Synthesis

Indigenous fire management: a conceptual model from literature

William D. Nikolakis [1,2] and *Emma Roberts* [2]

ABSTRACT. Culture influences how fire is perceived and managed in societies. An increasing risk of catastrophic wildfire has shifted political and academic attention on the use of Indigenous fire management (IFM) as an alternative to the common fire suppression paradigm. However, what is IFM? Here we conduct a conceptual framework analysis of scientific and scholarly literature to enhance our understanding of this complex global phenomenon. We present the five main concepts of IFM from literature and the relationships between them. This framework contributes to the development of a theory of IFM, examining the ontological, epistemological, and methodological issues within this evolving and dynamic phenomenon.

Key Words: *conceptual analysis; fire ecology; fire management; Indigenous peoples*

INTRODUCTION

Fire is perceived through the lens of culture, and is rooted in mythology and religion. In Ancient Greek mythology, the Titan Prometheus took fire from the Gods, and Indigenous cultures from the Pacific Northwest tell of fire being stolen by coyote, beaver, and dog, and then gifted to humans (Judson 1912). Western religions cast fire as being pagan, destructive, and even apocalyptic, shaping modern Western perspectives on fire (Wiebe 2008), and fire management (Pyne 2016). Despite the different narratives, fire is central to human development (Gowlett 2016, Pyne 2016), and has transformed our societies and landscapes (Boyd 1999, Laris 2002, Butz 2009, Wrangham 2009, Miller and Davidson-Hunt 2010).

Paleoecological and oral evidence shows Indigenous societies have used fire to manage landscapes regularly over millennia, and many groups still actively do this today (Kimmerer and Lake 2001, Archibald et al. 2012, Huffman 2013, Klimaszewski-Patterson et al. 2018). Many fire-dependent ecosystems are reliant on anthropogenic fire (Marsden-Smedley and Kirkpatrick 2000, Yibarbuk et al. 2001, Pellatt and Gedalof 2014), and fire is used to create food security, termed "fire-stick farming" in Australia (Jones 2012). Yet, a paradox exists, where the global land area burned has declined over the last two decades because of factors such as agricultural expansion and fire suppression (Andela et al. 2017), while the incidence of destructive fires is increasing because of factors like climate change and mismanagement (Flannigan et al. 2009, Jolly et al. 2015). The world is not seeing more fire, but is experiencing the wrong type of fire, in the wrong place, at the wrong time (Pyne 2016). Controlled burning to mitigate uncontrolled fires is critical in fire-dependent ecosystems. However, significant legal, political, and attitudinal barriers constrain this practice (Maguire and Albright 2005, North et al. 2015). Indigenous fire management (IFM) is increasingly touted as a way to bring fire back to landscapes (Russell-Smith et al. 2013, Mistry et al. 2016, Lake and Christianson 2019, Moura et al. 2019), but what is IFM?

Indigenous peoples across the world manage their lands with fire, guided by their knowledge, practices, lore, and customs (Yibarbuk et al. 2001, Huffman 2013, Zander et al. 2013, Lake et al. 2017, Rodriguez 2017, Moura et al. 2019). IFM is the proactive use of fire to achieve multiple and complex landscape-level objectives, such as cleaning the landscape, mitigating destructive wildfires, and reducing greenhouse gas emissions (Whitehead et al. 2008, Russell-Smith et al. 2015); ceremony (Fache and Moizo 2015); promoting biodiversity and food security (Boyd 1999, Lepofsky and Lertzman 2008); and generating sustainable livelihoods (Rasmussen et al. 2007, Fitzsimons et al. 2012, Russell-Smith et al. 2013, Mistry et al. 2016). We examine scholarly literature on IFM and its accompanying ontological (the nature of reality), epistemological (understanding reality), and methodological (ways for gaining knowledge about reality) complexities. Using a conceptual framework analysis approach, a grounded theory methodology (Jabareen 2009), we generate a conceptual model of IFM from scholarly literature, which illustrates its main concepts and their interrelationships as expressed in literature. We acknowledge that much of the scholarly literature is from a Western perspective, which is a significant limitation to this literature review. This paper offers a call to action to include Indigenous knowledge and voices on this important topic. The conceptual model developed from the literature can guide research and practice on this multidisciplinary phenomenon.

CONTEXT

Fire suppression, reflected in the figure of Smokey the Bear in North America, has dominated landscapes across the globe during the 20th century (Saveland 1998, Diver 2016). Fire is to be avoided and if unavoidable, extinguished to protect life and property (Pyne 1982). In a warmer world, uncontrolled wildfire remains a constant danger in fire prone areas, or "pyroscapes," with catastrophic megafires threatening ecosystems, infrastructure, and human populations (Hardesty et al. 2005, Flannigan et al. 2009, Krawchuk et al. 2009, Moritz et al. 2012, Eloy et al. 2018). Indigenous peoples of pyroscapes often possess knowledge of fire and its use on these landscapes (Huffman 2013). Indigenous burning practices have notably shaped these pyroscapes over time (Bowman et al. 2011, Steen-Adams et al. 2019).

