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FIRE SCIENCE AND MANAGEMENT (ME ALEXANDER, SECTION EDITOR)

Organizational Learning from Prescribed Fire Escapes: a Review of Developments Over the Last 10 Years in the USA and Australia

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Abstract

Purpose of Review Prescribed fire escapes continue to challenge most fire and land management agencies and many communities. This article considers the issue from knowledge management (KM) and organizational learning (OL) perspectives. We review organizational initiatives and the literature that have developed over the last 10 years to support learning from escaped prescribed fires, then use this to evaluate current learning practices and identify potential next frontiers for improving performance. Due to the difficulty obtaining statistics for non-federal entities, this review focuses primarily on developments in the US Department of Agriculture, Forest Service, but also captures reviews from the US Department of Interior, and the State of Victoria, Australia.

Recent Findings The recurring issue of prescribed fire escapes may in part be explained by the increasing challenges and expectations fire and land management agencies and prescribed fire managers face. Agencies are being asked to burn more area and suitably contain prescribed fires with fewer resources. In many jurisdictions, this challenge is heightened by increasingly tough climate conditions, shifting demographics internal and external to their agencies, changing patterns of land use, and requirements to meet increasing fuel reduction targets. A range of interventions has been developed and implemented by state and federal land and fire management agencies to support improved performance through KM and OL. However, prescribed fires continue to escape, often for the same reasons they always have, leading us to ask: is there a next frontier or level for improving performance though learning?

Summary This paper reviews recent developments in KM and OL to develop a model of organizational learning for prescribed fire. We then use this lens to review learning from prescribed burn escapes in Australia and the USA, highlighting the opportunities and challenges that agencies continue to face. Four areas of concentration to further strengthen OL are proposed, namely (i) strengthening the organizational learning culture, (ii) greater use of communities of practice to enhance lesson sharing, (iii) addressing the slow build time for prescribed burning expertise to replace pending retirements, and (iv) improving non-technical skills and human factors training.

Keywords Prescribed fire · Organizational learning · Knowledge management · Escaped fire

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Introduction

Aside from climate, fire is arguably the most powerful macro-scale force influencing historical evolution of much of the Earth's terrestrial flora and fauna [1–4]. Naturally ignited fire (wildfire) continues to play a critically important regenerative role in many ecosystems (e.g., [4, 5]). Historically, socially oriented human-ignitions have created and maintained culturally important and ecologically rich ecosystems resulting in substantial changes to the geographic range and composition of many vegetation types [3, 6–8].

Intentional human application of fire continues to be an important management tool. Every year, millions of hectares of grass, scrub, and forest undergo prescribed burning around the globe. Prescribed fire is used to maintain or improve biodiversity; support natural ecosystems; and restore, maintain,

and conserve fire-adapted landscapes (e.g., [9]). Prescribed fire is also increasingly used to reduce wildland fire (bushfire[1]) threat by consuming fuel, thus reducing the rate of spread and intensity of subsequent fires, and thereby generally reducing suppression difficulty [11–13].

Prescribed fire is an intensively planned affair. Here, we use the term to mean intentional ignitions planned and implemented by professionals as part of their land management agency's operations to meet management objectives, and in contrast to accidental or arson starts. Although specifics vary by country and organization, prescribed fire entails significant pre-work (e.g., consultations to articulate burn objectives, fieldwork to identify fuel types and conditions, appropriate weather and burn conditions, burn boundaries, topography, infrastructure, and associated personnel and resources needed to complete a successful burn) [see 14, 15 for more]. This is compiled into a "burn plan" that describes all facets of implementation: ignition, holding, and contingency plans. A burn plan must be approved by appropriate authorities. Many prescribed fires are years in the planning; implementation must then await appropriate environmental conditions. Similarly, although criteria vary for when a prescribed fire is classified as "escape," in general, an escape occurs when the onsite resources (including contingency resources called for in a burn plan) can no longer contain the fire as planned.[2]

Recent devastating losses from wildfire—of life, private and corporate property, and critical infrastructure–events around the world: in the USA (California) in 2017–2018; in Canada in 2016 (Alberta) and 2017–2018 (British Columbia); in Croatia, Portugal and Spain in 2017; and in Australia in 2009, 2019/2020—bring new urgency to discussions regarding the use of prescribed fire to mitigate or avoid destructive unplanned ignitions. Prescribed fire has much to offer: it effectively reduces wildland fuels, typically at a lower cost than suppression and mechanical fuels reduction operations and is a natural process that can enhance and improve ecosystem resilience [9].

Yet, even as the need increases, so do the challenges. Challenges arise at both planning and implementation phases:

- Planning phase:

  - Ongoing evolution of agriculture and tourism create a more complex mosaic of land use and ownership and the interplay between social, economic, environmental, and cultural aspects make it increasingly difficult to achieve prescribed fires in some regions [16•, 17, 18]
  - Demographic changes reduce capacity and knowledge (e.g., aging population, new residents' lacking fire experience, depopulation of rural areas and resultant loss of cultural practices) [4, 16•, 19–21, 22•]
  - Concerns over air quality and potential escapes can jeopardize community support and agency license [5, 20, 22•, 23–25]

- Implementation phase:

  - Fuel build-up from decades of attempted fire exclusion and fire suppression increases potential fire behavior, making control of wildfires increasingly difficult [4, 16•, 26, 27]
  - Climate change results in more frequent incidents of extreme fire behavior, increases length and severity of drought which result in more difficulty complying with burn prescriptions [28–31]
  - Correctly perceiving, understanding, managing, and communicating risk and uncertainty is an ongoing human factors challenge [4, 16•, 20, 21, 32–34]
  - Challenges of ensuring good practice among non-professionals (i.e., citizens) burning private property [16•]
  - Changing structure of agencies, including outsourcing and an increasingly aging (and retiring) workforce exacerbates gaps in burn skills and experience [29, 35]

These challenges make the path to success tortuous. Once planning is complete, it can take years for the appropriate conditions—environmental and organizational—to occur. Once ignited, the uncertainties in the dynamic interactions among weather, topography, fuels, fire, and human behavior make prescribed burning a complex and inherently risky endeavor [36]. Successful prescribed fire operations require competent individuals to function in effective teams, which themselves rest within multi-team organizations that operate at various scales.

Although escapes are uncommon (less than ~1% of all prescribed fires) and those resulting in significant property damage and injury even more rare, they can have enormous impact—on individuals, on affected communities, on the wildland fire community and operations, and on public policy and perception. For example, the 2000 Upper Frijoles prescribed fire escape (which became more widely known as the Cerro Grande wildfire) in New Mexico destroyed 235 homes [37]. The Margaret River prescribed fire escape in Western Australia destroyed 41 houses and heavily disrupted tourism central to the region's economy [20] (see Sidebar). Escapes almost always result in the

[1] The term *bushfire* is a collective term used by Australians to describe fire in the rural countryside and includes grass, scrub, and forest [10]. A bushfire is known as wildland fire in North America.

[2] In the USA, when project resources are not able, or are projected to not be able, to contain any fire outside of the approved burn unit within 24 h, it must be declared an escape. Sometimes an escape is also called when additional funds are needed to pay for contingency resources.

cessation of other local burn operations and sometimes nationally. Such response, although understandable, limits the ability of a prescribed fire program to meet its objectives.

In light of these challenges, it is incumbent on organizations to glean as much learning as possible from each burn and successfully incorporate those insights and lessons into future program operations. To assist in this, we critically review how organizations are learning, specifically how they are seeking to reduce future prescribed fire escapes by incorporating lessons learned from previous escapes, and identify potential next steps towards improving learning. Although this is not the first such effort to summarize learning from events (see examples: Maupin [38, 39] and Jin and McRae [40] for meta-reviews targeting fire managers, Wier et al. [41] for lessons and providing succinct guidance, Moriarty et al. [42] for an academic treatment of insights gained in one fuel type and see Black et al. [43] for structured review of organizational learning).

This paper includes an academic review of materials published over the past decade by fire and land management agencies intended to help their program personnel learn in the aftermath of prescribed fire escapes. Most fire management organizations have come to realize over the past decade that unintended outcomes, although rare, are extremely difficult to avoid. Thus, in addition to doing their best to avoid them they have adopted techniques to learn from their performance (both positive and negative).

