbitz et al. 2023; Dickson-Hoyle et al: Fire severity drives understory community dynamics and the recovery of culturally significant plants, accepted manuscript; Baron et al: Fuel types mismatch forest structure and composition in interior British Columbia: a way forward, accepted manuscript), and to historical analyses (Sutherland et al. 2023; Copes-Gerbitz et al. 2022b). Drawing from these different methodologies has helped many of us understand and address the complexity (Principle 1) of landscape fire through our research, as well as develop new understandings of the fire challenge in BC. A unifying feature of our ECR group is that we have coalesced around this common problem and actively (re)shaped our individual research to fit this problem space (Principle 4), with many of us developing new research or pivoting existing projects to address emerging needs from the 2017, 2018, 2021, and 2023 fire seasons in BC.

In addition, several of us have specifically crafted our research to bring together multiple ways of knowing about fire, including engaging with a wide range of communities and organizations. This engagement takes a variety of forms, including community-based research with co-developed research methods (Copes-Gerbitz et al. 2022a, c), Indigenous inquiries into fire response and recovery (Dickson-Hoyle and John 2021), interview-based research creation that foregrounds the voices of local fire experts (Burr 2022), and place-based work that has responded directly to research gaps articulated by fire managers and organizations (Kitchens et al. 2022; Baron et al. 2022; Crowley et al. 2019a, b). Importantly, we view these contributions as a way to highlight the diverse knowledges and expertise that exist in partner communities and collaborators (Principle 2) and focus on bringing these into ethical dialogue with western science to overcome biases in expertise and rigid decision-making (Goldstein and Kennedy 2022). In addition to research, we also engage in the BC problem space (Principle 4) more broadly through service to, participation in, and/or leadership for not-for-profit organizations, professional bodies, community groups, primary and secondary educational institutions, and networks that actively seek our expertise and provide a continual space for transformative learning to occur (Principle 3).

Our group discussions also used collaborative and reflexive learning tools and activities to “nurture” transdisciplinarity (Leavy 2016, 60), which we and others argue is an intentional and collective practice (Zscheischler and Rogga 2015; Andharia 2020). As a group, our initial focus was on discussing literature within and outside our disciplines, which gave us new frameworks to apply to the fire context. We then used an online whiteboard platform to facilitate a process of self- and group reflection that centered on describing our pathways to researching fire, our motivations and disciplinary strengths, and our personal and professional visions for the future of fire research. To inform this forum piece, we undertook a thematic analysis of the whiteboards that highlighted the frameworks we apply to fire research: the top five included resilience, social-ecological systems, ecosystem services, forest ecology, and landscape change. This process also illustrated that our personal experiences with fire — witnessing it, evacuating from it, lighting it, suppressing it, and researching it — influence the way we seek to apply transdisciplinarity. This transformative learning experience (Principle 3) was an opportunity for each of us contextualize our learning in a network of other ECRs studying fire and gave us a space to build collective leadership capacity — such as through articulating the principles presented here — to help address the fire challenge in BC.

Future directions for fire research

Enabling transdisciplinary research

The four guiding principles of transdisciplinary fire research — embrace complexity (Principle 1), promote diverse ways of knowing fire (Principle 2), foster transformative learning (Principle 3), and practice problem-centered research (Principle 4) — have arisen from and are embedded within our individual and collective experiences as ECRs engaging in fire research and cultivating an inclusive ‘transformative space.’ We see these principles as an evolution of recent calls for interdisciplinarity (Carmenta et al. 2011; Bowman et al. 2013; Roos et al. 2016; Tedim et al. 2021) and transdisciplinarity (Coughlan and Petty 2012; D’Evelyn et al. 2022; Shuman et al. 2022) in fire research. As such, the four principles provide a broader framework and foundation for a long-term and inclusive learning agenda. Indeed, these principles reflect the kind of transformational thinking that ECRs in other contexts are engaged in (see for e.g., Lim et al. 2017; Aubry-Wake et al. 2020; del Giorgio et al. 2020; Jeanson et al. 2020) as well as more equitable processes of research and writing. For example, we followed the practices of Liboiron et al. (2017) to ensure equity in author order. To help enable other ECRs to engage in transdisciplinary research and apply these four principles, we encourage ECRs to network within and outside of their institutions early in their programs to expand their learning opportunities and their sphere of influence. Furthermore, we recommend universities, principal investigators, and supervisors support and value transdisciplinary thinking and outputs, especially through dedicated training and funding in programs (Godwin and Ferrarese 2014). These efforts will help ensure other ECRs can take transdisciplinary learning, research, and practice into the next stage of their careers. Finally, coexisting with fire requires the inclusion of fresh ECR perspectives alongside the wisdom of later career stages, and the principles proposed here provide an inclusive framework for doing so.