Historically, as European colonizers expanded across landscapes, IFM regimes were drastically altered (or quashed), which had consequences for the relationship between humans and fire, as well as negative impacts on landscape health (Pellatt and Gedalof 2014, Bird et al. 2016, Whitehair et al. 2018). IFM has declined since colonization, but it has continued in many areas and is being reactivated despite political barriers and conflicting worldviews

[1]University of British Columbia, [2]Gathering Voices Society

with non-Indigenous stakeholders (Mistry et al. 2016). Landscapes have since been altered in fundamental ways by deforestation, agricultural development, grazing, invasive species, forest encroachment, urbanization, and climate change. In many cases, Indigenous fire knowledge and practice needs to be adapted to current and future conditions.

Recent record-breaking fires around the world have led to calls for decentralized and proactive fire management beyond fire suppression (Rasmussen et al. 2007, Charnley et al. 2015, North et al. 2015, Minor and Boyce 2018). A report by Abbott and Chapman (2018) in British Columbia, Canada called for the prioritization of proactive fire prevention, prescribed burning, and better fire management coordination with First Nations (Indigenous peoples). In the United States, a Forests and Rangelands (2014) government report recommended wildfire mitigation through risk reduction strategies and landscape restoration. An Australian CSIRO (2009) report proposed an adaptive fire management approach in order to accommodate climate change and biodiversity. There were also public calls for IFM in Australia after the 2019 fire season (see Fuller 2020).

The United Nations Sendai Framework for Disaster Risk Reduction 2015-2030, outlined that "Indigenous peoples, through their experience and traditional knowledge, provide an important contribution to the development and implementation of plans and mechanisms" for disaster risk reduction (United Nations Office for Disaster Risk Reduction 2015:23). The academy has also advocated for more Indigenous involvement in fire management (Rodríguez 2007, McGregor et al. 2010, Mason et al. 2012, Russell-Smith et al. 2015). Indigenous fire knowledge and practice can generate multiple social, economic, cultural, and environmental benefits (Northern Australia Environmental Resources Hub 2016) and IFM programs have been implemented in Australia, Canada, the United States, Brazil, and recently in Botswana. These programs involve collaborations between Indigenous and Western knowledge systems, and are embedded in, and shaped by the institutional context (Petty et al. 2015, Lake and Christianson 2019). Examining how IFM plays out within these collaborative processes and the institutional context is critical to understanding the development of IFM, and how it is applied as an alternative to fire suppression in specific areas.

Institutional and policy context
IFM was prohibited (and often displaced) over large areas (Ritchie 2009, Minor and Boyce 2018), particularly where Indigenous peoples were removed from their lands and resources, and forbidden from practicing their culture and language (Nikolakis 2019, Nikolakis and Nelson 2019, Nikolakis and Hotte 2020, Nikolakis et al. 2020). The emergence of IFM as a "legitimate" alternative to fire suppression involves a reactivation of Indigenous knowledge and enhanced participation in land governance (Whitehead et al. 2008, Huffman 2013, Sletto and Rodríguez 2013).

In countries like Canada, Australia, and the United States, subnational governments (states or provinces) typically have jurisdiction over fire management. On Indigenous lands, the federal or relevant Indigenous government is typically responsible for fire management. There can be a clash of values and goals for fire management, with subnational governments adopting a fire suppression approach, driven by Western knowledge and

practices. Whereas Indigenous worldviews, knowledge, and practices call for a more place-based and holistic approach using fire as a tool (Berkes 1999, Kimmerer and Lake 2001, Norgaard 2014, Russell-Smith et al. 2017, Minor and Boyce 2018). In practice, it is common that fire management regimes neither match the ecological fire regime, nor do they draw from all available knowledge sources; this leads to negative ecological and social outcomes (Moura et al. 2019, Welch and Coimbra 2019).

Indigenous fire management goals are diverse, ranging from hazard reduction (Lewis et al. 2018), to maintaining biodiversity and cultural values, like protecting ceremonial areas (McGregor et al. 2010), to more localized cultural burning practices throughout the year (Kimmerer and Lake 2001, Bilbao et al. 2010, Steen-Adams et al. 2019) and enhancing livelihoods (Yibarbuk et al. 2001). For subnational governments, the goals are calibrated to land tenure, such as industrial forestry, rangeland, tourism, and conservation areas. In conservation areas, the fire-related goals are to maintain specific ecological values and to reduce wildfire risk, often achieved through prescribed burns (Fernandes and Botelho 2003). Efforts to integrate these different values and goals through comanagement approaches are well documented, and require parties to respect value differences, and to create rules about how these forms of knowledge and practice are integrated (Fitzsimons et al. 2012, Lake et al. 2017).