Learning itself is complex. Researchers emphasize emergent and fluid characteristics [44] as well as the social complexity of organizations themselves [45]. Learning from prescribed fire escapes involves processes to build individual competence and team skills (explicit and tacit; procedural and experiential), prior to, during, and post implementation. Ideally, organizational learning processes capture, retain, and transfer new understandings across individuals, jurisdictions, and time. Ghili et al. [45] argue that organizational learning acts as a mediator between organizational innovation and knowledge management, between the during-action dance of individual and team performance (innovation) and the post-action structured, bureaucratic process of knowledge capture, synthesis, distribution, and integration. Throughout, the social and structural complexity of organizations themselves create challenges for how to best support and enable organizational learning.

Here, we assess experiences and insights gained and documented over the past decade from escaped prescribed fire reviews through the lens of conceptual developments in the fields of organizational learning, knowledge management, and organizational development. We focus primarily on the USA and Australia due to availability of data.

Methods

We conducted literature searches of both peer-review and "gray" literature in order to contextualize the practice of prescribed fire and its role and challenges as a land management tool and to identify discussions and reviews of escaped prescribed fires. We focused on documents published and publicly available between 2012 and 2018. Most published reviews fall into the "gray" literature category as they are rarely peer-reviewed from an academic or professional perspective. Reviews are commissioned by governmental entities written by teams selected for their peer- and managerial-fire expertise and usually follow the escape of government agency prescribed fires resulting in major losses. In the USA, federal land management agencies with fire responsibilities include the Forest Service of the Department of Agriculture and the National Park Service, Bureau of Land Management, Bureau of Indian Affairs and Fish and Wildlife Service of the Department of Interior. Individual states and local governments have fire responsibilities for private and state-owned lands within their jurisdictions. However, due to the considerable difficulty collecting comparable data from multiple agencies (five US federal agencies and 50 states; six Australian states each with two land management agencies), this review includes data largely from the Victorian Department of Land Water and Planning (DELWP[3]) which has had the most recent published review of its prescribed fire practices and the US Forest Service. The lack of literature covering escapes from prescribed fires on private lands in both the USA and Australia precluded review of this sector.

We analyzed published reviews (management-oriented non-academic literature) to detect patterns in the prescribed fire escapes themselves, the presumption being that patterns are indicative of tractable issues organizations can address, as opposed to random events that are not tractable. One indication of learning might be that there are new patterns in the causes of prescribed fire escapes.

We simultaneously conducted a search of the academic peer-reviewed literature. We summarize recent theories of organizational learning and use this to identify a practical analytic framework. Our search for recent organizational learning papers quickly led us into the related realm of knowledge management, where recent focus is mainly on codification of explicit insights into durable organizational processes. A

[3] In Victoria, the Forests Act of 1958 designates that DELWP is "responsible for the immediate prevention and suppression of fire and for planned prevention of fires in state forests, national parks and on public protected land" [32, p. 4]. The Country Fire Authority (CFA) is responsible for suppression and prevention of fire on private land in the more rural areas of the state.

complex endeavor such as prescribed fire, however, requires refined judgment of nuanced variables; thus, the transfer of experience and tacit knowledge is vital to success. We needed a multi-faceted framework that allowed us to consider learning from a variety of perspectives: scales of learning (individual, team, organization, inter-organization), time frames of learning (in-the-moment, reflective), types of knowledge (explicit, tacit, procedural, experiential), and processes of organizational learning (creating, retaining, transferring). Thus, we venture into aspects of organizational development and reach a bit further back in organizational learning theory to develop a sufficiently comprehensive framework. We then consider recent advancements in organizational learning processes for prescribed fire events in the USA and Australia through this emergent lens. We end with some thoughts on advances and current knowledge gaps that may be more productively explored in order to continue to improve prescribed fire operations and organizational learning.

Results and Discussion

Organizational Learning—Model Review and Framework Development

At least one recent review of the knowledge management and organizational learning literature suggests that knowledge management has absorbed organizational learning [cf. 46]. We disagree, at least as it relates to the practice of organizational learning. Current peer-review literature focuses on the structuring of knowledge maintenance rather than the process of learning. We seek to recover the learning phase and place it back in its proper and useful relationship. For instance, with the advent of big data, recent scholarship has virtually exploded with papers covering mechanisms for capturing, analyzing, and serving back know-how (e.g., building call center databases to assist with "known" issues). Although this is a core function of a learning organization, alone it is insufficient to achieve learning. Current literature is missing the myriad of ways in which organizations are expanding their practices of learning, as we explore in the context of prescribed fire escapes. It is also silent as to how an organization, particularly a field-oriented one, successfully moves lessons from databases to humans and instills these in current and ongoing training and operations.

Generically speaking, an organization's performance is comprised of both the application of prior experience (i.e., knowledge) and the process of acquiring and applying new knowledge (i.e., learning). Argote [47] defines three facets of knowledge: declarative (explicit understanding and facts), tacit (difficult to articulate and often experiential), and procedural (routines). Knowledge can be embedded in multiple locations including people (competent individuals, teams), routines (organizational processes), and knowing who knows what (transactive memory). Organizational learning is defined as a change in the organization's knowledge in response to experience [47, 48]. Change can be observed in organizational routines, cognition, and/or behavior, incorporating explicit and/or tacit elements [49•], at individual, team, organizational, and inter-organizational scales [50]. In general, organizational learning is considered an intentional activity [51]; however, cultural change is often accidental or indirect. Lessons may be positive (i.e., advances the organization's culture and practice) or negative (driving individuals and organizations into defensive modes) [52], based on the actual story (first-story) or on the meaning others assign to the narrative (second-story) [53]. Occasionally, there may be the need to remove (or forget) poor practices [54].

Argote and Miron-Spektor [49•] theorize a cyclical process in which experience gained through performing a task is translated into knowledge that shapes the organization's context and influences future experiences. Drawing from Glynn et al. [55], the authors highlight how organizational learning's interrelated sub-processes of creating, retaining, and transferring knowledge occurs in a context that includes the organization and the environment in which the organization is situated (Fig. 1).

In this view, learning is largely retrospective. Christianson et al. [56•], however, define organizational learning as "revision of response repertoires in ways that improve organizational performance". This usefully redirects our attention away from a sole focus on post-event changes in behavior and routines, towards examining the ways in which various actors, skills, routines, beliefs engage with an unfolding event; that is, *learning through* in addition to *learning from*. In their

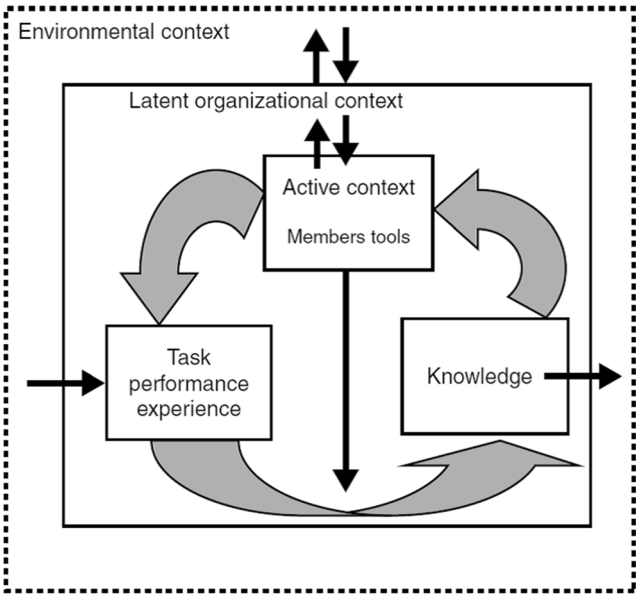


Fig. 1 A theoretical framework for analyzing organizational learning [Source: 47]

words: *learning through* is "learning focused on discovering and strengthening a set of organizational routines that facilitate the resumption of activity as the interruption winds down". In contrast, *learning from* is "learning as a separate event" [56•, p.850]. It recognizes that in the lead up to an unexpected event, people are acting and behaving as they normally do—that is, using "pre-existing repertoires." This allows the re-framing of a prescribed fire escape from a rare event that is difficult to learn from due to its uniqueness to a series of typical behaviors "less unique and less idiosyncratic than is the rare event itself" [56•, p.850]. As a consequence, the frequency and landscape of learning—who, what, where, when, and how—is dramatically expanded. We can now consider events as: (1) "audits of existing response repertoire," (2) "disruptions that provide opportunities to reorganize routines particularly with respect to interpreting, relating, and restructuring," and (3) events that "redirect organizational identity" [56•, p.847]. Each of these enriches our learning.