Opportunities for transforming fire research

While the two case studies shared here have broad relevance beyond their specific context, the four principles draw on the knowledge and practice of transdisciplinary research (Leavy 2016; Pereira et al. 2020; Zscheischler and Rogga 2015) that can be applied to many different fire contexts worldwide. For example, they are complementary to other efforts underway in Canada, including networks created to strategically fill identified knowledge gaps (Sankey 2018) and a framework for more effective knowledge exchange between fire research and management (McFayden et al. 2023). The principles support these ongoing efforts through a focus on the actions and

processes (embracing (Principle 1), promoting (Principle 2), fostering (Principle 3), and practicing (Principle 4)) required to advance transformative change in researching and managing fire — a uniting need in Canada (Sankey 2018; Public Safety Canada 2023). This need is similarly echoed in jurisdictions that are still grappling with colonial histories (Thomassin et al. 2019; Weir et al. 2022) or those where centralized decision-making on fire management excludes relevant local and practitioner knowledge.

More broadly, the four principles build on existing research frameworks such as pyrogeography and transnational wildfire science by highlighting the need for intentional commitments to inclusive learning and a longer-term perspective that includes emerging leaders in fire research. Principle 1 reflects the need to recognize the multi-scalar, social-ecological complexity of fire (Bowman et al. 2013; Coughlan and Petty 2012; Shuman et al. 2022), which is required for developing long-term learning pathways that help researchers navigate the complexity of the fire challenge. Principle 2 is a common consensus in modern fire research frameworks (D’Evelyn et al. 2022; Shuman et al. 2022), yet we echo many critical and Indigenous scholars by emphasizing the need to avoid simply ‘integrating’ Indigenous or local knowledges into a dominant system without actively addressing existing power imbalances. We also highlight the role of academic systems in either maintaining or transforming dominant models of knowledge generation and the potential role of ECRs in cultivating new spaces for collective learning and leadership. Building on Principle 2, Principle 3 offers a framework for questioning disciplinary assumptions to identify new research approaches that match the complexity of the fire challenge (Carmenta et al. 2011). Finally, while much of existing fire research is framed in response to a ‘problem’ (Principle 4), there is deep transformational learning required to understand, and therefore build appropriate collaborations, to prompt a transformation in the way we research and manage fire.

The four guiding principles proposed here center processes and outcomes that directly support the diversity of peoples who are engaged with fire and are working to promote positive change. Transforming the processes and practices of research through greater transdisciplinarity is a necessary step for transforming the fire systems we are inherently a part of. Importantly, the scope and scale of change needed requires collective momentum rather than individual efforts and a long-term commitment to learning. Guided by these four principles of transdisciplinarity, ECRs, and other fire researchers, can be agents of transformative change to help shift the status quo from challenged by fire to coexisting with fire.

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Authors' contributions

KC-G and IJS initially formed and maintained the momentum of our early-career group. KC-G, IJS, TD, JNB, KAK, SD-H, and MAC all facilitated group discussions or reflections. JNB, PGM, IJS, and MAC documented group discussions and reflections. KC-G and IJS conceived of the writing project. KC-G, IJS, SDH, PGM, and JNB led sections of the writing, PGM and JNB created figures, MAC and KC-G managed references, and KC-G, IJS, and SD-H were overall editors. All authors thoughtfully contributed to discussions and writing and approved of the submission.

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