Barriers to implementing IFM include public perceptions of safety, air quality concerns, and other political complications (Marsden-Smedley and Kirkpatrick 2000). There are actor networks and advocacy coalitions advocating for IFM in policy processes, as a legitimate alternative to fire suppression (Diver 2016). Understanding the key concepts of IFM, and the interactions between these, is crucial to constructing a theory of IFM within the policy process.

CONCEPTUAL BACKGROUND

Literature
Early IFM literature took an etic approach to understanding precontact Indigenous fire regimes (Pyne 1982, Boyd 1999), studying communities from the outside. Recent literature increasingly takes an emic approach, as scholars build relationships with Indigenous communities, or communities produce their own literature, with the aim of exploring how Indigenous knowledge and practices interact with (or outside of) contemporary fire management. This often occurs in protected areas or on Indigenous lands. Most studies on contemporary IFM are at a local scale and measure cause and effect, governance, and the outcomes of IFM programs (particularly in Australia). Literature reviews have taken a social science lens (Christianson 2015) and a natural science lens focuses on prescribed burning (Fernandes and Bothelho 2003). Comprehensive studies have summarized the historical impact of humans on global fire regimes (Bowman et al. 2011), as well as the commonalities of Indigenous fire knowledge worldwide (Huffman 2013). However, there is a lack of global interdisciplinary synthesis of IFM. Although our conceptual model aims to advance understanding of this interdisciplinary topic, it is not necessarily representative of IFM as a whole, where other forms of knowledge are critical. A majority of the literature analyzed in this study, as well as the methods in which findings are presented (peer review, English language, etc.), have a Western lens.

Table 1. Preliminary search of fire management topics.

Topic	Search term	Number of results from Web of Science Core Collection
Wildfire management	Wildfire AND management; fire AND management	21032
Prescribed burning	Prescribed AND burning	4310
Carbon and wildfire management	Carbon AND wildfire AND management; carbon AND fire AND management	1964
Indigenous fire management	Indigenous AND fire AND management; aboriginal AND fire AND management; aborigine AND fire AND management; "first nations" AND fire AND management	349

To fill this gap in global knowledge, a preliminary review of scholarly literature was first conducted using Boolean search terms in the topic field of the Web of Science core collection. Table 1 shows a relative dearth of IFM papers compared to overall fire management literature (around 1.66%). This smaller literature, however, provides an opportunity for a deeper literature review and a multidisciplinary conceptual analysis of IFM.

Conceptual drivers
Ontology, epistemology, and methodology are crucial to understanding IFM. Ontology refers to the nature of reality, which is socially constructed through cultural symbols, ideas, belief systems, and narratives (Potter 1996). Reality can be reframed through shock events, or through actors reorienting how reality is perceived through learning. Epistemology refers to understanding "reality," determining what constitutes knowledge, distinguishing "truth" from simple opinion, and choosing what is worth knowing. Societies with diverse cultures, politics, and histories will have different ways of evaluating knowledge and determining truth (Henry and Pene 2001, Jasanoff 2004). Methodology is concerned with the methods, procedures, tools, and techniques for gaining knowledge. Methodology offers a justification and rationale for why certain procedures and tools are applied to investigate a given problem (Singh 2015). A methodology determines the approach for inquiry, and is guided by a researcher's ontological and epistemological position as they attempt to understand reality.

There are different knowledge systems for understanding the reality of fire and its management. Indigenous and Western science knowledge systems have differing (and sometimes common) epistemologies for how knowledge is uncovered or understood. There has been increasing focus on integrating Western and Indigenous knowledge to better understand and manage ecosystems and natural resources (Bohensky and Maru 2011). Western scientific paradigms create knowledge through critical reasoning, replicable methodologies, peer review, and written documentation, with ecological science increasingly focused on holistic systems thinking, resilience theory, and social-ecological systems (Walker and Salt 2006, Bosch et al. 2007, Mason et al. 2012). Indigenous knowledge systems and science are often more experiential, localized, holistic, and are typically passed down orally through generations (Berkes 1999, Mason et al. 2012, Mistry and Berardi 2016). Both seek to understand phenomena by observing cause and effect, but the epistemological differences present challenges for collaborative approaches. Traditional knowledge holders may be hesitant to collaborate with the etic approach of Western science, uneven power dynamics, and skepticism about Indigenous knowledge (Moller

et al. 2009). IFM in practice has mitigated these concerns by drawing from both Indigenous and Western scientific paradigms, and prioritizing Indigenous community participation in the application of knowledge (McGregor et al. 2010, Lake et al. 2017). This, in turn, allows methodologies to be created for finding solutions to fire management problems at broader scales.