Edmondson and Harvey's [57] review also draws attention to these distinct frames. Their streams of organizational learning—production and innovation—also focuses on the learning through rather than learning from, yet further distinguishes these as *doing* (in-the-moment) and *reflecting* (backcasting). This is a subtle refinement of Argyris and Schon's [58] single and double-loop learning (refining existing routines as production, and fundamentally altering routines as innovation) by distinguishing, and thus highlighting the value of, in-the-moment learning from reflective learning. Owen's [59•] survey of how emergency management organizations utilize research is an example of the production stream. Owen observes that leading agencies (mature utilization) establish governance processes to ensure utilization of new knowledge, embed insights into job roles, actively test outputs, and support communities of practice. Improving the production stream involves understanding and working to bureaucratize and structure learning into new skills, processes, structures, and to some extent, culture. When project implementation does not go according to plan, generally, what is required is in-the-moment innovation—using what is known in new ways or creating an entirely new way. Improving performance via this stream suggests a focus on new paradigms of work culture, such as facilitated teaming [60] and encouraging high reliability behaviors [61, 62] to promote role clarity, sense of belonging, and psychological safety, which in turn nurture dynamic learning behaviors such as seeking feedback and ability to quickly experiment, assess response, and keep moving. Edmondson's work [63•] continues to highlight the critical importance of a psychologically safe climate for successful in-the-moment performance.

What emerges for us from the preceding review of the literature is a comprehensive learning framework such as displayed in Fig. 2.

According to this framework, after preparing for an operation using existing explicit procedures, knowledge, and routines, individuals and teams engage and learn in-the-moment during operations drawing on the team's culture, collective skills, tacit knowledge, intuition, and transactive memory. Afterwards, they engage in explicit backcasting, in structured and unstructured ways to gain insight into the events' evolution and result. Insights are captured, ideally in a form that facilitates the documentation and/or cultural retention, so that these are transferred between people, units, across time and space to influence future preparations and operations. Organizations and communities of practice further reflect on these events (sometimes significant individual events, sometimes patterns emerging across multiple events), identify new and reinforced preparatory processes (policy, training, planning routines), and potentially new implementation repertoires. An important step is the tracking and analysis of both tacit and explicit forms of learning and knowledge retention so as to improve impact on future efforts. Activities are influenced by other features of the latent organizational context (e.g., human resource practices, culture, mission) and the broader environmental context (e.g., ongoing changes in extra-organizational policy, demographics, land use, climate).

Status and Current Focus in Prescribed Fire Management

In this section, we briefly outline prescribed burning activities and information related to escapes on National Forests in the USA and the State of Victoria, Australia. Table 1 shows the number of prescribed fires and escapes for the US Forest Service between 1996 and 2014 and DELWP operations between July 1, 2005 and June 30, 2015.

We note that the trend suggested by the data given in Table 1 appears positive. However, there is concern that the highly skilled prescribed fire practitioners who have contributed to these trends are retiring more quickly than they are being replaced. Moreover, the increasingly demanding conditions for conducting these operations means that organizations and fire practitioners will be required to learn more quickly. Finally, these statistics are lag indicators telling us what has happened rather than providing present or forward looking indicators of capability and organizational culture.

US Federal Lands

National statistics tracking prescribed burning by the largest federal forest land management agency in the US report a consistent trend of less than 2% occurrence of prescribed fire escapes (Table 1). We were unable to find any comparable reports for other federal agencies, state, or private land management organizations.

For this paper, we read all publicly accessible reviews of prescribed fire escapes ($n = 34$) undertaken in the US since 2012 (Table 2) as published on the interagency Wildland Fire Lessons Learned Center's (WFLLC)

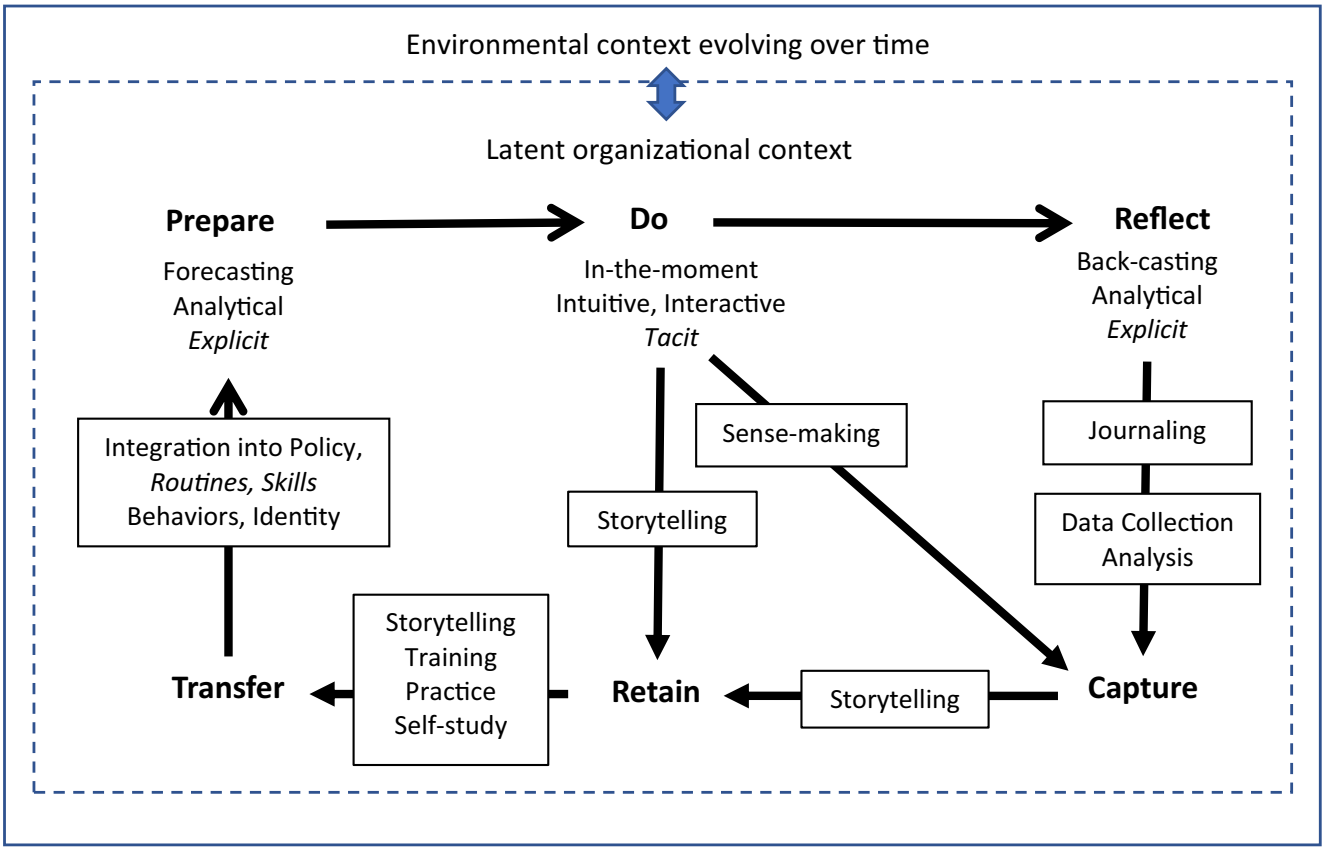


Fig. 2 Proposed framework to analyze organizational learning for prescribed fire identifying major phases; activities; temporal, cognitive and knowledge frames; and contextual exchange. Adapted from [43]

website (www.wildfirelessons.net/home). From these reviews, we found no obvious pattern in the types of prescribed fire escapes. There were escapes in all configuration of fuels (e.g., piles vs. broadcast), at all times of a prescribed fire operation (i.e., test fire, ignition, holding, patrol, and mop up), among all types of vegetation/fuel complexes (e.g., grass, shrub, forest), during the first fuels reduction entry or after multiple entries, and/or type of burn desired (e.g., underburn, stand replacement). Similarly, the escapes reviewed in these documents are the consequence of surprises in fuel receptivity, the capricious nature of winds, and erratic though expected fire behavior. Most discuss lessons in one form or another. Lessons learned covered a wide spectrum, from local, operational insights (such as when to move equipment), to broader recognition of the need to build

Table 1 Recent prescribed fire statistics for the US Forest Service and Victoria, Australia

Agency	US Forest Service [64]			DELWP Victoria [32]	
Period	1996–2001	2003–2007	2007–2014	2005/06–2009/10[a]	2010/11–2014/15[a]
Number of prescribed fires	24,133	19,468	33,677	3056	3371
Annual average	4022	3980	4811		
Acres treated	6,406,217	7,079,427	9,812,690		
Annual average	1,067,703	1,415,885	1,401,813		
Escapes	235	50	45	51	20
Annual average	39	10	6		
Reliability rate	99.03%	99.75%	99.87%	98.33%	99.40%

[a] The fire season in Australia is typically reported July 1st to June 30th. Hence reporting is in the format 2005/2006 etc.