There are various risks, perceived and real, for IFM as a methodology. Christensen (2003) and Stankey et al. (2003) document that mainstream fire management is generally risk averse. Decision makers avoid short-term risk in lieu of potentially long-term ecosystem benefits (Ryan et al. 2013). Fire management actors use mental shortcuts that introduce systemic bias and create a mismatch between objectives and practices (Maguire and Albright 2005). Often the precautionary principle is used, whereby the absence of fire is framed as a "safe alternative" to "risky" prescribed burning practices. Status quo bias is also prominent, where land managers feel less responsibility for the negative effects of "doing nothing," i.e., wildfire caused by climate change, than for the negative effects of deliberate interventions, i.e., damage from an escaped prescribed burn. Regret theory also plays a role, whereby land managers minimize potential losses rather than maximize the net value of a decision (Maguire and Albright 2005). These mental shortcuts inhibit innovative fire management policies and practices.

IFM as a solution
Locating IFM within broader environmental decision making brings insight to context. Figure 1 illustrates that environmental problems, their nature, and their recognition, are rooted in decision makers' ontologies. Once a problem is acknowledged, a risk-assessment is made and potential interventions are evaluated, drawing on existing knowledge and technical tools (Charnley et al. 2015). The portfolio of interventions for fire management are evaluated, be it fire suppression (status quo), prescribed burning, mechanical thinning, or a mixture of these. Where an intervention has previously been effective, it becomes the default option. Where the intervention has been ineffective, or the problem is unknown, then a space is created for interventions outside fire suppression (like IFM). If the solution is effective, we hypothesize this feedback will reshape existing ontologies to legitimate the innovation.
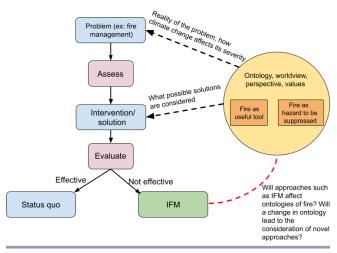
METHODS
To better understand emergent and multidisciplinary phenomena, Jabareen (2009) developed a "conceptual framework analysis" (CFA) approach, a grounded theory technique that builds a conceptual framework of "interlinked concepts that together provide a comprehensive understanding of a

Table 2. Conceptual framework analysis: deconstructing and categorizing the concepts (adapted from Jabareen 2009).

Concept	Description of concept	Inquiry character	Selected sources of data (fields of research)
Distinct ontologies	Different culture and fire ontologies and knowledge.	Ontological	Philosophy, anthropology, ethnography
Governance	Power dynamics, institutions, tenure, Indigenous rights and title, funding, political processes, colonialism, trust, relationship-building, cross-cultural communication, cogovernance, and stakeholder coordination.	Methodological	Governance, law, history, political science
Revitalizing Indigenous knowledge	Revitalization and mobilization of Indigenous fire knowledge and practices, experiential/reflexive management, cultural development, land management, intergenerational transmission of oral knowledge.	Epistemological	Anthropology, sociology, ethnography, ethnobiology, fire science, traditional ecological knowledge
Cobenefits	Biodiversity, ecological outcomes, health and wellness, hazard abatement, carbon credits, decreased greenhouse gas emissions, livelihoods and cultural development.	Methodological	Economics, ecology, community development studies, population health, fire science, climate science
Desired state	Reversing degradation, human involvement in pyroscapes, adaptation, heterogeneity/patchiness, "naturalness," resilience, and ecosystem services (cultural values, water, carbon, etc.).	Epistemological	Environmental psychology, ecology, climate science, forest policy, fire science

phenomenon" (Jabareen 2009:51). The goal of the analysis presented in this paper is to utilize the CFA approach to organize key concepts of IFM in ways that demonstrate interrelationships, as well as their ontological, epistemological, and methodological dimensions. The intention is to produce an illustrative framework of the multidisciplinary phenomenon in question, that contributes to its overall understanding. We employ Jabareen's eight-phase qualitative analysis to build a conceptual framework, which together compose a process of theorization. The theories in interdisciplinary literature form the data analyzed to build the conceptual framework, emphasizing a continuous interplay between data collection and analysis.

Fig. 1. Indigenous fire management (IFM) within environmental decision making. This dynamic framework shows environmental decision-making processes for a given environmental problem (in this case, wildfire). The dashed lines represent potential effects of ontologies on the decision-making process over time.

Conceptual framework analysis
The first phase involved a literature review of IFM, drawing on scholarly literature from ecology, fire science, community development, economics, and policy. This review identified 349 papers on IFM (see Table 1), and 72 were selected for deeper review, based on the following criteria: they were published after 2000 (to reflect contemporary rights and knowledge), and published in peer-reviewed journals. The second phase involved extensive reading and categorization of data, where literature was organized by discipline and relative importance within each discipline (by citations).