Table 2 A sample of prescribed fire escape reviews in the USA from 2012 to 2018

Year	Review name	State	Agency*	Escape phase	Fuel type	Burn type	Review type**	Lessons
2012	Apalachicola Unit 208	FL	USFS	Patrol	Underburn	Broadcast	Unstated	Y
	Box Creek	UT	USFS	Firing	Stand-replace	Broadcast	FLA	Y
	Compartment 7	NC	USFS	Mop up	Understory	Broadcast	Unstated	Y
	Cottonwood	CA	USFS	Firing	Brush	Broadcast	FLA	Y
	Forest Health	SD	USFS	Holding	Slash	Piles	Unstated	Y
	Lower North Fork	CO	State	Mop up, patrol	Restoration	Broadcast	Key factors	Y
	North Schell	NV	USFS	Firing	Stand-replace	Broadcast	FLA	Y
2013	Belle Fourche	SD	NPS	Firing	2nd entry	Broadcast	Unstated	Y
	Pasture 3B	SD	USFS	Patrol	Grass	Broadcast	Unstated	Y
	Stump Springs	UT	USFS	Firing	Understory	Broadcast	Unstated	Y
2014	Pole Creek	WY	USFS	Firing	Stand-replace	Broadcast	Unstated	Y
	Tract 17	CA	NWR	Firing	Grass	Broadcast	Unstated	sort of
2015	Arapaho	CO	NWR	Firing	Grass	Broadcast	Review	Y
	Bone Point	OR	USFS	Fire behavior	Understory	Broadcast	Unstated	sort of
	Cold Brook	SD	NPS	Holding	Grass	Broadcast	Unstated	Y
	Flat Ridge	UT	USFS	Firing	Sage/timber	Broadcast	Unstated	Y
2016	East Maury	OR	USFS	Firing, holding	Understory	Broadcast	Unstated	Y
	Foss Lake	MN	USFS	Firing	Masticated fuels	Broadcast	Unstated	Y
	Little Valley	NV	State	Mop up	Fuel reduction	Broadcast	Unstated	No
	Zimmer Ridge	SD	USFS	Patrol	Slash	Piles	AAR	Y
2017	AQ	WA	USFS	Firing, holding	Timber	Broadcast	Unstated	No
	Johnson Ridge	UT	USFS	Firing	Heavy brush	Broadcast	Unstated	Y
	Onion Creek House	TX	City	Firing	Grass/brush	Broadcast	Unstated	Y
	Pole Creek	WY	USFS	Patrol/monitor	Stand-replace	Broadcast	FLA	Y
	Ponderosa Pile	CA	USFS	Firing	Heavy	Pile	Review	Y
	Wewoka	OK	BIA	Patrol	First entry	Broadcast	RLS	Y
2018	Compartment 4	FL	NWR	Aerial ignition in wrong area	Maintenance bun	Broadcast	Review	No
	Gallinas	NM	USFS	Firing/patrol	Fuels	Piles/broadcast	FLA	Y
	Lodgepole Springs	ID	USFS	Patrol		Broadcast	FLA	Y
	Pine Grove	SD	USFS	Patrol		Pile	FLA	sort of
	Redondo	NM	USFS		Review separate from FLA		Unstated	
	Santa Cruz Island	CA	NPS	Patrol		Piles	FLA	Y
	Sims/Grape	CA	USFS	Post-fire		Piles	FLA	Y
	West 83	NE	*USFS	Mop up	Grass	Broadcast	Unstated	Y

**USFS* US Department of Agriculture, Forest Service, *NPS* US Department of Interior, National Park Service, *NWR* US Department of Interior, National Wildlife Refuge, *BIA* US Department of Interior, Bureau of Indian Affairs, ***FLA* Facilitated Learning Analysis, *AAR* after-action review, *RLS* Rapid Lesson Sharing

relationships (such as with the weather service), to staffing (consistency, but also a few regarding expertise). Among the host of human factors described, lessons in 18 of the 34 reports noted some aspect of communications (adequacy, clarity, process, skill, culture to support speaking up, technical issues) urged wariness of expectations (for instance, of under what conditions boundaries will hold). Fourteen of the reports noted the need for additional resiliency to adapt to changing conditions. Twenty of the reports noted the need for attention to some aspect of contingency resources.

Victoria, Australia

Similar to other southern Australian jurisdictions, Victoria has a long history of conducting prescribed burning operations and thus a commensurate history of escaped prescribed fires. Unfortunately, Victorian agencies have published very limited statistics on their prescribed fire escapes, thus limiting our ability to track improvement efforts. Most of the publicly available information on prescribed fire escapes is from the DELWP and its predecessors. However, escaped planned fires on private land is a significant issue, albeit more difficult to

obtain data on. For example, during a period of adverse fire conditions on October 6, 2015, more than 40 calls were made to Victorian authorities regarding re-ignitions and escapes from planned burns on private property [32]. By way of comparison, approximately 2% of planned ignitions on public lands in Western Australia (WA) have escaped [36]. However, it is important to note that the annual planned burning programs in WA typically involve considerably larger areas [65].

Organizational Learning in Prescribed Fire

In this section, we outline significant events or changes over the past decade in the prescribed fire learning environment in each country. In the USA, this is focused on new institutional learning processes for any fire-related accident—wild or prescribed—and insights gained from a 2012 review of learning specifically from reviews of prescribed fire escapes. In Australia, especially Victoria and WA, several fire events and their subsequent reviews have altered prescribed burning policies and practices.

We then use the organizational learning framework introduced earlier (Fig. 2) as a lens through which to assess a selection of current learning activities, focusing on recently published reviews of prescribed fire escapes. We distinguish the first three steps (prepare, do, reflect), then consider a second set (capture, retain, transfer) together in order to better discuss how tacit and explicit knowledge is treated. In the USA, these reviews—covering the full gamut of escape consequences—are commissioned or requested by local authorities and undertaken by a mix of internal experts and peers. Reviews of the more minor escapes in Victoria were also carried out by a mix of senior officers, fire managers, and/or peers, but the results were not released. Without knowing precisely why not, and without an authoritative explanation, further comment would at this point be speculative. Reviews of escapes with more serious consequences are generally conducted by a third party.

The USA

Since 2000, US wildland fire organizations, and in particular the Forest Service, have worked to change how they respond when operations go wrong, devoting considerable effort to cultivating a learning as opposed to a blaming orientation towards human error. The primary goal was to develop a completely different process for learning from events, revise policy, and develop training, educational materials, and a cadre of people skilled in the capture of information that helps both the prescribed burn team members involved and the organization to learn from the prescribed fire escapes. The US Forest Service formally adopted the facilitated learning analysis (FLA) process to review "unintended outcomes" (such as a prescribed fire escape, injury, or fatality) in 2013 [67]. The FLA paradigm seeks understanding and improving future performance, not fixing blame retrospectively. Efforts center on learning from "unintended outcomes" in dealing with wildfires or prescribed fires, though there is recognition that learning from "normal" events or events that go well is also valuable.