The third phase involved the identification of concepts within literature. The main findings and recommendations from each study were collated and grouped into overall themes, and from these groupings we documented common concepts. The fourth phase involved deconstructing each concept by identifying its main attributes and characteristics, and then organizing these concepts according to their ontological, epistemological, or methodological role. In the fifth phase, concepts were integrated, where they were reconsidered, combined, or dispensed with. The concepts were then synthesized into a theoretical framework (here presented as a contextual conceptual model) during the sixth phase.

The seventh phase involved validating the conceptual model to ensure it represents a reasonable theory for IFM from literature. In the eighth and final phase, the conceptual model was shared with academics and practitioners, and their feedback was incorporated where appropriate. Fifteen academics and fire practitioners were interviewed, including four academics from the U.S. (one Indigenous academic), four from Australia (one Indigenous practitioner), five from Canada (one Indigenous academic and practitioner), and two academics with work focused on Brazil and southern Africa.

RESULTS
A conceptual analysis identified five key concepts in the 72 articles. (1) Distinct ontologies: the ontology of fire is socially constructed and perceived differently by Western and Indigenous

worldviews; (2) Governance: IFM often involves collaboration between Indigenous and Western knowledge systems, and occurs within a contested institutional context. (3) Revitalizing Indigenous knowledge: Indigenous knowledge and practices are rooted in an experiential epistemology where the landscape drives decision making. (4) Cobenefits: IFM can generate a range of ecological, social, economic, and cultural benefits. (5) Desired state: IFM can achieve a desired ecosystem state of resilience (Table 2).

Concept #1: distinct ontologies: fire ontologies are distinct in Western and Indigenous worldviews
Relationally distinct fire ontologies exist: fire is either "good" or "bad," a "tool" or "hazard," "destructive" or "generative," and these views interact within existing institutional frameworks to shape the dominant epistemologies and methodologies for fire management.

Western fire ontologies have evolved over time. Heraclitus, of ancient Greece, believed all things were manifestations of fire (Wheelwright 1974), and later Aristotle classified fire as one of four elemental substances (Gomes 2018). In the 17th century, phlogiston theory reasoned all combustible materials contained the element "phlogiston," released into the air when something burned (Partington and McKie 1937). This theory was gradually superseded by our current scientific knowledge that fire is the combustion of fuels through the process of an exothermic reduction-oxidation reaction (for summary see Kondratiev 2018). As Western fire knowledge has evolved, so too has people's relationship with fire. Fire was a central aspect of domestic and daily routine, but following the Enlightenment and advances in technology, fire became less integrated into people's lives (Pyne 2016). Modernity has seen fire replaced by electricity for some, and the condemnation of fire by agronomists and foresters has reduced its use in land management and affirmed perceptions of fire as a destructive force to be suppressed (Pyne 2016).

In contrast, for many Indigenous peoples, the use of fire is based on a reciprocal relationship between the individual and the universe (Eriksen and Hankins 2014). Many Indigenous worldviews believe the Earth is a generative, living being, and that humans and all living beings are interconnected (Kidwell et al. 2002). As oral knowledge is important to Indigenous societies (Berkes 1999), fire knowledge, of when and how to use fire on the landscape, is often found in people's stories. These stories set out various "laws of the land" (Eriksen and Hankins 2014), for the responsibility of fire as a management tool and often incorporate the intrinsic value of nature, the potential for the landscape to be alive or sentient, and the spiritual dimensions of the land (Fernández-Llamazares and Cabeza 2018, Nikolakis et al. 2020). Fire is viewed by many Indigenous societies as a source of renewal, and burning cleans the landscape (Yibarbuk et al. 2001).

A clash of ontologies plays out in fire management in important ways. Colonizers brought European forest and fire management to areas they colonized and settled, despite many landscapes being fire-prone and fire-adapted (Pyne 2016). Colonization and fire suppression had drastic impacts on Indigenous people's ability to exercise their responsibilities to the land. It also changed these landscapes in important ways, as forests encroached on grasslands and fuel loads built up, enhancing the risk of devastating wildfire (Kimmerer and Lake 2001, Moura et al. 2019). IFM can not only mitigate risks, but can also contribute to the decolonization of fire management.

A significant ontological barrier to IFM is the idea of "traditional," where Western thinking frames traditional practices as those predating contact, and suggesting these are static (Pierotti 2018). Government agencies can simply reject IFM as an artefact with no place in modern landscapes (Mathews 2005). However, Indigenous cultures, worldviews, and knowledge systems are dynamic and adaptive, and can be applied to diverse settings and contexts (Berkes et al. 2000, Eriksen and Hankins 2014, Pierotti 2018). These distinct fire ontologies explain the divide in epistemologies and methodologies for fire management in colonized landscapes; the questions remain whether IFM can and should drive a convergence in ontologies.

Concept #2: governance: IFM is a collaboration influenced by political and power dynamics
IFM takes place in a complex governance environment. IFM programs are often collaborative and draw from multiple bodies of knowledge and normative views of what should (and should not) be done to the landscape (see Shaffer 2010, Russell-Smith et al. 2013, Sletto and Rodríguez 2013, Lake et al. 2017, Eloy et al. 2018). Learnings across Indigenous and Western knowledge systems can foster new fire knowledge and goals, one prominent example being a community savanna-burning methodology in northern Australia (Whitehead et al. 2008, Russell-Smith et al. 2013). However, in practice, the broader institutional framework may entrench uneven power dynamics that influence knowledge production (Ballet et al. 2007, Hunt 2014). Mainstream actors and agencies may remain ignorant to the potential of IFM (Mathews 2005) and Indigenous peoples may determine it unacceptable to integrate their fire knowledge with, or having this validated by, Western science. As Miller et al. (2010:2298) argued, "Indigenous knowledge is inextricably linked to the rights of indigenous people to make choices, to preserve and recreate knowledge through continuing engagement and practice on the land."

Tenure systems, land management bureaucracy, and vested economic interests impede Indigenous people's access to environmental governance and climate adaptation strategies (Nikolakis and Nelson 2015, Nikolakis et al. 2016a, b, Nikolakis 2020). On top of this, strict antifire laws often prohibit Indigenous communities from burning, which puts IFM at risk (Kull 2002, Miller et al. 2010, Minor and Boyce 2018). International commitments made by states can either impede or complement IFM, further contributing to complexity in the governance environment. For example, commitments to reduce greenhouse gas emissions in the Kyoto Protocol enabled savanna burning as an accountable activity, allowing IFM to be integrated into carbon markets in Australia (see Russell-Smith et al. 2013), while also drawing criticism for how such market integration can institutionalize Indigenous knowledge (see Mistry and Berardi 2016). Comanagement involving Indigenous peoples and the state is one way to bridge epistemologies and methodologies for land governance, particularly where this respects the authority and sovereignty of the groups involved (see Diver 2016, Denham 2017, Latta 2018, Nikolakis and Hotte 2020). The reorientation of authority through comanagement, and more broadly self-governance, may facilitate IFM at a larger scale.

A lack of funding and institutional support also impede IFM (Rasmussen et al. 2007, Fache and Moizo 2015). IFM is embedded in a complex governance environment, at various scales. As Mistry et al. (2019) document, IFM is an exercise in intercultural governance that requires carefully designed structures. Practitioners and academics emphasized that getting the governance right is dynamic and complex, but crucial for advancing IFM.

Concept #3: revitalizing Indigenous knowledge: Indigenous knowledge and practices are experiential and place-based
Indigenous peoples continue their fire management practices in many places (Kimmerer and Lake 2001, Fulé et al. 2011, Pivello 2011, Russell-Smith et al. 2013, Sletto and Rodríguez 2013). Sometimes there is an integration of Indigenous and Western knowledge systems in IFM programs (McGregor et al. 2010, Mason et al. 2012, Lake et al. 2017, Lake and Christianson 2019). Where knowledge and practice have been discontinued, efforts to promote the revival of these practices are an urgent priority, and involve sharing knowledge across generations (McGregor et al. 2010, Huffman 2013, Mistry et al. 2016, Lewis et al. 2018, Nikolakis et al. 2020). Community goals for an IFM program in British Columbia, Canada included strengthening cultural connection and well-being, restoring the health of the land, and respecting traditional laws (Nikolakis et al. 2020).

Fire knowledge is epistemologically rooted in a connection to place (Robinson et al. 2016). Fire management can be a spiritual ceremony, grounded in local stories or legends (Davidson-Hunt and Berkes 2003, Miller et al. 2010, Christianson et al. 2014, Norgaard 2014). IFM emphasizes a reciprocal relationship with the land, and a strong nexus between individual and landscape health (Eriksen and Hankins 2014, Gratani et al. 2016). Under Indigenous epistemologies, the land often guides human action, while Western approaches are typically guided by politics, science, and economic incentives.

Drawing from Indigenous knowledge, IFM has been shown to be an effective place-based strategy to address wildfire and produce additional cobenefits (see Laris 2002, Whitehead et al. 2008, Russell-Smith et al. 2013) and has important self-governance implications (Diver 2016). It is of critical importance that where Indigenous and Western knowledge are brought together, it is in ways that ensure respect, equity, agency, and decision-making power for all parties involved.

Concept #4: cobenefits: IFM generates multiple ecological, social, economic, and cultural benefits
In addition to reduced fire risk, literature demonstrates diverse market (income) and nonmarket (ecological, social, and cultural) outcomes from IFM (see for example Laris 2002, Bilbao et al. 2010, Hankins 2013, Bird et al. 2018), often termed cobenefits. IFM has generated significant greenhouse gas reductions by mitigating late dry season fires. The West Arnhem Land Fire Abatement (WALFA) project reduced carbon emissions from wildfire by 37.7% over seven years, relative to a preproject 10-year emissions baseline (Russell-Smith et al. 2013). The WALFA project also generates livelihood outcomes through carbon credit sales (Whitehead et al. 2008). Tribal nations in the United States are interested in generating livelihood opportunities from IFM (Rasmussen et al. 2007) and tribes in Northern California are implementing IFM programs (Diver 2016). IFM can also deliver "conservation-based development" (Rasmussen et al. 2007).