Simultaneously, a federal research effort sought to understand the content and effectiveness of learning, specifically from reviews of prescribed fire escapes, through a series of dialogs with managers [43]. The 60+ participants representing all levels of federal agencies with fire management responsibilities described relatively consistent advances in both conceptual and cultural practices related to *preparation* and *reflection*. For instance, while not required by policy, some units had adopted the concept of "pre-mortems," a process discussed by Klein [] as a way to anticipate how a prescribed fire might go wrong in advance of ignition, thus allowing operators to pre-identify response options and avoid an unintended outcome (preparation). By the mid-2000s, many units were conducting "after-action reviews," a structured debriefing (reflection) process developed by the US military and adopted by wildland fire operators to assist with organizational learning [68].

At the same time, the review pointed out gaps in effective *Capture*, *Retention*, *Transfer* and integration of lessons, including the need for systematic capture of essential information on prescribed fire escapes and subsequent trend analyses to describe patterns, pattern development, and potential mitigations (capture); processes to quickly incorporate insights into practice (retention); and training and mentoring programs (transfer). Revision of the Interagency Prescribed Fire Guide [69] incorporated many insights from this review (integration), including providing "lessons learned" boxes as tips for each section of the guide, and described a rich array of review types, including "Before Action Reviews," similar to the pre-mortem concept.

Since 2013, the US federal wildland fire community has continued to develop policy and procedures that institutionalize the FLA or a similar learning-based process (change in latent organizational context), developing new routines in which, in our case, prescribed burn teams and peers gather to learn from the event. The FLA, and its companion the learning review (LR), which is geared for more serious outcomes like fatalities [68], focuses on the events immediately prior to the "unintended outcome" and the conditions, actions, and context that seem to contribute. Learning, and sense-making, occurs through guided story-telling as each participant shares their experience. Technical skills are assessed by ensuring prescribed burn personnel hold appropriate certification. Equipment performance is evaluated by a subject matter expert referencing appropriate policy and/or equipment specifications. Procedural skills are assessed by checking whether

planning documents are complete and follow approved procedures. Burn implementation is assessed through the collective discussion. This process is now guided by a growing cadre of subject matter experts who have completed an approved training course overseen by a steering committee. When a review is requested or required, this organizational unit pulls together the trained peer cadre and provides coaching to that cadre as they guide the local unit through their learning. The review cadre produces a written document that is transmitted to the local unit and posted on the interagency WFLLC website (and increasingly, multimedia products).

The subsequent sections here draw primarily from the 34 published reviews (although only nine are FLAs, one is a Rapid Lessons Shared, the majority have a learning orientation), but also wrap in other known activities that do or could assist.

Prepare

Preparatory actions such as pre-mortems can identify during-incident dynamics to watch for and allow the crew time to pre-identify potential and desired responses. Reviewing previous escapes and lessons learned from those is another excellent technique to help a prescribed burn team prepare. These can be used to develop "triggers" or "trigger points" (events or conditions) which if encountered would prompt specific types of response.

One of the reviews noted the value to the prescribed burn team of conducting a "pre-mortem"; an additional six noted the value of these and similar exercises. The current review paradigm places primary emphasis on first-person and team learning. Reviews indicate these individuals do seem to be extracting explicit lessons from the events, though lessons tend to be worded in the third-person, such as "identify off-site resources" and it is unclear who and how these valuable suggestions should be used in future preparations. In most cases, fuels, weather, and fire behavior are captured and presented in detail, and sometimes analyzed, but the connection to how this should play into building awareness and impact for future operations is not always made clear. Some documents comment on whether the decisions made by the prescribed burn team seemed appropriate. The majority (18) of the reviews includes specific recommendations[4] or directives, most targeted at their own level of operation or immediate internal partners/levels, which if acted upon would likely have a significant positive impact on future operations. A few note a need for action at broader organizational levels. However, even when directed at their own levels, it is often unclear who the appropriate person is to ensure follow-up on an insight, encouraged activity, or recommendation. There appears to be no consistent process or central entity or avenue for collecting, tracking, or monitoring follow-up. Some mechanism to ensure monitoring of review outcomes to determine efficacy of resultant changes would undoubtedly contribute to improved future preparations.

Documentation and analysis of social and human factors remains at the topical level—such as need for additional communication. While possibly adequate for local improvement, if acted upon, there is generally insufficient information provided in the reviews to guide deeper analysis of human interactions and/or organizational process (e.g., beliefs, culture, or team dynamics in either tacit or explicit domains), such as would be valuable for broader organizational learning (more on this later). We are aware that some areas incorporate a recent review into annual "refresher" courses required for certain fire positions, but our understanding is that this is locally determined and organized. This is an intuitive mechanism for integrating lessons and likely could be enhanced with broader coordination.

Another type of preparatory tool has been proposed in Canada. Jin and McRae [40] developed the Prescribed Fire Excursion Index (PFEI) to help Ontario prescribed fire managers identify the factors other than traditional weather prescriptions that may lead to an escape. However, as the designers note, the PFEI is "an interim product" which "has certain limits"—a small dataset, and poor documentation for some incidents, and would benefit from reporting using a better definition of a prescribed fire escape.

Do

Prescribed fire escapes may be seen as audits of response repertoire [56•]. In this context, audits take the form of spot fires, slop-overs, increases in fire behavior (rate of spread, fireline intensity, crown fire initiation), sudden changes in wind speed and direction, and/or fire spread direction, fuel condition, and breakdowns in equipment and/or communications. Barton and Sutcliffe [70] found that planned or unplanned micro-disruptions (such as any of the above) during an operation can be essential in helping a group recognize the need to adjust operations to changing conditions. While instances of micro-disruptions were identified, this is not a consistent activity. Increasingly, reviews recognize the inevitability of human error—particularly individuals missing signals that are identifiable in retrospect, but which go unnoticed for any of a variety of reasons. Because of this, there is an

[4] The 2018 FLA Implementation Guide cautions against trying to make too much of a single data point (any single event), and falling into the trap of causality, which often leads to creation of "fixes" in the form of system-level changes via recommendations [67].

increasing frequency of recommendation for prescribed burn teams to pre-identify how to build in "slack" and "redundancy" to maximize the opportunity for someone, somewhere to notice and to feel encouraged to share this information in sufficient time for the organization to adapt.

Outside of considering lessons and recommendations in review documents as tools, existing requirements and best practices prompting prescribed burners to step back during a burn to review prescription parameters, complexity ratings, etc., can and do provide additional types of micro-disruptions. Triggers, discussed earlier, are indicators of the potential for the onset of micro-disruptions. Ensuring a culture of psychological safety, in which anyone feels comfortable asking questions or speaking up, is a contextual feature that can enable verbal micro-disruptions—'what's going on here?'. As one FLA team stated:

> Our recommendation is to acknowledge the complexity of our environment and the limitation of our abilities and to use this information to build room for the inevitable error to exist without consequence. This could take the form of consciously practicing consistent feedback in order to develop a shared mental model of operations and the environment. How "good" is your Situational Awareness? How can you allow for the inevitable missing information or misperception of the environment? [71, p. 27]

Another recent innovation that spans from *doing* to *transfer* is the Rapid Lesson Sharing process. Developed and coordinated by the WFLLC, these are intended to quickly capture and disseminate trends and insights during a fire season, using similar data collection processes as FLAs.

Considering learning in the broader contextual frame, several organizations are emphasizing learning-through-doing by creating opportunities for practitioners to gain experience burning alongside more experienced or seasoned prescribed burners. The US National Interagency Prescribed Fire Training Center (www.nifc.gov) annually hosts combined classroom and field sessions to simultaneously provide training and accomplish prescribed burns. The Nature Conservancy, a non-profit organization, has developed and is sponsoring prescribed fire practitioner "exchanges" (TREX) worldwide in which practitioners can learn experientially from experts and mentors while conducting project burns [www.conservationgateway.org; 72]. The Coalition of Prescribed Fire Councils, another non-profit organization in North America established in 2009, also seeks to "promote the appropriate use of prescribed fire for enhancing public safety, managing resources, and sustaining environment quality (www.prescribedfire.net). It serves states and local areas. These organizations are actively working to build both tacit and explicit expertise to ensure success of burns and sufficient capacity for increasing prescribed fire in a time of significant loss of expertise due to retirements.