Individual participation of Indigenous peoples in environmental management (including fire management) has produced positive health outcomes, derived from enhanced physical activity, reduced psychological distress, and increased connection to the land (Burgess et al. 2005). Campbell et al. (2011:83) concluded these programs deliver "significant and substantial savings in primary health care expenditure for the management of chronic disease." IFM programs also deliver individual emotional and spiritual health benefits (Miller et al. 2010, Norgaard 2014).

IFM programs enhance intergenerational knowledge and culture transfer, which is coupled with healthy and intact ecosystems (Fernández-Llamazares and Cabeza 2018). In Central Brazil, ceremonial practices and mentorship are combined to pass on fire knowledge (Welch and Coimbra 2019) and in British Columbia, educational programs and mentorship support IFM practices (Lewis et al. 2018).

"Pyrodiversity" describes the interactions between anthropogenic fire regimes, biodiversity, and ecosystem effects (Martin and Sapsis 1992, Bowman et al. 2016). In many savanna ecosystems, mosaic landscapes created through prescribed burning improve biodiversity (Laris 2002, Bilbao et al. 2010). Landscape mosaics with many small fires result in more long-unburnt patches (Trauernicht et al. 2015), which are important habitat for bird, reptile, and mammal species (Kelly et al. 2012, Taylor et al. 2012, Nimmo et al. 2013). However, Parr and Andersen (2006) argued the theory that "pyrodiversity begets biodiversity" has not received sufficient critical analysis, and that fire management should focus more on the specific levels of burning required for biodiversity goals, as well as operational guidelines for attaining them.

Concept #5: desired state of ecosystem: IFM can achieve a resilient ecosystem
Determining what is a healthy ecosystem is socially constructed, and rooted in worldviews, values, and experiences (Papworth et al. 2009). Fire suppression in fire-prone regions has created a perception of safety, but has not achieved a desired healthy ecosystem state, and has paradoxically increased fire risk (Ingalsbee 2017). Understanding cultural fire regimes can help restore fire-prone ecosystems and their services (Steen-Adams et al. 2019). The desired state of an ecosystem is evolving and subject to shifting baselines, where people's perception of a healthy ecosystem changes from one generation to the next, or even within one's own lifetime, as their outlook changes (Papworth et al. 2009). This presents a risk as landscape knowledge is passed down to younger generations through a lens where negative ecological changes may go unnoticed and unaddressed. IFM has the potential to address this lapse in ecological memory by encouraging intergenerational knowledge transfer on what is a healthy or resilient ecosystem (Maffi and Woodley 2010).
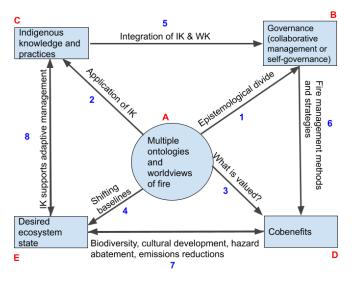
The desire to achieve an ecosystem that is "natural" has epistemological flaws. The idea of "pristine nature" is a colonial idea that disregards Indigenous land management in markedly transforming the landscape (Denevan 1992, Gratani et al. 2016). The concept of nature, land use, and Indigenous land justice are bound up in the politics of territorialization, which shapes norms and rules for legitimating land access and use (Sletto 2016, Welch and Coimbra 2019). Further, climate change shapes what people see as the baseline of ecosystems, and hinders attempts to restore these to any baseline (Harris et al. 2006). Increasingly, there is a

focus on integrating Indigenous knowledge and science with mainstream science concepts of systems thinking, resilience, and adaptive capacity in fire science, ecology, climate science, and many other relevant disciplines (Walker and Salt 2006, Bosch et al. 2007).

The need for adaptive strategies in fire management is critical (North et al. 2015, Mistry et al. 2016). IFM must be specific to the ecological characteristics of the landscapes to which it is applied, and this varies across biomes, regions, and ecosystems (see Kull 2002, Shaffer 2010, Russell-Smith et al. 2013, Lewis et al. 2018, Moura et al. 2019, Welch and Coimbra 2019, Nikolakis et al. 2020). Contemporary IFM must also consider critical infrastructure, land tenure, public risk perception, and air quality, which are crucial when managing populated landscapes. There are multitudes of competing objectives, goals, and narratives that influence IFM and its objectives.

Conceptual model
Figure 2 presents a conceptual model of the five key concepts of IFM from literature: (A) Multiple fire ontologies; (B) Governance; (C) Indigenous knowledge and practices; (D) Cobenefits; and (E) Desired ecosystem state. The interrelationships between these concepts are mapped out.

Fig. 2. Conceptual model. IK, Indigenous knowledge; WK, Western knowledge.

The conceptual model identifies (A) multiple fire ontologies, with different ways of knowing and thinking about fire. At (1), the model shows these ontological differences create an epistemological divide bridged by collaborative governance, which influences, and is influenced by, the institutional context (B). At (2), the application of IFM brings this into a broader fire management regime (C). At (3), ontological differences affect the cobenefits people value and manage for (D), with the tendency in Western perspectives to favor market benefits. Ontology also influences our ideas of how a desired ecosystem should appear and function (E). At (4), these ideas will change as our baseline of what a healthy landscape looks like evolves. At (5), integrating Indigenous and Western knowledge systems through

collaborative processes can transform fire governance, the methods used, and benefits produced, at (6). At (7), the cobenefits managed for will influence the desired state of an ecosystem, for instance, managing for timber or carbon will have different implications for the ecosystem than managing for biodiversity or cultural values. Balancing these different goals and values requires participatory and adaptive forms of management, and Indigenous knowledge and practices can support this. At (8), the link between desired ecosystem state and Indigenous knowledge points both ways, as Indigenous knowledge is often experiential and involves a continuous interplay between applying strategies and reading the landscape.

DISCUSSION AND CONCLUSIONS
IFM is a practice and tool that can bridge distinct epistemologies of fire (Mason et al. 2012, Lake and Christianson 2019). However, IFM is distinct and exists on its own terms, outside of Western fire management frameworks. The conceptual model in Figure 2 presents five key IFM concepts from scholarly literature: fire ontologies, governance, Indigenous knowledge, cobenefits, and desired ecosystem state. The relationships between these are mapped out, illustrating the interdependencies between IFM concepts, as well as their accompanying ontological, epistemological, and methodological roles. These concepts play out to influence if and how IFM is used as a fire management strategy. This model aims to deepen understanding of the key elements of IFM represented in the literature, noting that most of this literature was developed by non-Indigenous academics. More effort to include and amplify Indigenous perspectives and worldviews on IFM is critical.

There are important temporal and spatial dimensions to IFM. The intervention depends on ecosystem type and season, and this creates challenges for knowledge sharing. Indigenous knowledge and practices are typically place-based and relevant to a specific fire regime and ecological context. For example, insights from north Australia's savannas are not readily transferable to Canada's boreal forest. That being said, the main concepts illustrated in the conceptual model (Fig. 2) were found to be representative of global IFM literature. The conceptual model captures important commonalities to implementing IFM.

As societies and communities learn to coexist with fire and expand thinking beyond Western ontologies and perspectives, there are important issues to consider. If IFM is pursued through market-based mechanisms (like carbon credits), will this institutionalize and constrain the dynamism and experiential nature of Indigenous fire knowledge? Reciprocal relationships, and the connection between physical and spiritual worlds, are not easily integrated into Western scientific approaches (if integration is a management goal). New forms of governance will be important, and while adaptive comanagement is one way for bridging epistemologies and building trust, there remains questions about the ownership of Indigenous knowledge. One fire academic observed, "academics come and take the stories [of cultural fire] and it gets put out into the academic world, and that knowledge is taken away from the community." Putting safeguards in place to preserve Indigenous ownership of knowledge is crucial.

Institutions and power dynamics will shape the evolution of IFM. An Indigenous fire practitioner stated, "for Indigenous communities there is both a cultural and an ecological risk to *not*

burning" [emphasis added]. They elaborated that "[t]his results in risks for Indigenous communities performing their culture. Should they risk arrest to perform cultural fire ceremonies? Or should they risk a cultural loss by not performing them?" These laws, norms, and power dynamics may shift over time as IFM is implemented and legitimated by the dominant regime. There remain important questions as to whether IFM will expand beyond Indigenous land tenures, into contested areas as crises accelerate the acceptance of other fire solutions (see Fig. 1). As a fire academic reflected, "IFM is being considered as a solution because megafires are occurring, and this leads to a paradigm shift in fire management." It could be that as the benefits of IFM are demonstrated, this could facilitate a paradigm shift away from fire suppression, to more proactive and community-driven approaches. Further research is needed to better understand whether there exists a transformation toward IFM because fire suppression is demonstrably ineffective, or whether there is a broader shift in ontologies and epistemologies recognizing the importance of Indigenous knowledge for sustainable development in a changing climate.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/issues/responses.php/11945

Data Availability:

The data/code that support the findings of this study are available in the literature review and Appendix 1. These data/code were derived from a bibliometric analysis commenced 6 March 2019 from resources available in the public domain.

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