Reflect

Of the 34 reports reviewed (Table 2), recommendations and lessons learned were identified by both participants and review teams (which sometimes included Line Officers as well as prescribed burners). Eighteen reviews included specific recommendations; most frequently, these were offered by the review team only. Sixty-two percent of the reports reviewed noted either communications or other human factor-related lessons covering the spectrum from project planning to implementation phases. Many encouraged more active curiosity and questioning; examples include:

- Conducting "what-if" conversations; continuously updating understanding of conditions
- Checking assumptions (such as about fuel receptivity within the prescribed burn unit, over time, and in fuels adjacent to but outside the intended project boundary)
- Checking the effectiveness of communications, actively speaking up
- Recognizing who has expertise or familiarity with the unit, procedures, or knowledge of the fuels and accounting for them
- Ensuring mindful attention to conducting the burning operation and adequate staffing until the burn is complete
- Seeking ways to build more "slack" into the system to allow for small errors (such as reducing dependencies and connections); see Weick and Sutcliffe [73] for additional ideas

In the absence of understanding how these same orientations occur or not on successful prescribed burns and on suppression incidents, it is difficult to know whether these are local or general lapses in attention to detail. However, none of these are unique, and all in some way or another indicate a lapse in best practices—be it of a formal procedure or an informal team practice [cf. Maupin 38, 39].

Despite the obvious evolution in reflective learning practice, some managers observe that: "these reviews are really expensive and time-consuming, yet they seem to all say the same thing over and over. Why do we keep doing them?" This is an excellent question, one answer to which rests on who is the target of learning? Current documentation and communication practices do not provide consistent or sufficient details to support meta-analysis. Occasionally, a region will review a suite of prescribed fire escapes, but this is not a routine practice. At the local unit level, some reviews have caused fire managers to change the way they operate—for instance, fully

committing contingency forces to an incident rather than simply putting them on notice in case of need. There is significant variation across reviews, with some clearly identifying what change is desired and who holds the keys to that change, while others are vague. Black et al. [43] found that the review teams and the participants were the primary beneficiaries of these efforts, thus potentially worthy as a workforce development opportunity; however, that still seems to leave a lot of learning yet to be captured. Another useful direction would be to consider integrating a more academic perspective to add rigor to reviews. As noted earlier, current management and learning paradigms benefit from conceptual and applied theorists. Klein et al. [74] and McLennan and colleagues [75] draw from psychology to describe varieties of anticipation, and then use this to consider drivers of behaviors that are integral to safety and decision-making. Similarly, Constantinides [76] builds on Turner's [77] consideration of "failures of foresight" to analyze a disaster. Considering the evolution of prescribed fire escapes through such lenses could prove enlightening and valuable.

Capture, Retain, Transfer—Explicit Knowledge

Establishment of the LR and FLA processes (as policy and as a consistent replicable process supported by consistent training and credentialing) does much to institutionalize organizational learning routines to capture lessons. While necessary, in and of itself, it does not ensure transfer or integration of lessons into future behavior, at local or organizational levels. The processes focus on *sense-making*, *story-telling*, and experiential knowledge. To date, there is no systematic analysis or rigorous evaluation of these interpretations and insights to deepen learning (analysis), particularly at an organizational level. Nor is there evidence of advances in retention and transfer (*integration*) of lessons identified to improve operational performance. Post-review knowledge transfer remains vague and unstructured; though reviews offer ways others may learn from their experiences, sometimes very clearly and specifically. Unfortunately, we found no policies or processes that enable, require, or consistently guide integration of these insights and recommendations into future preparatory activities.

Considerable interagency effort has been devoted to diffusing knowledge and innovation through networks, but this has mostly focused on databases to aid in building libraries (retention). For example, the interagency WFLLC, which was established in 2002, seeks to connect practitioners with each other electronically, and captures, retains, and makes review documents readily accessible. Additionally, regional, federally funded "Fire Science Networks" facilitate exchange of new science through place-based professional communities of practice.

One of the most intuitive settings for transfer of learning is during spring training courses (such as the Burn Boss Refresher, see www.nwcg.gov/publications/training-courses/rt-300). Courses generally include review of some event or FLA; however, it is apparently an *ad hoc* process, with the specific event determined by local leaders. Broader organizational and leader support to institutionalize this process (i.e., attain consistency through formal policy or informal community of practice) might assist.

Occasionally, agency policy is updated as a consequence of a review (such as after the 2012 review); however, the process depends upon volunteer member committees under the US National Wildfire Coordinating Group, an interagency body whose actions are non-binding until each agency specifically adopts recommendations. The scant evidence of transfer of lessons from one burning unit to another, or resulting changes in larger organizational behavior, processes, and routines, suggests that there are opportunities to further improve organizational learning.

Capture, Retain, Transfer—Tacit Knowledge

In addition to explicit technical and systems knowledge, specific domain understanding is critical for success. The ability to make nuanced judgments is a form of expertise most often developed experientially and is often tacit rather than explicit. The training paradigm in US planned (prescribed) and unplanned (wildland) fire programs combines classroom learning focused on technical and procedural skills with on-the-job training focusing on building tacit and explicit experiential skills. Personnel fully qualified in a trainee's specific task are engaged as coaches who evaluate the trainee's performance. However, there are no training or other qualifications required in order to function as a coach/trainer and no oversight; thus, in addition to having no common bar or expectations for coach/trainer, there is limited ability to insert new insights or culture via this mechanism. In 2016, The Nature Conservancy's TREX program formalized a "coaches network" which might provide some ideas for improving federal leadership training.

It is widely felt within the wildland fire community that it is losing experienced prescribed fire managers faster than we are developing them. In combination with increasingly altered fuel and weather interactions, which pose novel fire environments to both experienced and novice practitioners alike, capacity development is an arena that needs additional attention (cf. Moriarty et al. [42] for consideration of a specific new fuel type created by mountain pine beetle infestations).

Victoria, Australia

Contextual factors continue to evolve, requiring ongoing adaptation and learning if organizations wish to maintain their prescribed burning capability. It is notable that unlike the

USA, Australian state and territorial governments play a relatively larger role in fire management and that Australia does not have the same types of federal agencies present that the USA has (e.g., the Forest Service and the Bureau of Land Management).

Following the catastrophic 2009 Black Saturday fires, the Victorian Bushfires Royal Commission (VBRC) made 67 recommendations for fire management in Victoria [78]. The VBRC found that there had been inadequate prescribed burning conducted on the 7.7 million ha of Victorian public lands. It recommended that the State commit to a rolling program of prescribed burning to achieve a minimum target of 5% of public land each year. This recommendation set in motion the requirement for the State to achieve a threefold increase in its prescribed burning program on public land. But since 62% of Victoria is in private ownership, there is a need for a whole-of-government approach to conduct prescribed burns more strategically across land tenure, to include private land also.

Other Australian land and fire management agencies paid close attention to the VBRC recommendations, recognizing that there was a national need to address how prescribed burning programs were delivered [79]. This led to the establishment of a national initiative to align and improve prescribed burning practices, which developed into the National Burn Project (NBP, 2011-2017), co-funded by the Australian Attorney-General's Department and AFAC[5] member agencies. The NBP's mission was "To bring together inter-related aspects of prescribed burning in Australasia to design guiding frameworks and principles for a more holistic and consistent approach to prescribed burning" [80]. The NBP worked closely with agencies and researchers to review practice and evidence. The NBP has published various resources and run workshops to enable the sector to improve knowledge sharing, learning, and practice [5, 81–83]. In July 2017, the Centre of Excellence for Prescribed Burning (CoEPB) was established to continue this work [aidr.org.au/programs/centre-of-excellence-for-prescribed-burning/; 84–87].

High-profile prescribed fire escapes such as the 2011 Margaret River Fire in WA (see Sidebar) and the 2015 Lancefield-Cobaw Fire in Victoria have attracted considerable scrutiny and influenced prescribed burning policies and practices [20, 32, 88–92]. Escapes from planned burns also continue to occur on private lands, and unfortunately, sometimes in clusters that have caused considerable damage [16•, 32, 93].

In Victoria, the Lancefield-Cobaw Fire escape led to an independent investigation making 22 recommendations to improve the management of planned burns by DELWP [32]. These recommendations focused on:

- Building a better identity for fire management and planned burning on public land so that it can develop more robust and sustainable relationships with the local communities [94]
- More active and meaningful community engagement
- Creating a structure to better integrate burn planning and operational implementation
- Improving systems and processes to ensure risk assessment to reflect the broader landscape and that appropriate resourcing is provided to meet that risk
- A thorough review of the risk management and approvals process, ensuring that risk assessments and outputs are clear, current, and useful

One of the interesting features of these recommendations is that in addition to tackling prescribed burn operational and process issues, they address broader organizational structure, engagement, identity, and relational issues.

Prepare

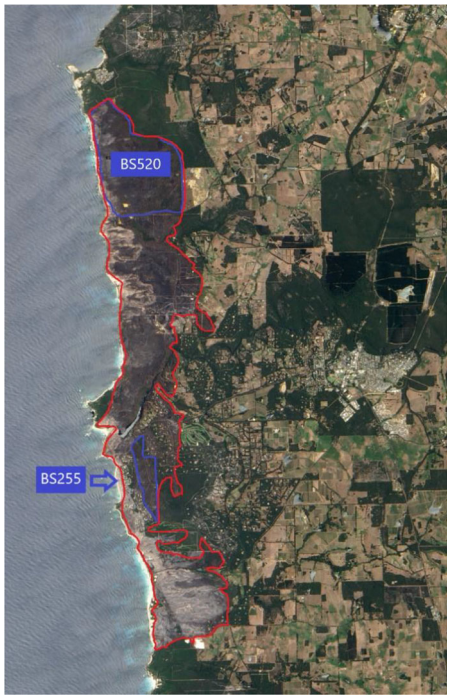
Victorian agencies continue to refine and deliver a range of training programs to develop fire management and prescribed burning personnel, particularly to develop skills to use the various systems, processes, and knowledge of key concepts and good practice.

In addition, changes in policy, planning, and decision-tools as a consequence of reviews have led to increased attention on effectiveness and acknowledgment of risk. Following the Lancefield-Cobaw prescribed fire escape, DELWP moved away from a purely hectare-based target and developed the "Safer Together" policy [95] that specifies a more strategic approach to the use of planned burning to more directly reduce risk of impact of wildfire on the community. This framework helps DELWP to assess the number of hectares burnt, the effectiveness of the program [9], as well as to prioritize planned burns to ensure that the residual risk for the state remains at or below 70%.[6]

In early 2016, DELWP introduced the Planned Burn Risk Assessment Tool (PBRAT) to support improved decision-making [96]. The tool is aimed at providing a more consistent peer-reviewed and risk-based approach for planning prescribed burns on public land [97]. However, an internal review observed that the fire management risk assessment processes were imperfect, failing when there were (i) unforeseen circumstances, (ii) rapidly changing circumstances, (iii) time-critical decisions required, and (iv) need for expert judgment [98].

[5] AFAC: Australasian Fire and Emergency Service Authorities Council (www.afac.com.au/).

[6] "Residual risk" is 100% if none of the land has been burnt. It is not possible to reduce this risk to zero. A benchmark of 70% is seen as a practical figure.



Sidebar Image NASA Earth observatory satellite image showing planned fire (BS520 and BS255—purple) and escaped fire (red) perimeters of the Margaret River Bushfire (November 2011)

The origins of the November 2011 Margaret River Bushfire were two prescribed fires at Ellenbrook (BS520, 722 ha) 13 km north-west of the town and at Prevally (BS255, 131 ha) just to the west. These prescribed fires were undertaken to reduce the risk to nearby communities given that there had been an extended absence of fire in these forested areas. The Ellenbrook prescribed burn was first ignited on September 6th 2011 in order to create a burnt edge around the perimeter of the planned burn area. Despite several subsequent attempts, the perimeter of the Ellenbrook prescribed burn could not be secured because of high fuel moisture levels. On November 20th, the Prevally prescribed fire was commenced and the following day the Ellenbrook prescribed fire received further ignitions. These burns were undertaken with the knowledge that forecast weather would become unfavourable on November 23rd. The judgement of the prescribed fire managers was that these fires could be completed and made safe in less than 3 days. Despite several attempts, 1.5 km of the south-western perimeter of the Ellenbrook prescribed fire remained unsecured. No spot forecasts from the Bureau of Meteorology for the Ellenbrook prescribed fire were obtained by the land management agency on either November 21 or 22. On November 23, actual weather conditions were more extreme than forecast with northerly winds of 37 km/h observed rather than the forecast winds of 27 km/h. Various other events exacerbated the situation including a misunderstanding of a spotter aircraft's concerns regarding smoke emanating from the Ellenbrook prescribed burn on the afternoon of November 22 and resourcing issues for patrolling the Ellenbrook fire. It appears that either later on November 22 or the morning of November 23, the Ellenbrook prescribed fire escaped and burnt south towards Margaret River. The Prevally prescribed fire flared up and escaped on the morning of November 23. The special inquiry [20] notes a range of additional factors important in this prescribed fire escape. For example, the attraction and retention of experienced staff, constant turnover of staff, and the long hours and drive distances adversely affecting judgement of prescribed fire staff.

The Margaret River Fire destroyed 41 houses and heavily disrupted tourism central to the region's economy. The escaped fires burnt a total of 3400 ha, almost four times the area of the plan for the prescribed fires (see Keelty [20] for further details).

This heightened the requirement to improve learning in order to build expertise. The review concluded that there were important gaps in analysis of insights, links to training, and dissemination of learnings to relevant staff. Reports of prescribed fire escapes in particular were rarely communicated to all of the relevant staff. This latter problem is beginning to be addressed via a Rapid Lesson Sharing approach (see share.em.vic.gov.au/wizard).

Do

Learning-by-doing is an important principle for Australian land and fire management agencies. Victorian agencies use the Centre for Creative Leadership's 70:20:10 model of learning for training fire management personnel [99]. This model proposes that 10% of learning is achieved through formal training (e.g., classroom and online), 20% results from learning from others (e.g., peer feedback, coaching, and lessons learned), and 70% occurs through on-the-job practice and problem-solving exercises. This raises the question of whether adequate resources and training are being provided to support the coaching and mentoring envisaged in this model [100]. An aging workforce and the loss of some of the most experienced practitioners further exacerbates this challenge. Agency support for coaching and mentoring personnel involved in fire suppression activities appears to be somewhat greater than it is for personnel involved in prescribed fire management. The AFAC [85] review of training for prescribed fire in Australia noted that just two jurisdictions (South Australia and Tasmania) identified mentoring as part of their programs. The review also found that most agencies were struggling to manage their prescribed fire instructors' teaching workload so that they could also maintain their practical burning skills.

Reflect

After-action reviews, pre-mortems, and staff rides are used by Victorian fire and land management agencies to help capture opportunities to reflect and learn and to improve performance of individuals and teams. Although these tools are well known, there is some concern that these are not consistently used across Victorian agencies, and that at times, personnel may be reluctant to speak up in these sessions. This observation is supported by Stack and Owen's [101] survey of agency personnel as part of their Cobaw[7] Fire staff ride evaluation. The authors reported that 40% of survey respondents said that their agency

[7] In 2003, a prescribed fire escaped from the Cobaw State Forest, an incident that pre-dated the 2015 Lancefield-Cobaw fire escape. The 2003 escape formed the basis of a staff ride developed in 2012 [101].

buried what happened when things went wrong, and 28% said that blame was assigned to individual people.

In response to the Lancefield-Cobaw Fire escape, the Victorian government also asked the State's Inspector-General for Emergency Management (IGEM) to review other prescribed fire escapes. IGEM has published two reports analyzing the issues around escapes and identified common themes and potential learnings for the agencies concerned [97, 102].

Capture, Retain, Transfer—Explicit Knowledge

Several of the items discussed in the *preparing to learn* section are products that enable Victorian organizations to capture, retain, and transfer explicit knowledge. For example, the *Safer together* policy and the PBRAT put in place processes to more systematically assess risk, increase checks and balances, and provide guidance on good practice. Similarly, the independent investigation on the Lancefield-Cobaw Fire escape and by IGEM on subsequent prescribed fire escapes makes explicit the potential opportunities for learning.

Transfer of learning typically occurs during training courses such as Burn Officer in Charge [85]. Courses may include review of some previous prescribed fire escaped case studies; however, it is apparently somewhat ad hoc, with some case study materials and fieldwork determined by the instructor responsible. There appears to be limited evidence of transfer of lessons from one burn unit to another or resulting changes in larger organizational behavior, processes, and routines suggesting there are further opportunities for improved learning. A prescribed burn manager neatly observed that "burns escape for the same reasons they have always escaped."

At a national level, AFAC, NBP, CoEPB, the Bushfire Cooperative Research Centre, and the Bushfire and Natural Hazards Cooperative Research Centre have produced a variety of practice guidelines and research to help Australian agencies improve their prescribed burning capability. Owen's [59•] review of the uptake of research found that within agencies, there were different perceptions between senior managers and front-line staff as to how effective the organization perceived been in disseminating advances in research. The research suggested that front-line staff perceived lower levels of effectiveness of how research is disseminated, and that there were different levels of research utilization maturity between agencies.

A further issue is that explicit knowledge learned from a prescribed fire escape is taken up mainly by those directly involved and only partially distributed to the rest of the organization. For example, in Victoria, prescribed burn bosses or controllers rarely hear about or participate in learning opportunities beyond their local area, such as a community of practice with their prescribed burn planning and operational colleagues.

Capture, Retain, Transfer—Tacit Knowledge

Fire and land management agencies rely heavily on the tacit knowledge of their more experienced staff to plan and manage prescribed burning operations. English's [103•] review of tacit knowledge transfer in Victorian agencies highlighted the need for agencies to understand (i) what tacit knowledge is and (ii) how it is used, withheld and shared by individuals within an organization. English [103•] proposed that the Victorian fire and land management agencies need to consider four changes in their operations to better foster knowledge exchange and development:

1. Developing new systems and resetting organizational norms to foster a more egalitarian workplace that supports interaction and sharing of information between practitioners, researchers, and community (the non-fire agency population)
2. Using new forms of operational analysis that explore how staff use and develop their knowledge in context
3. Reconsidering the current knowledge exchange processes (e.g., after-action reviews and debriefs) to better recognize and leverage practitioners' tacit knowledge
4. Adopting an investigative approach that better recognizes the central role tacit knowledge plays in dynamic situations such as bushfire decision-making

English [103•] suggests that the USA's FLA process may be a suitable approach.

For each of the six OL dimensions, we found a number of similarities and a few notable points of difference. The OL emphasis for both countries over the past decade has focused on the middle dimensions of doing, reflecting, and capture of explicit knowledge. Significant advances continue to be made. The areas of greatest challenge appear to be in closing the loop and attending to development of tacit knowledge.

Concluding Comments

On a number of counts, the USA and Australia face similar challenges and issues in ensuring effective organizational learning with regard to avoiding prescribed fire escapes. Not only is it an ongoing challenge to effectively adapt to evolving and dynamic bio-physical and societal environments; each organization is itself a complex, multi-level system shaped by its mission, traditions, formal and informal processes, and social factors. It should come as no surprise that while we find

land and fire management agencies working hard to improve their learning—with some success—we also find significant areas for improvement. It is also interesting to observe that the Australian entities have taken a more centrally coordinated top-down approach to reviews and dissemination. The US experience has been a more bottom-up approach. Both have legitimacy and value; perhaps one future step would be to exchange best practices.

Based on our assessment of available review documents, we highlight four areas we believe require specific attention if fire and land management agencies are to improve prescribed fire performance. These include (i) developing a richer organizational learning culture, (ii) developing structures and processes to support lesson sharing, (iii) addressing the increasing skills-gap, and (iv) improving non-technical skills and human factors training.

Improving organizational learning in prescribed fire would have obvious spin-off benefits in other areas of activity including wildfire response and organizational adaptation to change.

Developing a Richer Organizational Learning Culture

We note that US agencies appear to be better placed than their Australian counterparts in producing and nominally distributing materials to support lesson sharing, particularly those generated by prescribed burn team participants. However, agencies in both countries still struggle to obtain real traction in sharing and in learning—that is, fully integrating lessons into future operations, suggesting the need to develop stronger processes to institutionalize effective transfer and tracking routines.

As alluded to earlier, although the LR and FLA processes and documentation represent real progress, there is more to organizational learning than what has currently been realized. There are both local and collective aspects. At the collective level, organizations are unable to retain the very real lessons—both local and organizational—developed during the reviews due to lack of process for ensuring these are shared and acted upon. The ability to discern patterns or trends from prescribed fire reviews—somewhat absent in the USA's 2012 review mentioned earlier and constrained as noted in this current review—is virtually impossible without consistency in review documentation (format, type of information, and repository). As well, more rigorous assessment of the human element, based on social science theory, such as communications, psychology, high reliability, teaming, risk assessment, would be valuable for both local and collective learning.

Edmondson's research [60, 63•] underscores how organizational learning is highly dependent on a psychologically safe climate in which people feel free to voice their concerns. This speaks directly to local work environments and supervisory behaviors. Evidence from both the USA and Australia indicates that while the new processes have started to surface, agencies still have some way to go when it comes to developing a richer understanding of how unintended outcomes develop (indicating progress in providing more psychological safety). Willingness to speak up is just the first step—the test is how leaders and the wider organization respond [63•]. It is also equally well established that people *stop* speaking if nothing changes as a consequence of their effort [63•].

Developing Opportunities to Support Lesson Sharing

In the USA and Australia, agencies could benefit from engaging in deliberate and sustained effort in any of a variety of opportunities to support sharing lessons. Evidence exists that lessons are available and shared to some degree at the small group and team (temporally and spatially local) level. Yet as one prescribed burn practitioner in Australia was to "note, the lessons do not get to those who need them, especially upper management and prescribed burn controllers." There is much room for improving the link between capture of distributed insights and broad integration into organizational practice (transfer, preparation).

Address the Skills Gap Between Time Needed to Build Requisite Expertise and Pending Retirements

The expertise required to successfully plan, conduct, and oversee prescribed burning operations takes time to build. Most US and Australian agencies are losing these skilled practitioners faster than they can develop their replacements. Senior practitioners observe that it is hard enough to find an experienced practitioner to oversee prescribed burns let alone perform coaching or mentoring functions. Progress in the dimension of tacit knowledge development (capture, retain and transfer) is adversely affected by a mixture of retiring expertise, limited capability to resource the assumed learning by doing approach, and perhaps an underestimation of the organizational and practical challenges in achieving effective tacit knowledge transfer required to develop highly competent prescribed fire practitioners and teams. We note a couple of ways agencies can deliberately seek to tighten this gap. Perhaps most exciting are the multi-agency prescribed fire practitioner workshops in which experienced burners work alongside of and mentor newer burners as they conduct burns. Another complementary option might be to take a page from other sectors which retain expertise through adjunct and emeritus roles or by engaging retired senior practitioners and managers to act as mentors [104, 105].

Improve Non-Technical Skills and Human Factors Training

Reports on prescribed fire escapes focused largely on the operational and procedural aspects of the event. There has been more limited commentary on the human factors aspect of events. Research on high-reliability organizations points to non-technical skills—the "soft" skills of human dynamics—as central to safe and effective performance and learning [106, 107]. US and Australian organizations could expand efforts to embed emotional/social intelligence, human factors, and non-technical skills into training and development programs. There are efforts to build upon these programs such as AFAC developing online human factor modules [108] and the inclusion of team member skills in AIIMS2017 [109], inclusion of some interview training for the FLA process, some use of pre-mortems, and staff rides at the operational level [101, 110, 111]. Identifying critical skills and competencies, then ensuring integration into training and development could greatly assist. Such skills would enable prescribed fire personnel to better understand their own cognitive and emotional styles as well as increase ability to be aware of and better manage the adverse effects of stress, fatigue, cognitive biases, and social influences on themselves and others.

In conclusion, there have been significant advances in learning, and yet more remains to be done. It is hoped that experiences in the USA and Australia may be used to further enhance organizational learning capabilities to continue to improve prescribed burning operations.

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Compliance with Ethical Standards

Conflict of Interest All authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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